ACADEMIC ASSOCIATES

Study Guide

INTRODUCTORY Physics

Chris Kolomyjec and Grant Keenan

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PREFACE

This Study Guide is intended to be used by students in Year 9 and 10 preparing them for upper school Physics courses. It covers basic concepts in Physics and mathematical skills needed by Physics students and calculations.

The book is designed so that it can be used either in a whole class learning environment, by small groups or individual students working by themselves. Many students enter upper school studies in Physics without having the necessary background knowledge or not knowing anything about the topics covered in upper school Physics courses. If properly used by students, this book provides the background knowledge and a taste of the topics covered in upper school Physics courses. In this study guide, the Physics concepts are clearly explained, well-illustrated and have worked examples to assist student learning. At the end of each sub-section, there are checkpoint questions for which detailed answers are provided, giving immediate feedback to students to assist with their learning. Many questions are 'explain' type questions that we suggest students need to practise if they are to be successful in Upper School Physics studies.

There are also Review Questions at the end of each chapter and two Trial Tests for students to use to monitor their progress. Detailed answers are also provided to these questions.

Chris Kolomyjec, Grant Keenan

Perimeter 13×8=104
28
-15
13
90° Right angle
20+7=
Cube
P
ongruent
sin θ
cos θ
90°
30°
P
Q
R
(a+b)² = a²+2ab+
3,5,7,9......
14+6=2
Even, Odd
2,4,6,8.....
Volume=
(a-b)²=a²-2

Physics Fundamentals

1

1.1 THE SI (SYSTÈME INTERNATIONAL) SYSTEM OF UNITS

This system of units of measurement was adopted in 1960 and consists of several base units, some of which are shown below:

Quantity	Name of Unit	Unit symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A

1.2 DERIVED UNITS

These involve combinations of base units, some of which are shown below:

Physical quantity	SI unit	
	Name	Symbol
area	square metre	m^2
speed	metres per second	$m\ s^{-1}$
velocity	metres per second	$m\ s^{-1}$
acceleration	metres per second per second	$m\ s^{-2}$
volume	cubic metre	m^3
force	newton	N
work, energy, heat	joule	J
power	watt	W
electric charge	coulomb	C
electric potential	volt	V
electric resistance	ohm	Ω
frequency	hertz	Hz
pressure	pascal	Pa

1.3 OTHER NON SI UNITS

The following should be included on account of common usage:

Quantity	Name of unit	Symbol	Comments
mass	gram tonne	g t	1000 g = 1 kg 1000 kg = 1 tonne
time	minute hour day	min h d	60 sec = 1 min 60 min = 1 hour 24 hour = 1 day
angle	degree	°	example 58°
electrical energy	kilowatt hour	kWh	1 kWh = 3.6 x 10^6 J

1.4 DECIMAL MULTIPLES

These are formed by means of the prefixes given in the table below:

Factor by which the unit is multiplied	Prefix	Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^9	giga	G
1 000 000 = 10^6	mega	M
1 000 = 10^3	kilo	k
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p

1.5 SPECIAL NOTES ON UNIT WRITING

(a) Only the singular form of units must be used.

Example km **not kms**

(b) The power to which a unit is raised applies to the whole unit including the prefix.

Example $km^2 = (km)^2 = (1000\ m)^2 = 10^6\ m^2$ **not 1000 m²**

(c) The use of notation like $\frac{m}{s}$ or m/s **is to be avoided**.

In this case $m\ s^{-1}$ is preferred.

1.6 SCIENTIFIC NOTATION

Scientists are often dealing with either very small or very large numbers. In both cases, many zero digits need to be written down and this proves to be tedious and also prone to errors (it is easy to omit/add zeros).

In order to minimise errors in transcribing and also to enable very large/small numbers to be entered into calculator displays scientific notation is commonly used.

Scientific notation involves writing quantities as numerals between 1 and 10 which are then multiplied by a power of 10.

For example, 150 000 000 000 km is written as 1.50×10^{11} km
0.0000567 mm is written as 5.67×10^{-5} mm

Entering scientific numbers into a calculator involves the following steps:

(i) the number between 1 and 10
(ii) pressing the EXP or EE key, followed by a number representing the power of 10
(iii) pressing the (+/-) key in case of a negative power followed by the power of 10

Calculators can automatically display numbers in scientific notation by using set up keys appropriate to the specific calculator.

1.7 ROUNDING AND SIGNIFICANT FIGURES

Rounding

It is often necessary to round numbers to a certain number of decimal places or to a certain number of significant figures. The following examples illustrate how this rounding is done:

6.12499 rounds to 6.125 if 3 decimal places are required
6.125 rounds to 6.12 if 2 decimal places are required
6.135 rounds to 6.14 if 2 decimal places are required

Also, 6.12499 rounds to 6.12 if three significant figures is used (see below)
6.15201 rounds to 6.15 if three significant figures is used (see below)
17.9500 rounds to 18.0 if three significant figures is used (see below)

Significant figures

When a measurement is made or a calculation is performed, some idea should be given as to the precision of the result.

Significant figures are those digits in a measurement that are definitely known plus the first uncertain digit.

A measurement of 4.58 g from a two place balance has three significant figures, (the third one is the '8'). Since many balances have an error of ± 0.01 g, this also implies that the reading on the balance could be 4.59 g or 4.57 g.

In any number the first significant digit is the first non-zero digit. The next significant digit is the next digit and so forth.

If a number is expressed as some number multiplied by some power of 10, the 10 and its power do **not count** in the determination of the number of significant figures

For example: 0.0104 has three significant figures
23.56×10^{-6} has four significant figures
0.730 has three significant figures
0.0714 has three significant figures

Note: A measurement such as time = 700 s involves ambiguity in terms of the number of significant figures. The measurement may be to 1 significant figure if the person doing the measurement was only able to estimate it say without using a watch. Indeed it may also have three significant figures if the person measuring time has a watch capable of being read to the nearest second.

Ambiguity can be avoided by using scientific notation. Thus 700 s can be written as:

7×10^2 s (1 significant figure) or 7.00×10^2 s (three significant figures)

Use of significant figures in calculations

In multiplication and division the answer should only be expressed to as many significant figures as the number involved in the operation that has the **least** number of significant figures.

Example: $3.652 \times 2.29 = 8.36308 = 8.36$ (the "2.29" has only 3 significant figures)

Note: If a question asks for an answer to part (a) and that answer is to be used for an answer to part (b) later, then the answer to part (a) must be quoted to the appropriate number of significant figures but this truncated number must not be used for the subsequent calculation of part (b). To carry the answer to part (a) forward it is essential to carry **all** the digits. This process eliminates rounding error. The following example illustrates this point.

Example: Joanne, a dress designer, measures a rectangular piece of cloth using a tape measure. She records the following measurements: length = 106 cm, width = 54 cm

Find (a) the area of the dress segment in square cm
(b) the area of cloth required for 5 dress segments

Solution: (a) area of 1 cloth segment $= 106 \times 54\ \text{cm}^2$

$= 5724\ \text{cm}^2$

$= 5.7 \times 10^3\ \text{cm}^2$

(answer to 2 significant figures since "106" has 3 significant figures and "54" has 2 significant figures)

(b) area of 5 cloth segments = $5724 \times 5 = 2.9 \times 10^4\ \text{cm}^2$ and not $5.7 \times 10^3 \times 5\ \text{cm}^2$

(the '5' is a counting number and not a measurement, thus it does not count with respect to number of significant figures in the final answer which must be two because of the 54 cm measurement.

If we were to use $5.7 \times 10^3 \times 5$ instead of 5724 we would get an answer of $2.8 \times 10^4\ \text{cm}^2$ and this could result in Joanne being short of material for 5 cloth segments.

CHECKPOINT!

In 1.1, and 1.2 below, if you are converting from a smaller unit to a larger one, you divide by the conversion factor. Conversely, if you are converting from a larger unit to a smaller one you multiply by the conversion factor.

1.1 Convert the following:

(a) 10 000 s to min ______________________________

(b) 1 Ms to hours ______________________________

(c) 3 ks to days ______________________________

1.2 Express:

(a) 4.4 km in centimetres

____

____

(b) 3.8×10^{10} g into tonne

____

____

(c) 0.00567 mm into metres

____

(d) 7.2 kWh into joule

____

(e) 761 nm into metres

____

(f) 13 pm into nanometres

____

1.3 Express the following in scientific notation:

(a) 0.0008 ______________________________

(b) 0.20321 ______________________________

(c) 29678 ______________________________

(d) 14×10^3 ______________________________

(e) The volume of a rectangular block given the dimensions 6.3 cm, 12.1 cm, 0.84 cm. Express your answer in (i) cm^3 (ii) m^3

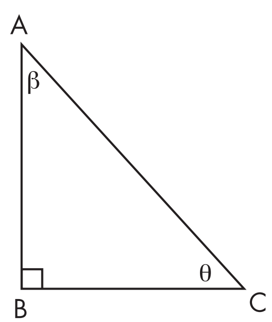
(i) ______________________________

(ii) ______________________________

(Write final answers using two decimals in the scientific notation)

1.8 ESSENTIAL TRIGONOMETRY

A right triangle is one where one of the angles is 90^0. It is customary to label the corners (or vertices) as well as the sides.



$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{AB}{AC}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{BC}{AC}$$

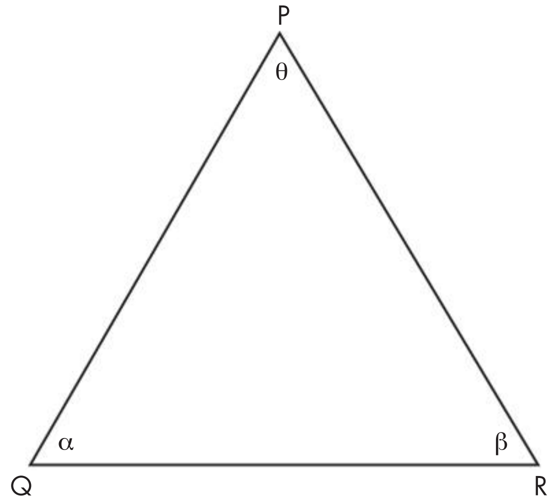
$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{AB}{BC} = \frac{\sin\theta}{\cos\theta}$$

The letters **SOHCAHTOA** could help in memorising **sin, cos** and **tan**

Try these: $\cos\beta$ = ______________ $\sin\beta$ = ______________

Isosceles right triangles have both non 90^0 angles equal ... hence these angles must both be 45^0

Non right triangles



Two rules for solving these non right triangles are used, "cos rule" and the "sine rule"

(a) Cos Rule

In words, one of the ways to memorise the 'cos rule' is as follows:

One side squared = the sum of the squares of the other two sides minus twice the product of the other two sides multiplied by the cos of the angle between these two other sides.

For example,

$$(PQ)^2 = (PR)^2 + (RQ)^2 - 2(PR)(RQ)\cos\beta$$

You complete the following:

$(QR)^2 =$ ______________________________

$(PR)^2 =$ ______________________________

(b) Sine Rule

Sine of an angle divided by the side opposite that angle equals the sin of another angle in the triangle divided by the side opposite the latter angle.

$$\frac{\sin\beta}{PQ} = \frac{\sin\alpha}{PR} = \frac{\sin\theta}{QR}$$

CHECKPOINT!

1.4 (a) Draw a non right triangle with vertices labelled A, B , C and angles Ω, Φ and φ opposite AC, BC and AB respectively.

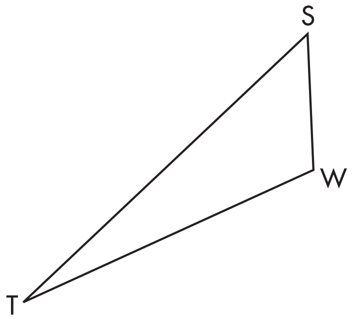
(b) On the triangle write expressions for the following:

$(AB)^2$, $(BC)^2$ and $(AC)^2$

(c) Complete the following:

$$\frac{\sin \Phi}{BC} = \underline{\qquad} = \underline{\qquad}$$

1.5 Evaluate the following in the triangle below:

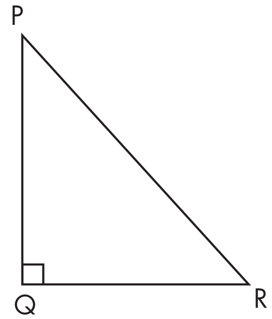


Given ST = 23.3 , SW = 9.8, ∠TSW = 30.0°

Find TW.

When finished, find the other angles in the triangle.

Note: The cos rule for non right triangles is also valid for right triangles. For example,



$$(PR)^2 = (PQ)^2 + (QR)^2 - 2\,((PQ)(QR) \cos 90^\circ$$

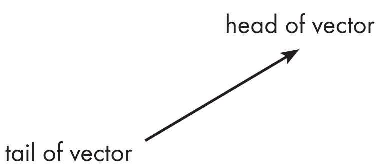
$$= (PQ)^2 + (QR)^2 \quad [\cos 90^\circ \text{ is zero}]$$

which is identical to the Pythagorean Formula for a right triangle.

Motion

2

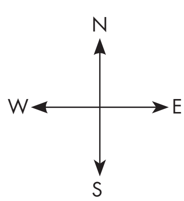
2.1 VECTORS AND SCALARS

VECTORS	SCALARS
Have size (magnitude) and also direction Examples: velocity, force, acceleration, displacement*, momentum Vectors are drawn using a straight arrowed line. The arrow points in the direction of the vector and the length of the arrow represents the magnitude of the vector  A general vector A in this book is drawn as: **A** (bold) Some books draw an arrow on the top of the letter: $\vec{A}$ **difference between start and finish*	Have size or magnitude only Examples: temperature, time, speed, distance, mass, energy, voltage

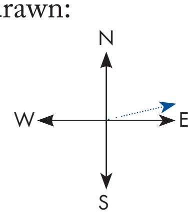
2.2 DIRECTIONS USING VECTORS

Directions are often stated with reference to the conditions in the problem. For example there could be a car moving at 60 km h^{-1} along a freeway, a force of 234 N pushing a toboggan down a ski slope. In many situations compass directions are referred to.

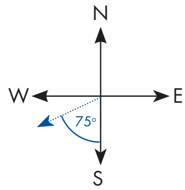
The convention for compass directions **on the page** is:



A force that is in the direction E 13^{o} N is drawn:



A velocity of a car in the direction S 75° W can be drawn



Note: The direction of the velocity in the previous diagram can also be quoted:

W 15° S

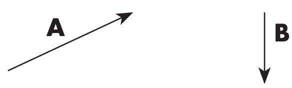
In the force diagram (before the velocity diagram) what alternative direction can be quoted?

2.3 VECTOR ADDITION

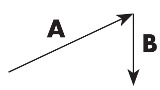
Two or more vectors are added using a scale drawing called a vector diagram. The result is a vector called the **resultant**. The **resultant** is a vector that has the same effect as the combination of vectors that produced it. The procedure for adding vectors is:

The **resultant** vector is drawn from the *'tail of the first drawn vector to the head of the second drawn vector.'*

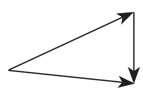
Example Two vectors **A** and **B** as shown below are to be added:



First draw vector **A**, then vector **B** is drawn so that the tail of vector **B** just touches the head of vector **A**.

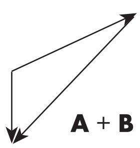


The resultant vector is drawn below:



Note that the resultant vector is drawn from the *'tail of the first drawn to the head of the second drawn'.*

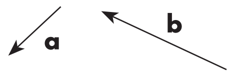
What is wrong with the following diagram for the resultant of the two vectors **A** and **B**?

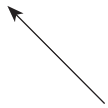
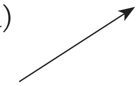


Answer: ____

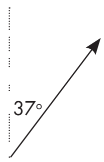
CHECKPOINT!

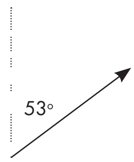
2.1 Which choice below represents the resultant of forces **a** and **b**?

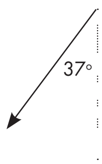


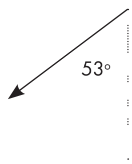
(i)  (ii)  (iii)  (iv)

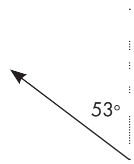
2.2 A bird flies 3 km to the West and then 4 km to the South. Which vector below represents the resultant displacement of the bird?

(i) 

(ii) 

(iii) 

(iv) 

(v) 

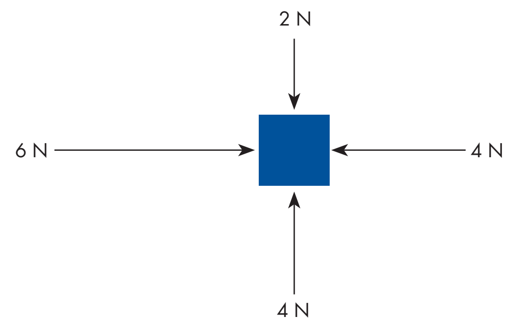
2.3 The magnitude of the resultant of a 12 m displacement and a 7 m displacement is 5 m. The angle between the two displacements is:

(i) 0° (ii) 30° (iii) 45° (iv) 90° (v) 180°

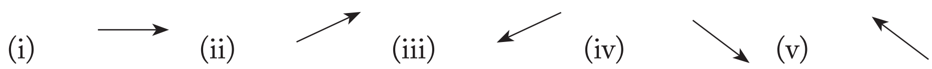
[Hint: Draw a vector diagram.]

2.4 A velocity of 30 km h^{-1} West is added to another velocity of 20 km h^{-1} North. Use a vector diagram to determine the magnitude and direction of the resultant velocity.

2.5 Four forces are applied to an object as shown below:



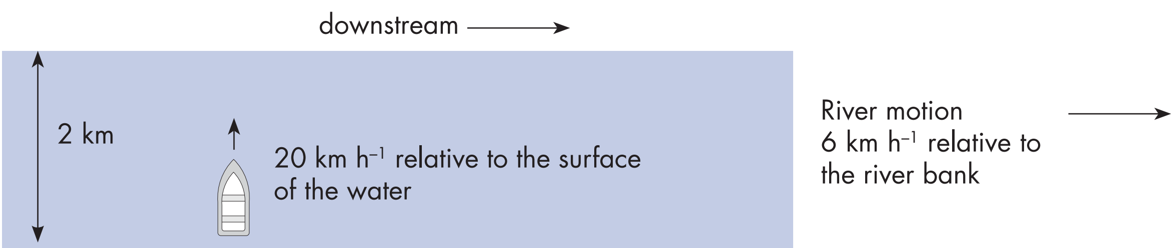
Which is the correct choice for the direction of the resultant force?



2.4 RIVER BANK/BOAT PROBLEMS

The following example illustrates the use of vector addition.

The diagram below shows a boat starting to cross a river which is 2 km wide. The boat travels at 20 km h^{-1} **relative to the surface of the water** and points directly across the river. The river is moving at 6 km h^{-1} downstream **relative to the river bank.**

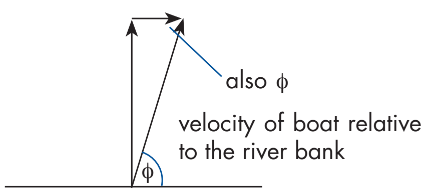


(a) What is the boat's velocity relative to the river bank?

(b) How long does it take for the boat to cross the river bank?

(c) At what point does the boat land on the other side?

Solution: The boat's velocity relative to the river bank is the combined result of its velocity relative to the surface of the water and the velocity of the river relative to the river bank.



(a) Using Pythagoras, it can be shown that the velocity of the boat relative to the river bank is given by $\sqrt{20^2 + 6^2}$ = 20.88 km h^{-1}.

To find the angle relative to the river bank (see ϕ in diagram above).

$\phi = \tan^{-1}\dfrac{20}{6} = 73.3^{o}$ (to access this key on a scientific calculator, press 2nd function tan or inverse tan)

(b) The boat continues across the river at 20 km h^{-1} despite the fact that it is being carried downstream. This is because the motion of the river current is perpendicular to the direction in which the boat is pointed. The river's motion **does not affect** the boat's movement across the river.

The time taken to cross the river is given by:

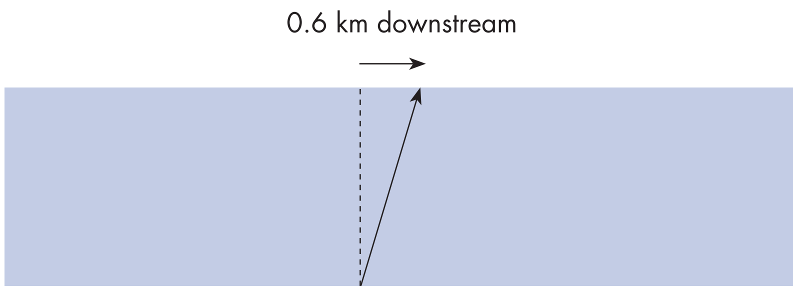
$$\text{time} = \frac{\textit{distance}}{\textit{speed}}$$ (where speed is the speed relative to the surface of the water)

$$= \frac{2}{20} = 0.1 \text{ h} = 6 \text{ minutes}$$

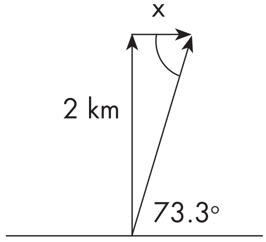
(c) As well as travelling across the river, the boat is carried at 6 km h^{-1} downstream for 0.1 hour (time taken to cross from part (b) above). The distance travelled downstream is given by:

$$\text{Distance} = \text{speed} \times \text{time} = 6 \times 0.1 = 0.6 \text{ km}$$

The boat touches the river bank 0.6 km downstream from a point directly across the river



Note that part (c) of the problem can be solved by drawing a vector triangle as follows which shows displacements and the angle obtained from part (b) above.



Note: When drawing the above diagram, do not mix up displacements and velocities on the same diagram.

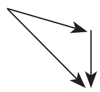
2.5 VECTOR SUBTRACTION

To subtract a vector, you add the **opposite** vector.

To subtract **B** from **A**, you begin with vector **A** and add the **opposite** of vector **B**

Hence $\mathbf{A} - \mathbf{B} = \mathbf{A} + (\mathbf{-B})$

Example: $\searrow$ minus $\uparrow$ = $\searrow$ plus $\downarrow$

Resultant 

Unlike vector addition, where the order of addition is not critical, in vector subtraction, $\mathbf{A} - \mathbf{B} \neq \mathbf{B} - \mathbf{A}$, the order is critical in vector subtraction.

Vector subtraction is commonly used when calculating a change in a vector quantity, e.g. to find the change in velocity $\Delta\mathbf{v}$, from an initial velocity and a final velocity,

$$\Delta\mathbf{v} = \mathbf{v} - \mathbf{u} \quad \text{where } \mathbf{v} = \text{final velocity and } \mathbf{u} = \text{initial velocity}$$

CHECKPOINT!

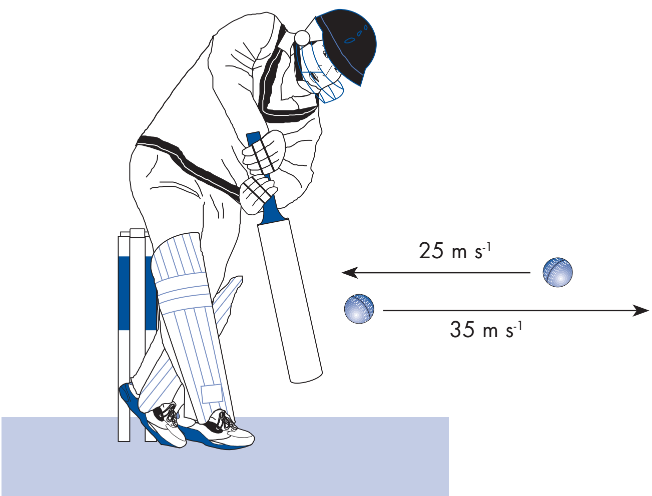
2.6 Subtract the vector 4 m North from 3 m North.

2.7 Subtract 4 m North from 3 m South.

2.8 Subtract 3.0 m s^{-1} East from 5.0 m s^{-1} South.

2.9 If a car slows down while initially travelling at 40 m s^{-1} South to a speed of 15 m s^{-1} South, what is the change in velocity?

2.10 A cricket ball of mass 500 g is bowled at a speed of 25 m s^{-1}. The batsman hits the ball directly back to the bowler at 35 m s^{-1}. Calculate the change in the ball's velocity.

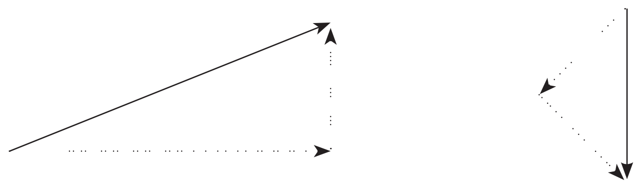


2.6 VECTOR RESOLUTION OR FINDING THE COMPONENTS OF A VECTOR

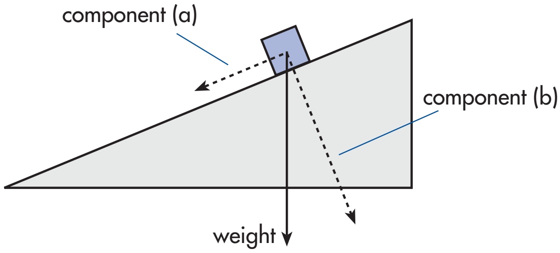
Of all the vector procedures, perhaps vector resolution is the most important. The idea of vector resolution is used throughout Physics, and particularly with Physics in the final years of high school.

For any vector, there are always two other parts or components of the vector which can be drawn at right angles to each other and which can be added vectorially together to give the original vector. These two other vectors are called the **component vectors**.

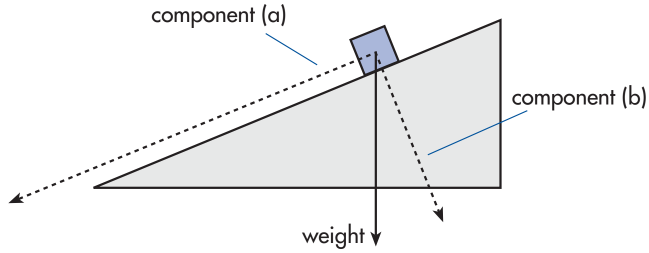
In the following diagrams, the components are shown as dotted vectors



Notes: (a) The magnitude of a component can **never be greater** than the original vector. We can see that in the following diagrams where in the **second** diagram one of the components of a weight force relative to an inclined surface is **incorrectly** drawn.



Correctly Drawn Components
(both components are smaller than the weight vector)



Incorrectly Drawn Component
(component (a) is greater than the weight vector)

(a) For reasons of clarity it is always recommended that vector components be drawn as dotted vectors, remembering that these are parts of the original vector.

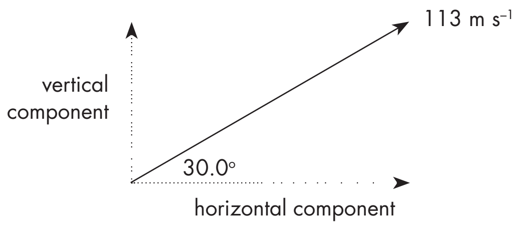
(b) The magnitude of vector components can be found by using elementary trigonometry; the component magnitude is always expressed in terms of the angle between the required component and the original vector (see Worked Examples 2.1 and 2.2 on page 19).

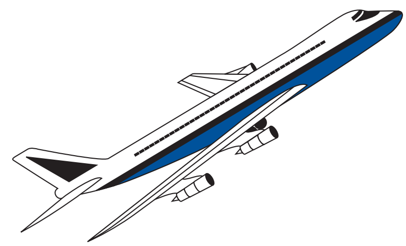
(c) The process of vector resolution (or finding the components of a vector) is extremely useful in situations involving several vectors which may add up vectorially to produce a non-right triangle. Using vector resolution simplifies such situations – finding components, summing them and adding them results in a final simple Pythagorean solution , thereby avoiding the use of the cos and sine rules (see Worked Example 2.3 on pages 20, 21).

Worked Examples

2.1 Find the horizontal and vertical components of the velocity of a aircraft which initially takes off from a runway with a velocity of 113 m s^{-1} at an angle of 30.0° to the runway.

Solution:





To express the horizontal component in terms of the original vector, use the fact that

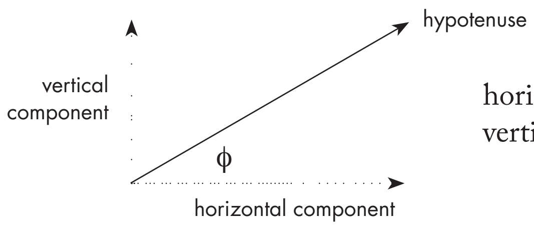
$$\cos 30^\circ = \frac{\textit{horizontal component}}{113 \text{ m s}^{-1}}$$

therefore, horizontal component = 113 cos 30.0° = 97.9 m s^{-1}

similarly, the vertical component = 113 cos 60.0° = 56.5 m s^{-1} **OR** 113 sin 30.0°

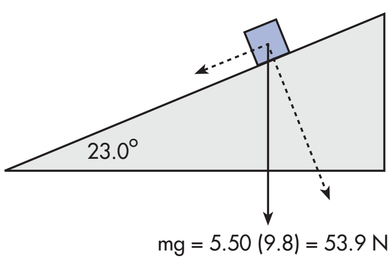
since $\sin\phi = \cos(90 - \phi)$ and $\cos\phi = \sin(90 - \phi)$ (both identical)

We can use the same idea of finding the horizontal component in any general triangle containing an original vector as the hypotenuse.



horizontal component = hypotenuse × cos ϕ
vertical component = hypotenuse × sin ϕ

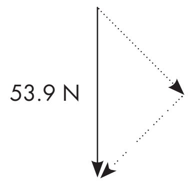
2.2 An object of mass 5.50 kg rests on a 23.0° incline. Find the components of the weight vector parallel to, and perpendicular to, the incline.



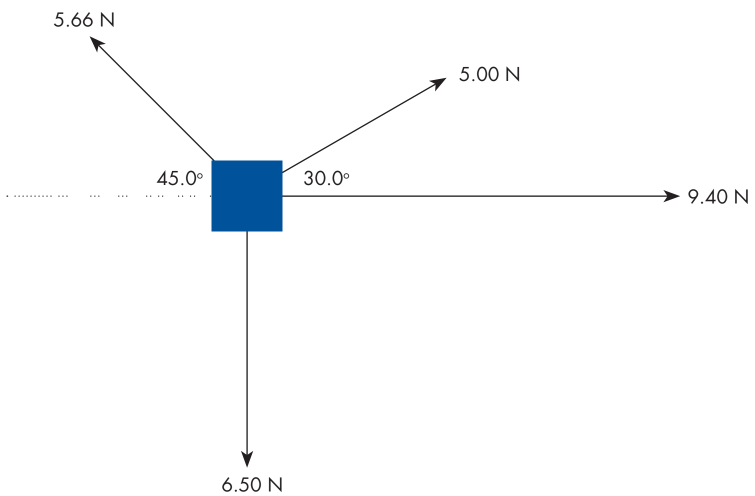
The component parallel to the incline can be expressed as (53.9) × cos 67.0° = 21.1 N
or (53.9) × sin 23.0° = 21.1 N

The component perpendicular to the incline = (53.9) × cos 23.0° = 49.6 N

Note that if we vectorially add the two components (see section on vector addition) we will obtain the original 53.9 N vector. To get the exact same 53.9 N answer, you will have to use all the digits from your calculator display. Try this!



2.3 Four vectors act simultaneously on a point as shown in the diagram below:



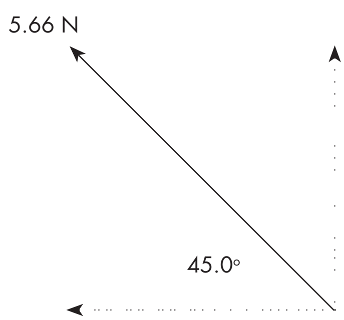
(a) what is the total force acting on the object?

(b) which way will the object move?

Solution: We can vectorially add any two vectors, get a resultant vector, then add this to the next vector etc. This process will more than likely involve quite a deal of trigonometry involving non-right triangles, which students often find difficult. It is far easier to resolve each of the vectors into any relevant horizontal/vertical components and end up with a simple Pythagorean triangle (together with simple determination of any angles).

This process of vector resolution (or finding the components of each vector) is quite straightforward but it is essential that setting out is very clear.

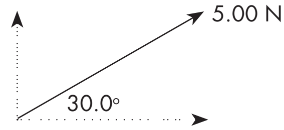
First consider the 5.66 N vector:



(i) The component vector to the left is given by 5.66 × cos 45.0° = 4.00 N

(ii) Similarly, the component vector upwards is given by 5.66 × cos 45.0° = 4.00 N

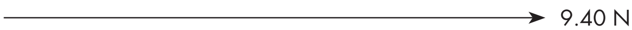
Now consider only the 5.00 N vector:



(iii) The vector component to the right is given by 5.00 × cos 30.0° = 4.33 N

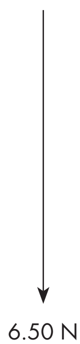
(iv) Similarly the vector component upwards is given by 5.00 × cos 60.0° = 2.50 N

Next consider only the 9.40 N vector:



(v) This vector has only one component to the right, i.e. itself, 9.40 N

Finally consider only the 6.50 N vector:



(vi) It has only one component that is vertical, that is 6.50 N acting downwards.

We now can add up vectorially all the vector components to the right, all those to the left, find their resultant easily, then add up all the vector components acting vertically upward, all those acting vertically downwards.

(vii) Σ (vector components acting to the right) = (iii) + (v) = 4.33 + 9.40 = 13.73 N

(viii) Σ (vector components acting to the left) = (i) only = 4.00 N

(ix) The vector sum of these is simply 13.73 – 4.00 = 9.73 N acting to the right.

Similarly,

(x) Σ (vector components acting vertically upwards) = (ii) + (iv) = 4.00 + 2.50 = 6.50 N

(xi) Σ (vector components acting vertically downwards) = (vi) only = 6.50 N

The vector sum of these is zero. The entire problem reduces to 9.73 N acting to the right.

Therefore, the object also moves to the right since the resultant force of 9.73 N acts to the right.

2.7 RECTILINEAR MOTION NOT INVOLVING GRAVITY

In this type of motion objects can either move with acceleration/deceleration or at a steady speed/velocity.

Constant motion problems (acceleration is zero)

The relationship between distance, speed and time is:

$$\text{speed} = \frac{\textit{distance}}{\textit{time}} \quad \text{and} \quad \text{average speed} = \frac{\textit{total distance}}{\textit{total time}}$$

OR

$$v = \frac{s}{t} \qquad v_{\text{average}} = \frac{s_{total}}{t_{total}}$$

The relationship between velocity, displacement and time is:

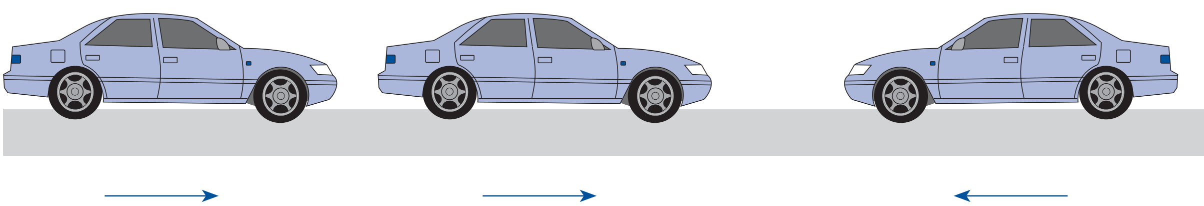
$$\text{velocity} = \frac{\textit{displacement}}{\textit{time}} \quad \text{and} \quad \text{average velocity} = \frac{\textit{total displacement}}{\textit{total time}}$$

OR

$$\mathbf{v} = \frac{s}{t} \qquad \mathbf{v}_{\text{average}} = \frac{s_{total}}{t_{total}}$$

Worked Examples

2.4 Three cars are shown below:



A 30 m s^{-1} **B** 30 m s^{-1} **C** 30 m s^{-1}

All three cars have the same speed. **A** and **B** also have the same velocity because both their speed and direction are the same. **A** and **C** (and **B** & **C**) have different velocities because although their speeds are identical, their direction of travel is different.

2.5 A woman walks northwards at a constant velocity. At t = 2 s the woman is 3 m North and at t = 26 s the woman is 39 m North. Calculate (a) the woman's speed (b) the woman's velocity

(a) $$\text{speed} = \frac{\textit{distance}}{\textit{time}}$$

$$= \frac{(39-3)}{(26-2)}$$

$$= 1.5 \text{ m s}^{-1}$$

(b) $\quad$ velocity $= \dfrac{\textit{displacement}}{\textit{time}}$

$= \dfrac{(39-3) \text{ m North}}{(26-2) \text{ s}}$

$= 1.5 \text{ m s}^{-1}$ North

2.6 On vacation, a family starts their journey at 9.00 am and travels 100 km South. After stopping for lunch, they then travel a further 250 km South, after which they have afternoon coffee. They then realise that they have misread their map and travel 50 km North to reach their camping ground at 5.00 pm. Find (a) their average speed and (b) their average velocity.

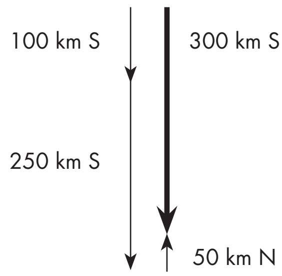
(a) $\quad$ average speed $= \dfrac{\textit{total distance}}{\textit{total time}} = \dfrac{100 + 250 + 50}{8 \text{ hours}} = 50 \text{ km h}^{-1}$

(b) $\quad$ average velocity $= \dfrac{\textit{total displacement}}{\textit{total time}}$

$= \dfrac{100 \text{ km S} + 250 \text{ km S} + 50 \text{ km N}}{8 \text{ hours}}$

$= \dfrac{300 \text{ km S}}{8 \text{ hours}}$

$= 37.5 \text{ km h}^{-1}$ South



CHECKPOINT!

2.11 During a triathlon a male triathlete runs 15 km West, then cycles 20 km North and finally swims 2 km East.

(a) What distance does he travel?

(b) What is his displacement?

2.12 A car drives 3 km East for 5 minutes, then 4 km South for 8 minutes and finally 3 km West for 2 minutes.

(a) Calculate the car's average speed (in km h^{-1}) for the whole trip.

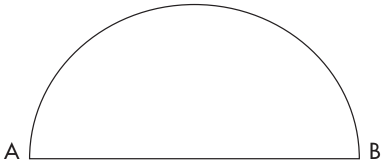
(b) Find the car's average velocity (in km h^{-1}) for the whole trip.

2.13 A group of soldiers on a route march travel at 4 km h^{-1} while marching. At the end of every 2 h marching, the group rests for 0.25 h. If this process is maintained for 8 hours, how far will the group have travelled?

2.14 A cyclist travels at a constant speed of 15 m s^{-1} in a straight line for 15 s. She then travels in the same direction at 20 m s^{-1} for another 15 s. Calculate her average speed for the whole 30 s.

2.15 How much time does it take to travel from a position 25 m South of the post office to a position 100 m North of the post office at an average speed of 15 m s^{-1}?

2.16 A dog takes 18.0 s to run with uniform speed around a semicircular track with diameter 72.0 m. If the dog runs from a position A to a position B as shown below:



(a) What is the dog's speed?

(b) What is the dog's velocity?

2.8 GRAPHICAL TREATMENT OF NON-ACCELERATED MOTION

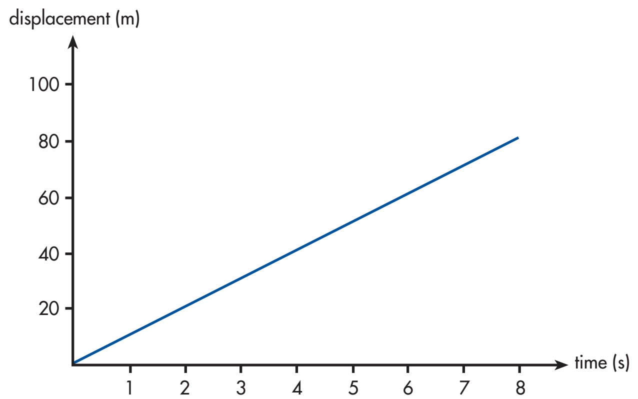
In this section, we will consider motion in a straight line, where an object can move only one way or the opposite way.

Worked Examples

2.7 Consider an object moving with steady velocity. Readings of displacement versus time were taken:

Time (s)	Displacement (m)
0.0	0.0
2.0	20.0
4.0	40.0
6.0	60.0
8.0	80.0

The information in the table can be plotted on a displacement/time graph:



The points on the graph lie on a straight line. Such a straight line shows a **uniform** or **constant velocity** in the given direction. The velocity is the slope (gradient) of the line. Gradients also require units.

$$\text{slope (or gradient)} = \frac{\textit{vertical change}}{\textit{horizontal change}} = \frac{\text{('rise')}}{\text{('run')}}$$

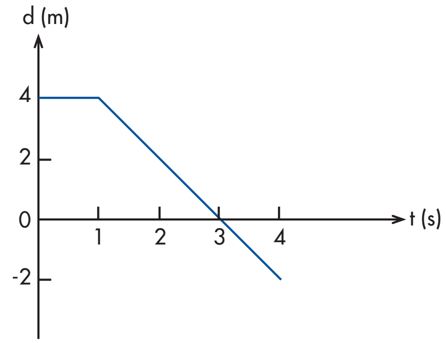
$$= \frac{80 - 0}{8 - 0}\ \frac{\text{m}}{\text{s}}$$

$$= 10\ \text{m s}^{-1}$$

(**Note:** to minimise error, use the largest dimensions from the graph)

In a straight line situation, vector quantities such as displacement and velocity have two possible directions. Motion in one direction is often described as the **forward direction** and is given a **positive** value. Motion in the opposite direction is in the **reverse direction** and is given a **negative** value. You can make your own choice as to which you call positive and which you call negative.

2.8

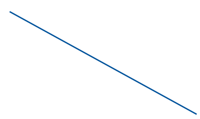


The sketched graph shows the motion of an object. During the first second (i.e. from t = 0 s to t = 1 s) the displacement remains constant at 4 m forwards from the reference point. The object is stationary. The slope of the graph for the first second is zero, confirming that the object is stationary.

From the end of the first second (from t = 1 s) the object's displacement starts to decrease. The object is moving closer to the reference point. This means that the object is moving **backwards** or in the **reverse** direction.

At t = 3 s, the object passes through the reference point
At t = 4 s, the object is 2 m behind the reference point.
After t = 4 s, the information about the object's motion is unavailable.

The graph between t = 1 s and t = 4 s is a straight line with negative slope; this means that the object is moving in reverse with constant velocity. The value of the velocity is given by the slope of this straight line. The slope will look like:



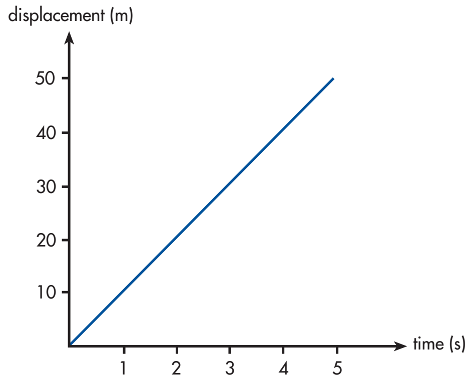
$$\text{velocity} = \frac{\text{rise}}{\text{run}}$$

$$= \frac{(-2-4)}{(4-1)}$$

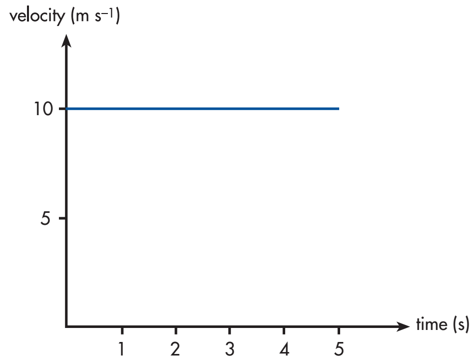
$$= -2 \text{ m s}^{-1}$$ *(the negative sign indicates motion in the reverse direction)*

2.9 From a displacement vs time graph, a graph of velocity vs time can be drawn as shown in the following example:

Displacement (m)	Time (s)
0	0
10	1
20	2
30	3
40	4
50	5



The slope of this line = $\frac{\text{rise}}{\text{run}} = \frac{50}{5}$ = 10 m s^{-1}, and the corresponding velocity vs time graph is:



Note: The area under any section of the velocity/time graph gives a value for the displacement in that time. For example for t = 1 the area under the v/t graph = 10 × 1 = 10 m.

2.9 PROBLEMS INVOLVING CHANGE IN VELOCITY (ACCELERATION)

Acceleration is defined as the change in velocity in the time taken for this change in velocity to occur.

$$\text{acceleration} = \frac{\textit{change in velocity}}{\textit{time}}$$

$$= \frac{\textit{final velocity} - \textit{initial velocity}}{\textit{time}}$$

$$\mathbf{a} = \frac{\mathbf{v - u}}{\mathrm{t}}$$

where **v** = final velocity
u = initial velocity
t = time

Quantities	t	**v**	**u**	**a**
Units	s	m s^{-1}	m s^{-1}	$\frac{m\ s^{-1}}{s} = m\ s^{-2}$

Notes:

1. The symbol Δ is sometime used to denote 'change of'.

$$\text{i.e.} \quad \mathbf{a} = \frac{\Delta \mathbf{v}}{t}$$

2. The term 'acceleration' is used to describe motion when an object slows down as well as speeds up.

In the case of an object slowing down, $\Delta\mathbf{v}$ is negative, hence the value of **a** is also negative. In these cases the terms **retardation** or **deceleration** are sometimes also used. However, the term **negative acceleration** is probably the best to use in the case of negative values of **a**.

Worked Examples

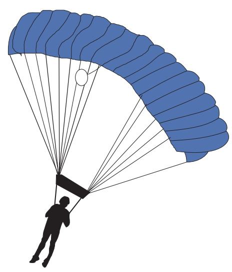
2.10 A car travelling at 5.00 m s^{-1} speeds up to 28.0 m s^{-1} in a time of 9.40 s. Calculate the acceleration of the car.

Solution $$a = \frac{v - u}{t}$$

$$= \frac{28.0 - 5.00}{9.40}$$

= 2.45 m s^{-2} in the direction of the car's motion.

2.11 A parachutist in free fall eventually opens his parachute and finds that in 1.80 s he slows down from 51.0 m s^{-1} to 5.10 m s^{-1}. Calculate the parachutist's acceleration.



Solution:

$$a = \frac{v - u}{t}$$

$$= \frac{5.10 - 51.0}{1.80}$$

a = -25.5 m s^{-2} in the opposite direction to the original fall direction

The negative value indicates that the parachutist is decelerating at 25.5 m s^{-2} or undergoing retardation at 25.5 m s^{-2}.

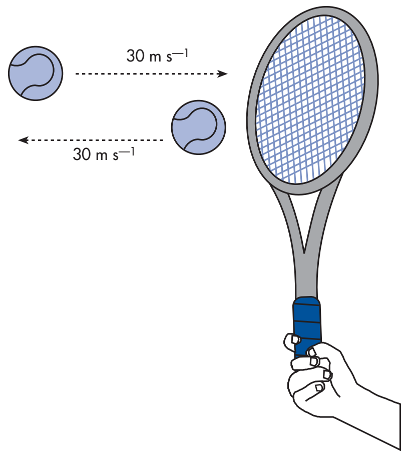
An object can accelerate when its direction changes, even if the speed remains the same as shown in the following example.

2.12 A ball is travelling towards a tennis racquet at 30 m s^{-1}. It takes an impact time of 0.30 s to cause the ball to change direction and is found to travel away from the racquet at 30 m s^{-1}. Calculate the acceleration of the ball during this time.

Solution:

Motions in different directions are involved. We need to distinguish between these.

Let motion of the ball towards the racquet be positive. Therefore motion away from the racquet will be negative.



In this case, $\mathbf{a} = \dfrac{\mathbf{v} - \mathbf{u}}{t}$ where **v**, **u** represent vectors

$$= \frac{(-30)-(30)}{0.30}$$

$$a = -200 \text{ m s}^{-2}$$

(The negative sign indicates away from the racquet)

Note: We could have designated 'towards' as negative, and 'away' as positive. In this case:

$$\mathbf{a} = \frac{\mathbf{v} - \mathbf{u}}{t}$$

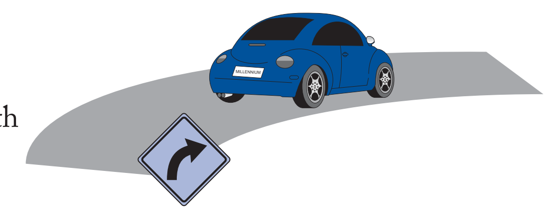
$$= \frac{30-(-30)}{0.30}$$

$$a = 200 \text{ m s}^{-2}$$

(Here the acceleration is still away from the racquet)

2.13 A car travelling South at 16.0 m s^{-1} rounds a bend and travels East at the same speed. The duration of the entire motion is 12.0 s. Calculate the car's acceleration.

Solution: We need to first calculate the change in velocity:



$$\Delta \mathbf{v} = \mathbf{v} - \mathbf{u}$$

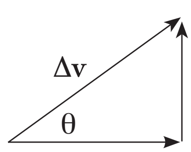
$$= 16 \text{ m s}^{-1} \text{ East} - 16 \text{ m s}^{-1} \text{ South}$$

$$= \longrightarrow \; - \; \downarrow$$

$$= \longrightarrow \; + \; \uparrow$$

(Recall earlier vector subtraction, Section 2.5)

=



By Pythagoras $\Delta \mathbf{v}$ = 22.6 and since the triangle is an isosceles one, θ = 45 degrees therefore:

$$\mathbf{a} = \frac{\mathbf{v - u}}{\mathbf{t}}$$

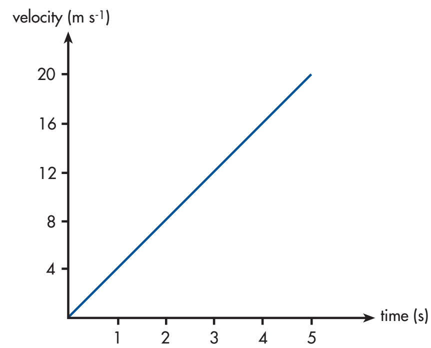
$$= \frac{22.6 \text{ ms}^{-1} \text{ NE}}{12.0}$$

$$\mathbf{a} = 1.89 \text{ ms}^{-2} \text{ NE}$$

2.10 GRAPHICAL TREATMENT OF ACCELERATED MOTION

Consider the following data for an object. The velocity vs time graph can be drawn:

time (s)	velocity (m s^{-1})
1	4
2	8
3	12
4	16
5	20

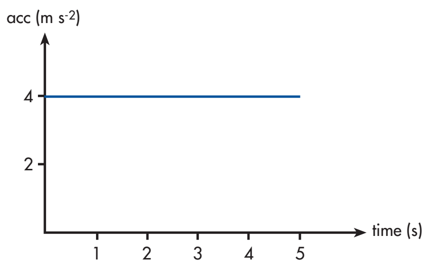


The corresponding acceleration vs time graph can be constructed by noting that the slope of the above graph produces a value for the acceleration.

$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{20}{5} = 4 \text{ m s}^{-2}$$

(recall that gradients require units)

Hence

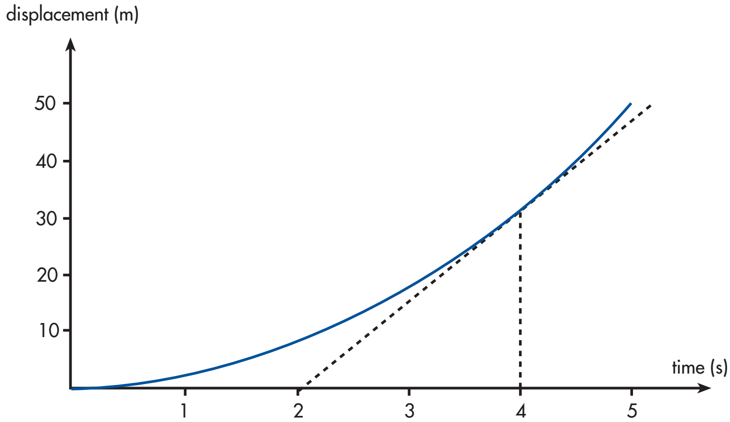


(the value of acceleration does not change)

To obtain the displacement vs time graph it is necessary to calculate the area under the velocity vs time graph for the various time intervals.

Time (s)	Area	Displacement (m)
1	(½)(1)(4)	2
2	(½)(2)(8)	8
3	(½)(3)(12)	18
4	(½)(4)(16)	32
5	(½)(5)(20)	50

Hence



Note: The slope of a tangent to the graph curve at a given instant of time produces a value for the velocity at that time.

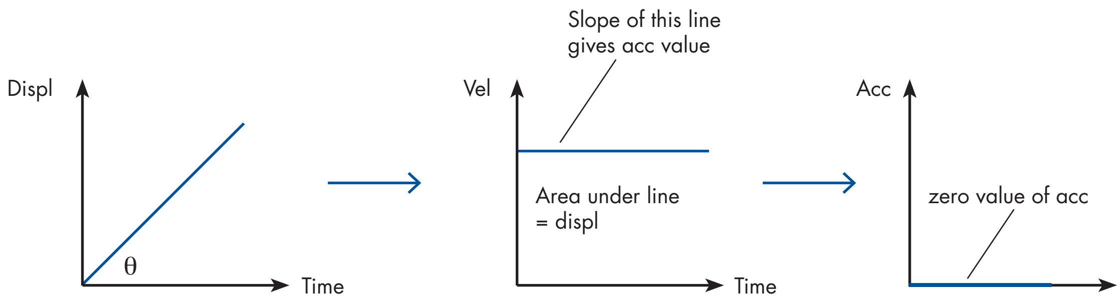
For example, at $t = 4$ s

$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{48.0 - 0}{5 - 2} = 16 \text{ m s}^{-1}$$

The slope values at other times will produce values of velocity at those times.

Summary

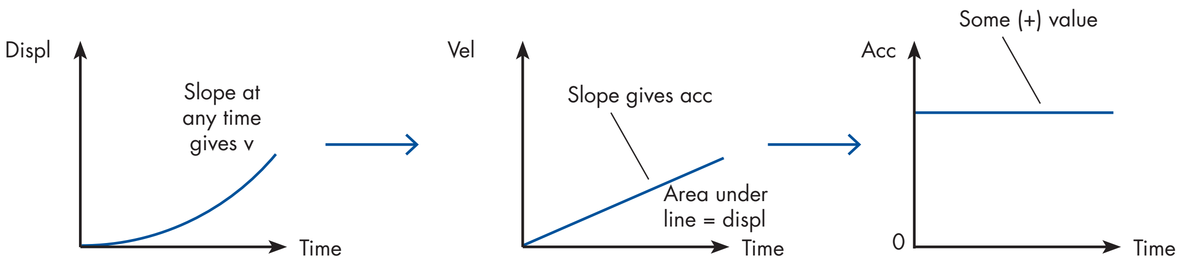
Non-accelerated motion



$$\text{Slope} = \tan\theta = \frac{\text{rise}}{\text{run}}$$

constant velocity

Accelerated motion



CHECKPOINT!

2.17 A cyclist travels a distance of 40 m in 5 s at a constant velocity. Plot a displacement vs time graph for her motion.

(a) From the graph obtain the velocity and plot the velocity vs time graph. From the graph calculate the total distance travelled in 4 s. Check the answer on the displacement vs time graph.

(b) From the velocity/time graph plot an acceleration vs time graph.

2.11 KINEMATIC EQUATIONS OF MOTION

Problems involving uniform (constant) acceleration in a straight line over a time interval can be solved using a set of formulae called the 'kinematic equations of motion'.

$$\mathbf{s} = \mathbf{u}t + \frac{1}{2}\mathbf{a}t^2 \qquad \mathbf{v}^2 = \mathbf{u}^2 + 2\mathbf{as} \qquad \mathbf{v} = \mathbf{u} + \mathbf{a}t$$

where **s** = displacement, **u** = initial velocity, **v** = final velocity, t = time

Note: The use of **s** = **v**t is only valid when **non-acceleration** is involved.

These equations are useful for solving problems in which the values of certain variables are known and the other unknown variable required. The values of the known variables are substituted and then solved for the required unknown variable using one of the above equations (care taken to look out for any non accelerated motion).

Worked Examples

2.14 A radio controlled toy car starts from rest and accelerates with a uniform acceleration of 0.5 m s^{-2} in a straight line. What velocity does it reach after accelerating for 4 s?

Solution:

known

u = 0 m s^{-1}
t = 4 s
a = 0.5 m s^{-2}

unknown

v = ?

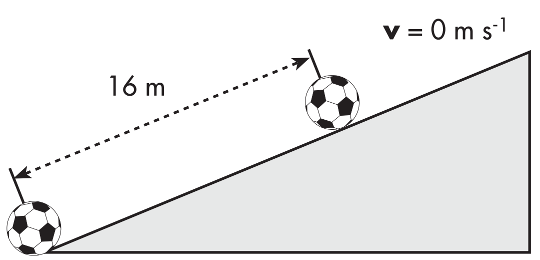
$\mathbf{v} = \mathbf{u} + \mathbf{a}t = 0 + 0.5(4) = 2$ m s^{-1} in the direction of motion

2.15 A ball, initially travelling at 4 m s^{-1}, rolls up a slope and slows uniformly to a halt, 16 m up the slope.

(a) What is the ball's acceleration?

(b) How long does the ball take to stop?

Solution: A diagram representing the situation helps greatly and should be drawn. When in doubt, always draw a diagram... in fact, always draw a diagram in all cases!



known

u = 4 m s^{-1}
v = 0 m s^{-1}
s = 16 m

unknown

a = ?

(a) To calculate **a** from the knowns listed, we can use the formula:

$$\mathbf{v}^2 = \mathbf{u}^2 + 2\mathbf{as}$$

Rearranging the formula to obtain a:

$$\mathbf{a} = \frac{\mathbf{v}^2 - \mathbf{u}^2}{2\mathbf{s}} = \frac{(0)^2 - (4)^2}{2(16)} = -0.5 \text{ m s}^{-2} \text{ up the slope}$$

The negative sign confirms that the object is slowing down.

(b) t can be obtained using the formula $\mathbf{v} = \mathbf{u} + \mathbf{at}$

and rearranging it to give $t = \dfrac{\mathbf{v} - \mathbf{u}}{\mathbf{a}} = \dfrac{0 - 4}{-0.5} = 8 \text{ s}$

Alternatively, t can be obtained using the formula $\mathbf{s} = \mathbf{ut} + \frac{1}{2}\mathbf{at}^2$

i.e. $16 = 4t + \frac{1}{2}(-0.5)t^2$

Solving this necessitates putting the equation into a quadratic form (squared variable, variable, constant in that order).

Rearranging the above, we obtain

$-0.25t^2 + 4t - 16 = 0$

Here, a = -0.25, b = 4 and c = - 16

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{-4 \pm \sqrt{(4)^2 - 4(-0.25)(-16)}}{2(-0.25)}$$

$$= \frac{-4 \pm \sqrt{16 - 16}}{-0.5}$$

$$= \frac{-4}{-0.5}$$

$$t = 8 \text{ s}$$

Some calculators will solve quadratic equations in such a way that you do not have to use the quadratic formula; it is simply a matter of typing in the values for 'a', 'b' and 'c'.

CHECKPOINT!

2.18 An object travels from rest for 10 s at an acceleration of 3 m s^{-2}. Find:

(a) distance covered by object

(b) object's final speed

2.19 A car starts from rest and after 5 s has a speed of 30 m s^{-1}. Find:

(a) its acceleration

(b) distance covered

2.20 How far will an object fall from rest in 3 s, and what will be its final velocity? (Use acceleration due to gravity as 9.8 m s^{-2}). (Neglect air resistance).

2.21 A bomb is dropped from a plane which is flying horizontally at a height of 49 km. How long will it take to reach the earth? (Neglect air resistance).

2.22 A car starts from rest and accelerates at 12 m s^{-2} for 3 s. It travels at a constant velocity attained after 3 s for 2 s. Then it accelerates at half the previous rate for 4 s. It then undergoes a uniform deceleration and is brought to a halt in another 6 s.

(a) Calculate its velocity when travelling at constant speed

(b) Calculate its maximum velocity

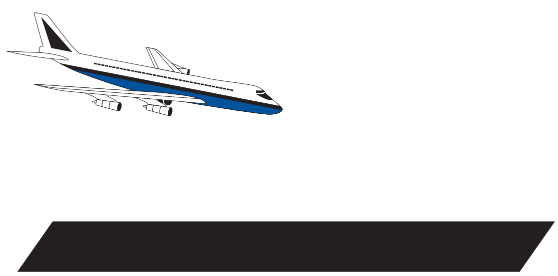
(c) Plot a velocity vs time graph and from the graph determine the distance travelled and the retardation.

2.23 After stopping at a station, a train accelerates at a steady rate of 0.25 m s^{-2}.

(a) How far does the train travel at this acceleration in 2 minutes?

(b) At what speed is the train moving after it has travelled 1.0 km?

2.24 What time does it take for an aircraft to decelerate uniformly from 360 km h^{-1} to a stop if the horizontal distance covered relative to the runway is 1.5 km?



2.25 A particle initially at rest, moves with accelerations of 3 m s^{-2} due North and then 4 m s^{-2} due East. The time for the initial accelerated motion is 5.00 s and the time for the subsequent motion East is 7.00 s. Assuming the time taken for the plane to change direction is very small, i.e. virtually instantaneous:

(a) What is the velocity after the first 5.00 s?

(b) What is the final velocity after the second 7.00 s interval?

2.26 A marble is dropped from an 850 m high cliff. Calculate:

(a) The distance travelled after 4 sec.

(b) The distance travelled after 5 sec.

(c) The distance travelled in the 5^{th} second.
[HINT: subtract ans to (b) from ans to (a)]

(d) How long will it take for the marble to travel 850 m?

(e) What is the velocity of the marble just prior to impact with the ground?
Use acceleration due to gravity = 9.8 m s^{-2} and assume negligible resistance.

2.12 MOMENTUM

Momentum involves both the velocity and mass of an object.

Momentum is sometimes loosely regarded as the 'oomph' of an object that moves.

The greater the momentum of an object, the harder it is to stop it.

Example

A golf ball thrown at the same speed as a larger hockey ball is easier to stop because the golf ball has less mass and therefore less momentum than the hockey ball.

Momentum is designated as **p**

and $p = mv$ where **p** is measured in kg m s^{-1}, **v** is measured in m s^{-1}, m is measured in kg

Note: Momentum is a vector quantity.

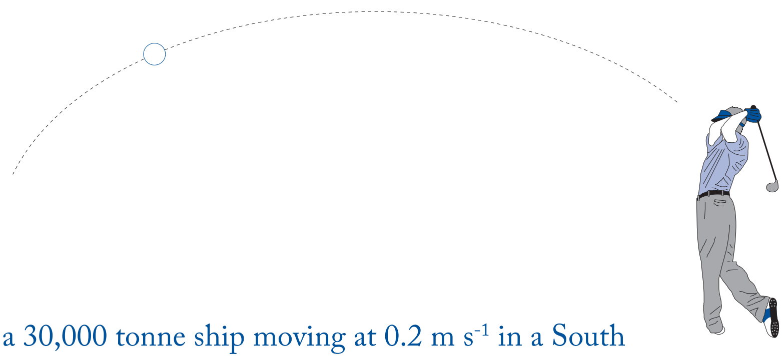
Worked Examples

2.16 Calculate the momentum of a golf ball of mass 30 g moving at 10 m s^{-1} West.

$p = mv$

$= (0.030)(10)$

$p = 0.3$ kg m s^{-1} West

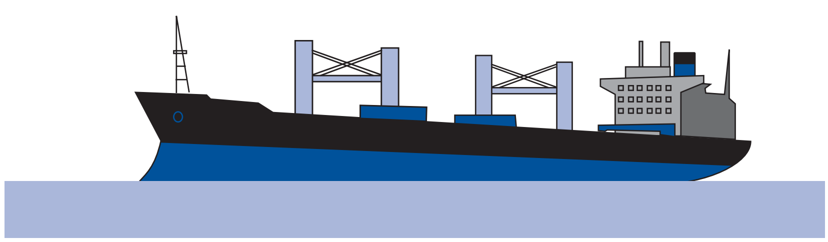


2.17 Calculate the momentum of a 30,000 tonne ship moving at 0.2 m s^{-1} in a South Westerly direction.

$p = mv$

$= (30{,}000 \times 10^3)(0.2)$ (1 tonne = 10^3 kg)

$p = 6 \times 10^6$ kg m s^{-1} SW



2.18 A rocket has a momentum of 1.4×10^5 kg m s^{-1} East. If its mass is 6.2×10^2 kg, what is its velocity?

$$p = mv$$

$$\text{Rearranging } v = \frac{p}{m}$$

$$= \frac{1.4 \times 10^5}{6.2 \times 10^2}$$

$$v = 226 \text{ m s}^{-1} \text{ East}$$

2.13 CHANGE IN MOMENTUM

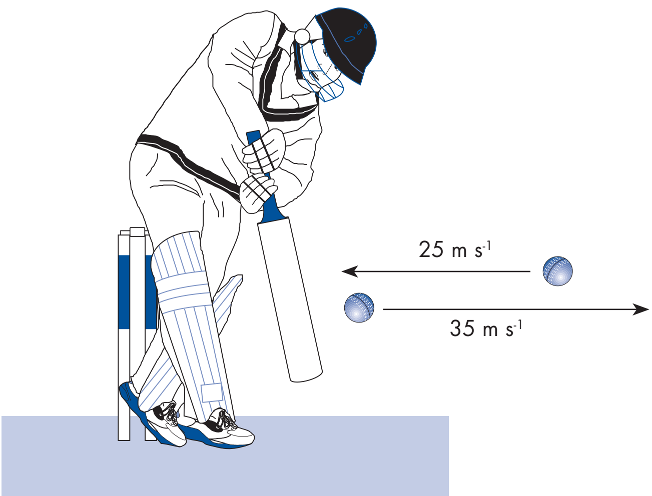
Change in momentum is calculated by using:

$$\Delta p = p_{final} - p_{initial}$$

$$= mv - mu$$

Worked Example

2.19 A cricket ball of mass 500 g is bowled at a speed of 25 m s^{-1}. The batsman hits the ball directly back to the bowler at 35 m s^{-1}. Calculate the change of the ball's momentum.



Solution: Since directions change, we must nominate signs for different directions.

Let motion towards the bat be positive.

Hence $\Delta p = mv - mu$

$$= m(v - u)$$

$$= 0.5\,[(-35) - (25)]$$

$\Delta p = -30$ kg m s^{-1} *(negative sign indicates away from the bat)*

CHECKPOINT!

2.27 Calculate the momentum of:

(a) a 0.5 kg bird flying NNE at 7 m s^{-1}

(b) a 20 g snail moving at 1 mm s^{-1}

(c) a 1.5 tonne van speeding at 120 km h^{-1}

2.28 When a soccer ball of mass 0.45 kg is kicked from rest, it moves off at a speed of 22 m s^{-1} in an Easterly direction.

Calculate the change in momentum of the ball.

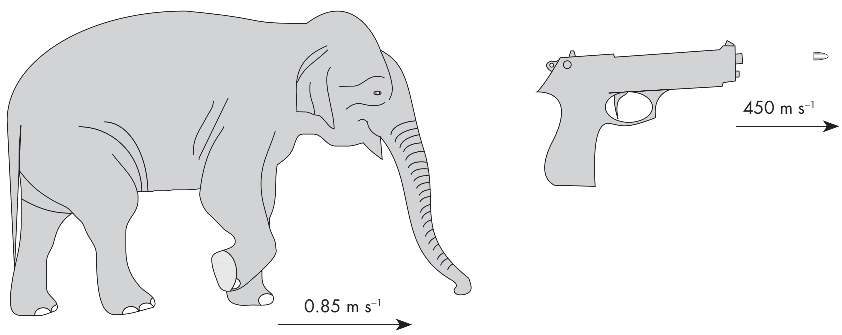
2.29 A car of mass 2.1 tonne carries two people of masses 45 kg and 75 kg at a velocity of 36 km h^{-1} West. What is the momentum of the car and its occupants?

2.30 What would be the velocities of the following bodies if they had a momentum of 90 kg m s^{-1} to the right?

(a) a 85 kg football player

(b) a 450 g football

2.31 Which has the greater momentum: a 2 tonne elephant travelling at 0.85 m s^{-1} or a 20 g bullet travelling at 450 m s^{-1}?



2.32 A 0.250 kg bullet is fired horizontally with a velocity of 990 m s^{-1} at an armour plated tank. It strikes the surface of the tank at an angle of 45.0° and is deflected off the surface at the same angle with the same speed. Find the change in momentum of the bullet.

2.33 Find the mass of a rocket which leaves its launch ramp at 18.0 m s^{-1} if its momentum is 2.63×10^3 kg m s^{-1} upwards.

2.34 A truck (mass 3.80×10^4 kg) is hauling a load of fruit (fruit mass 4.25×10^3 kg). The driver sees a kangaroo and puts on the brakes and stops very abruptly while travelling at 70 km h^{-1} in a southbound direction. What is the change in momentum of the fruit-laden truck?

2.14 NEWTON'S LAWS OF MOTION

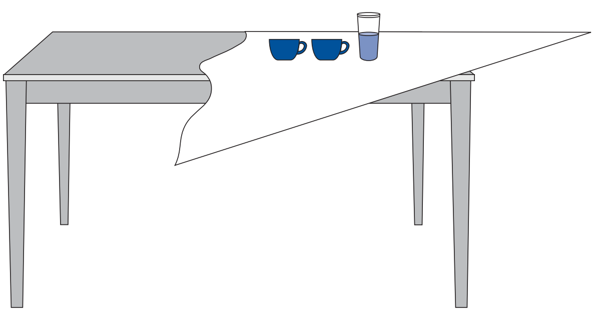
As mentioned earlier (page 40) the greater the momentum of an object, the harder it is to stop it. In other words, forces must be involved.

Isaac Newton (1642 – 1727) developed several relationships between forces and their effects on different objects. These are called Newton's Laws of Motion.

First Law

An object of zero acceleration will either have a zero velocity (be stationary) or have constant velocity. This law is sometimes quoted as 'An object tends to maintain its state of motion unless acted on by an external unbalanced force'. An object of large mass requires a large force to change its velocity by a noticeable amount; the object is said to have a large **inertia**. The mass of an object is a measure of its inertia.

Examples



(a) The frictional force is not large enough to accelerate the crockery so it stays in place if the tablecloth is being pulled out very quickly from under the crockery.

(b) If you are standing in the aisle of a bus, your inertia will tend to keep you moving the way you were going. If the bus stops suddenly, you will tend to move forwards trying to maintain your previous velocity, so you tend to keep going.

(c) When a car starts suddenly, you can feel the back of your seat pushing on you. Also, if the car is hit from the rear by another car you will get left behind if you don't have a head-rest – whiplash injuries can result. Even loose luggage can slide over smooth surfaces with gentle starting of a car – hence the use of rough surfaces or tie downs will prevent movement.

Second Law

The rate of change of momentum of an object is proportional to the nett force acting on that object.

i.e. $\mathbf{F}_{nett} \;\alpha\; \dfrac{\Delta p}{t}$

i.e. $\mathbf{F}_{nett} = \dfrac{mv - mu}{t}$

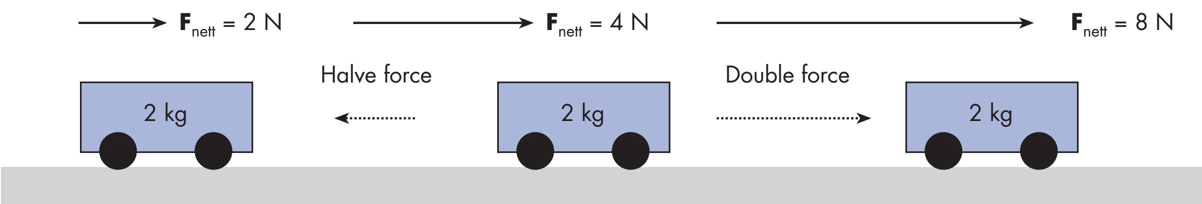
i.e. $\mathbf{F}_{nett} = m\mathbf{a}$ where m is measured in kg , **a** is measured in m s^{-2}, **F** is measured in N

For a particular object,

(a) the greater the resultant or nett force, the greater the acceleration,

i.e. $\mathbf{a} \;\alpha\; \mathbf{F}_{nett}$

When mass is constant, halving the resultant force will halve the acceleration and doubling the resultant force will double the acceleration.

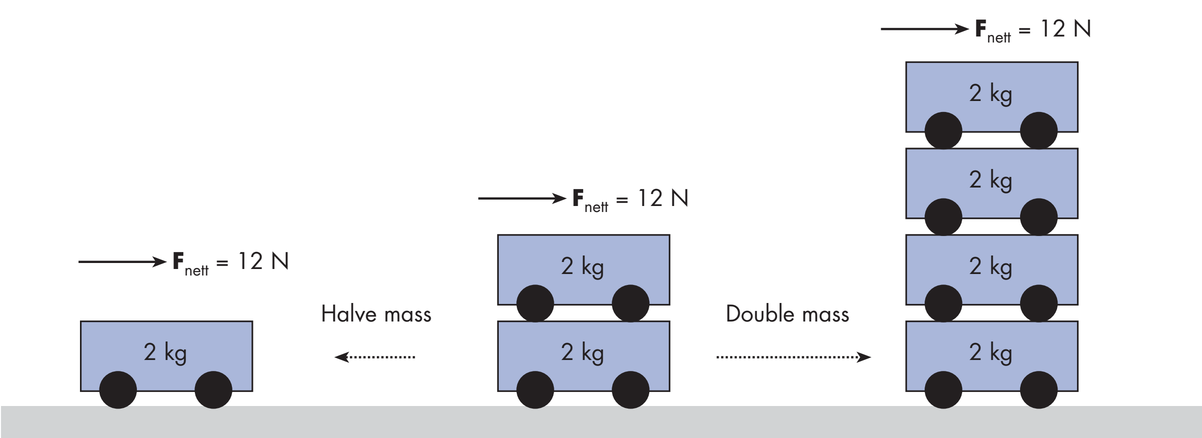


$\mathbf{a} = \mathbf{F}_{nett} = \dfrac{2}{2} = 1 \text{ m s}^{-2}$ $\mathbf{a} = \mathbf{F}_{nett} = \dfrac{4}{2} = 2 \text{ m s}^{-2}$ $\mathbf{a} = \mathbf{F}_{nett} = \dfrac{8}{2} = 4 \text{ ms}^{-2}$

(b) the greater the mass of an object, the smaller the acceleration of that object for a particular resultant force,

i.e. $\mathbf{a} \;\alpha\; \dfrac{1}{m}$ (acceleration is inversely proportional to the mass)

If the force is constant, halving the mass will double the acceleration, and doubling the mass will halve the acceleration.



$a = \dfrac{12}{2} = 6 \text{ m s}^{-2}$ to the right $a = \dfrac{12}{4} = 3 \text{ m s}^{-2}$ to the right $a = \dfrac{12}{8} = 1.5 \text{ m s}^{-2}$ to the right

Third Law

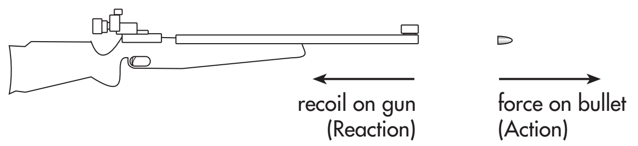
For every object A that exerts a force **on B**, B exerts an equal and opposite force **on A**.

This is sometimes more loosely quoted as: 'For every action force, there is an equal and opposite reaction force'.

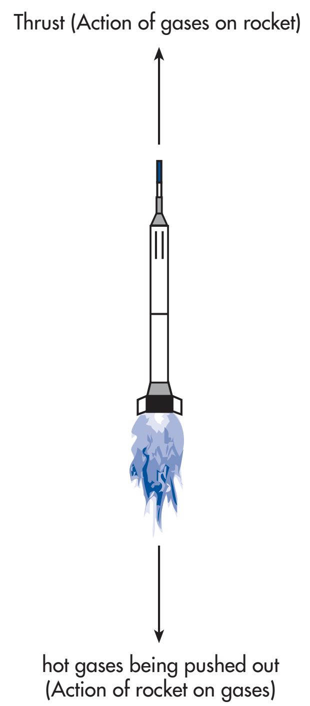
Note: The action and reaction forces have equal magnitude but are not the same since they act on different objects. Therefore these forces do **not** cancel out.

Examples

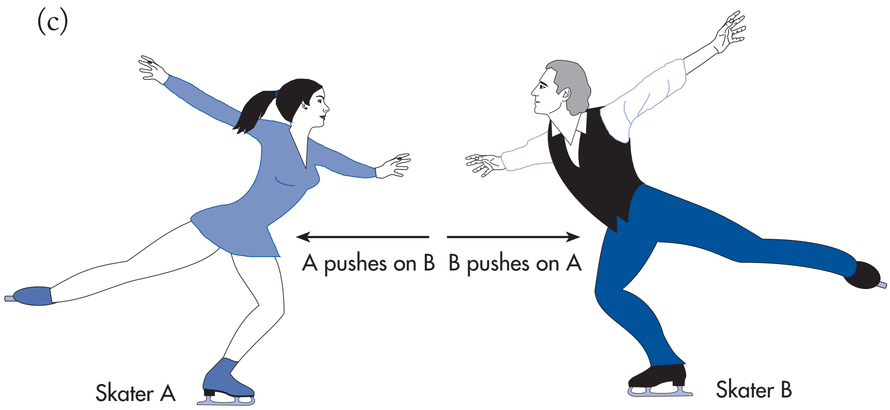
(a)



(b)



(c)



2.15 CALCULATIONS INVOLVING NEWTON'S LAWS

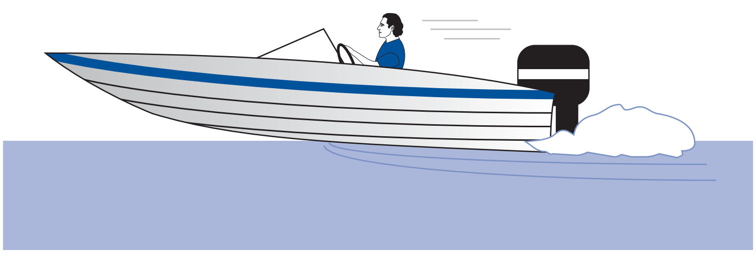
Worked Examples

2.21 A cyclist is accelerating at 2.5 m s^{-2}. The cyclist has a mass of 60 kg and the bicycle has a mass of 20 kg. Calculate the size of the resultant force acting on the cyclist and the bike.

Solution: Since the acceleration is to the right, then the resultant force or nett force also acts to the right.

known	unknown
$m_{total} = 60 + 20 = 80$ kg	$\mathbf{F}_{nett} = ?$
$\mathbf{a} = 2.5$ m s^{-2}	$\mathbf{F}_{nett} = m\mathbf{a}$
	$= (80)(2.5)$
	$= 200$ N to the right

2.22 The thrust (force moving the boat) from the outboard engine of a speedboat is 1000 N. If the boat has a mass of 500 kg and the friction force opposing the motion of the boat through the water is 200 N, what is the acceleration of the speedboat?



Since friction opposes motion, the nett or resultant force on the boat is 800 N to the left

Therefore, $\mathbf{a} = \dfrac{\mathbf{F}_{nett}}{m}$

$= \dfrac{800}{500}$

$= 1.6$ m s^{-2} to the left

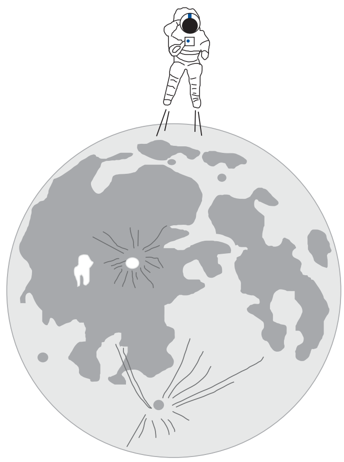
2.16 WEIGHT

On the Earth's surface, weight is a force which is given by:

Weight = $\mathbf{F}_W$ = mg , where $\mathbf{F}_W$ is measured in N, m is measured in kg

g is the value of the acceleration due to the Earth's gravity, having a value of 9.8 m s^{-2}

Note: The value of **g** varies with distance from the centre of the Earth; this will be covered later in future Physics courses. The weight formula above can also be used for different planets, moons etc. As an example the value for **g** on the moon is about one sixth that of the value on the earth whereas on Jupiter it is 26 m s^{-2}.



Everyday usage of 'someone's weight as (say) 75 kg' is technically incorrect. When weight is expressed as '75 kg', what is meant is the force equivalent of 75 kg, i.e. 75 × 9.8 N.

Weight is a force with units of Newton and acts downwards towards the Earth's centre.

2.17 MECHANICAL ENERGY (POTENTIAL AND KINETIC)

We will consider two types of mechanical energy, gravitational potential energy and kinetic energy.

Gravitational Potential Energy is given by the formula:

E_p = mgh

where m is in kg,

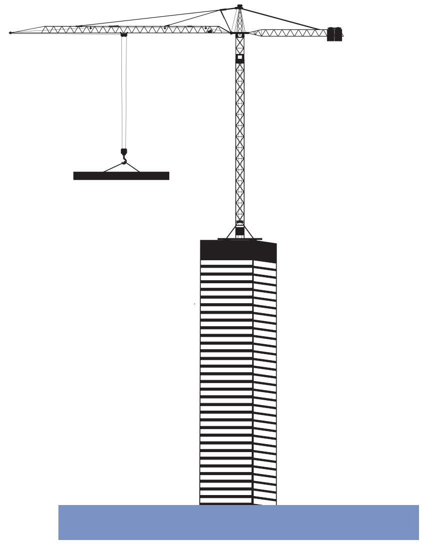
g is the value of acceleration due to gravity (9.8 m s^{-2})

h is the distance or height above a reference level (usually the ground), measured in m

E_p is measured in joule (J)

Note: (a) E_p is a scalar quantity. (b) E_p is sometimes written as P.E. (c) E_p is also termed simply 'potential energy'. (d) If h = 0 , then E_p is also zero.

Worked Examples



2.22 A crane lifts a steel beam of mass 1.5 tonne to a height of 5 m above the ground. Calculate the potential energy of the beam.

Solution

$E_p = mgh = (1.5 \times 10^3)(9.8)(5) = 7.35 \times 10^4$ J

The same crane is now lifted to a building that is 35 m high. The crane lifts the same beam to a height of 5 m above the top floor of the building that the crane is resting on.

Calculate:

(a) the potential energy of the beam relative to the building's highest floor.

(b) the potential energy of the beam relative to the ground.

Solution

(a) The beam is still 5 m above the floor of the high building, so that the E_p value is the same as the previous result.

(b) Relative to the ground below the beam is (35 + 5) m above the ground.

Therefore, $E_p = mgh = (1.5 \times 10^3)(9.8)(35 + 5) = 5.88 \times 10^5$ J

Kinetic Energy is the energy an object has because of its motion.

$E_k = \frac{1}{2} mv^2$ where m is in kg, v is the speed (in m s^{-1}) and E_k is measured in J.

Note: (i) If an object is stationary, it has zero kinetic energy.
(ii) E_k is a scalar quantity; the direction of motion does not matter.

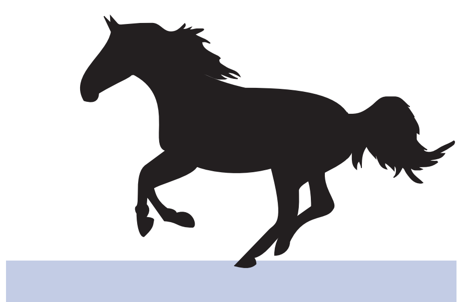
2.23 Find the kinetic energy of a 345 kg horse galloping at a speed of 36 km h^{-1}.

Solution

The speed must first be converted to m s^{-1}.

$$36 \text{ km h}^{-1} = \frac{36 \text{ km}}{1 \text{ hr}} = \frac{3600 \text{ m}}{60 \times 60 \text{ s}} = 10 \text{ m s}^{-1}$$

therefore $E_k = \frac{1}{2} mv^2 = \frac{1}{2}(345)(10)^2 = 1.725 \times 10^4$ J



2.24 A tugboat of mass 480 tonne is travelling at 2 m s^{-1}. Calculate its kinetic energy.

Solution

$$E_k = \frac{1}{2} mv^2$$

$$= \frac{1}{2} (480 \times 10^3)(2)^2$$

$$= 9.6 \times 10^5 \text{ J}$$

The same tugboat as above now travels at a new speed that is twice its original speed. What is its new energy of motion?

Solution

$$E_k = \frac{1}{2} mv^2$$

$$= \frac{1}{2} (480 \times 10^3)(4)^2$$

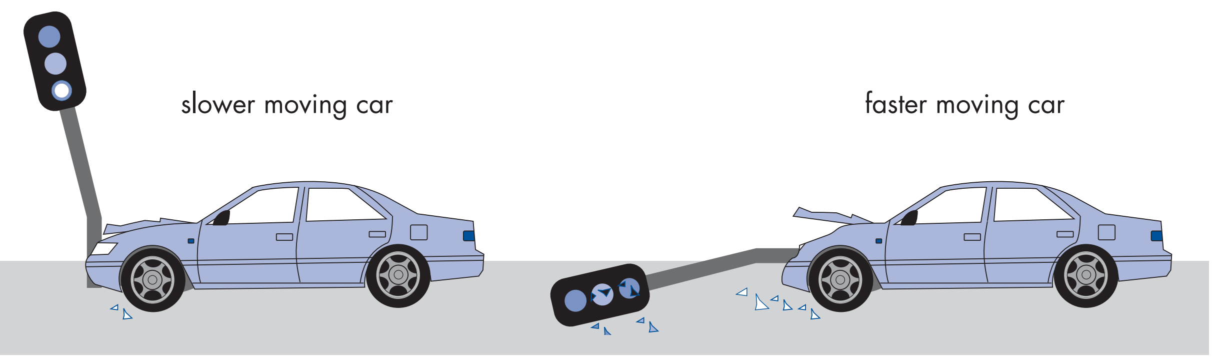
$$= 3.84 \times 10^6 \text{ J}$$

A more elegant way of solving the problem is to note that E_k is proportional to the $(\text{speed})^2$

Since the speed doubles then the E_k will increase by a factor of **4**

Therefore $E_k = \mathbf{4}\,(9.6 \times 10^5) = 3.84 \times 10^6$ J

From the example above it can be deduced that a car travelling at 100 km h^{-1} does **4** times more damage than if it were travelling at 50 km h^{-1} as shown below:



2.18 WORK

In Physics, work means the process of transferring energy from one form to another (unlike the everyday meaning of the word). Work is involved in lifting a baby into a cot and in coasting downhill on a bike.

The amount of work is given by:

$W = Fs$ **in the direction of the force**

W is measured in J, F is measured in N (use magnitude of **F**), s is measured in m

Note: (a) If an object does not move, no work is done on it.
(b) Work and energy are interchangeable – if energy is transferred, work must be done. Conversely, if work is done on an object, its energy must change (it will move).
(c) Work, like energy, is a scalar quantity.

If the force is applied in a direction **not** the same as the direction of motion, then the appropriate component of the force must be used in the previous formula.

When a person pushes a stationary cart with a force, the cart accelerates, starts to move and gains kinetic energy. The energy that is transferred is referred to as the work done by the force.

Example (a)

If you lift a child into his cot, you must move him with a force over a certain vertical distance, so

$W = \mathbf{F}s$ where **F** represents the weight of the child,

s is the vertical distance he is moved at constant velocity

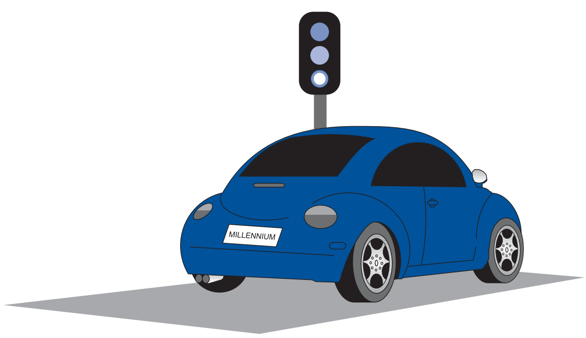
$= mgs$

$= mgh$ (same as E_p gain)

Example (b)

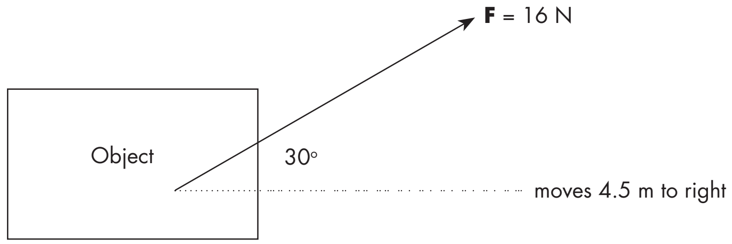
If you accelerate a car from 10 m s^{-1} to 15 m s^{-1}, a force must be applied. This force causes the kinetic energy of the car to increase.

Therefore work done = gain in E_k (neglecting any frictional effects)



Worked Examples

2.25 An object has a force applied to it as shown. It moves 4.5 m to the right.



Calculate the work done on the box (assume no other relevant forces act on the object).

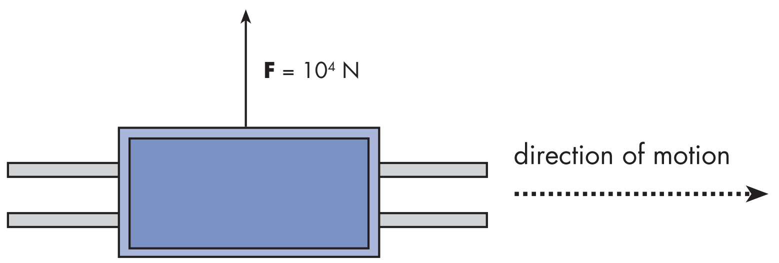
Solution

It is necessary to find the component of the force in the same direction as the motion.

$$F_{\text{parallel to motion}} = \mathbf{F}\cos 30^\circ = 16\cos 30^\circ = 13.9\ \text{N}$$

$$W = (13.856)(4.5) = 62.4\ \text{J}$$

2.26 How much work is done by a force of 10^4 N as shown in the diagram below if the force acts at right angles to the direction the rail car is moving?

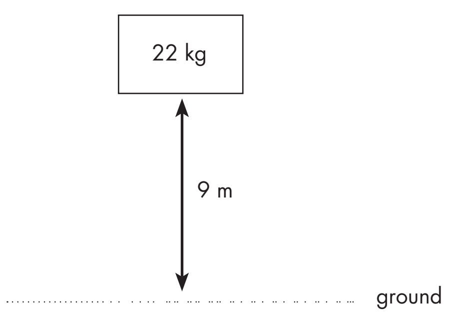


Solution

There is no component of the force acting in the direction of motion, therefore the work done is zero.

2.19 CONSERVATION OF MECHANICAL ENERGY

Consider a 22 kg mass held at rest 9 m above the ground:



To raise the object above the ground a distance of 9 m requires work to be done on the object.

$$\begin{aligned} \text{Work} &= \text{gain in } E_p \\ &= mgh \\ &= (22)(9.8)(9) \\ &= 1.94 \times 10^3 \text{ J} \end{aligned}$$

The gravitational potential energy of this mass at a height of 9 m above the ground is 1.94 kJ

If the mass falls, its E_p decreases but its speed increases, i.e. it gains E_k

At the instant just before the mass hits the ground, it will have maximum speed and zero E_p

Hence there is no loss of energy, merely a transfer from E_p to E_k (ignoring air resistance)

This is the **Principle of Conservation of Mechanical Energy:**

loss in E_p = gain in E_k

Worked Examples

2.27 A body of mass 5 kg is raised 5 m into the air and then released.

(a) Calculate its initial E_p

(b) Calculate its potential and kinetic energies at a point 2 m above the ground

(c) Calculate its potential and kinetic energies just before it hits the ground.

Solution

(a) initial $E_p = mgh = (5)(9.8)(5) = 245$ J

2 m above the ground, $E_p = mgh = (5)(9.8)(2) = 98$ J

Loss of $E_p = 245 - 98 = 147$ J $= E_k$

(c) Final $E_p = mgh = 0$ J

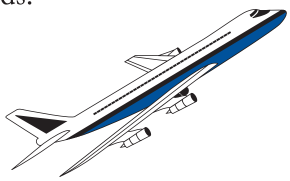
Final E_k = loss in $E_p = 245$ J

When the mass strikes the ground, this kinetic energy is converted to work against the ground resistance, sound and heat.

Review Questions

CHAPTER 2: MOTION

1. A plane taking off leaves a runway at 32° to the horizontal, travelling at 180 km h^{-1}.How long will it take to climb to an altitude of 1 km? Express your answer in seconds.
   [**Hint:** $t = \frac{s}{v}$]



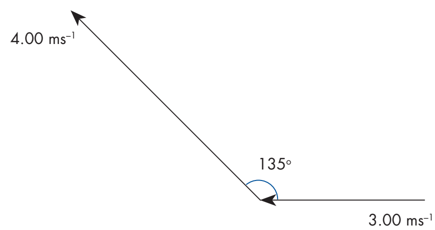
2. What is the vector whose components are 4 N horizontally to the right and 5 N vertically upwards?

3. What is the northerly component of a wind blowing at 16 m s^{-1} from the South East?

4. What is the horizontal component of a force of 16 N acting at 59° to the horizontal?

5. What is the acceleration of a small object down a smooth plane inclined at 20° to the horizontal? Use the acceleration of any object as being 9.8 m s^{-2} vertically downwards.

6. Find the resultant of velocities 3.00 m s^{-1} and 4.00 m s^{-1} inclined at 135° to each other as shown below:



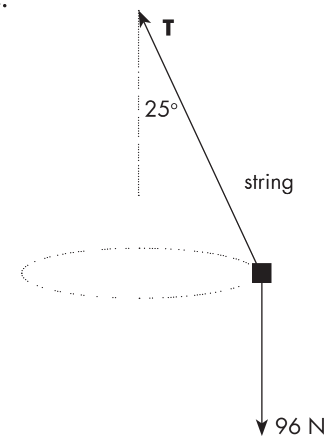
7. A ship steaming due North at a speed of 16.0 km h^{-1}, encounters a current running at a speed of 6.0 km h^{-1} in a direction S 60° E. What is the resultant velocity of the ship?

8. Four forces 16 N , 4 N , 8 N , 4 N act on an object in directions NE, NW, W and S respectively. Find the vector sum of all the four forces.

9. A car travelling down an inclined slope of 30° moves at a constant speed down the slope. Find the value of the frictional force (as a fraction of the car's weight) that opposes the car's motion.

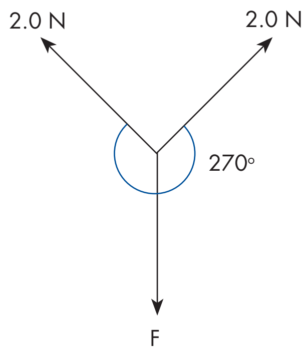
   [**Hint:** draw a diagram similar to the one on page 19 and note that the force parallel and down the slope and the force parallel and up the slope are equal and opposite.]

10. Find the component of tension in the string below which acts towards the centre of the circle.

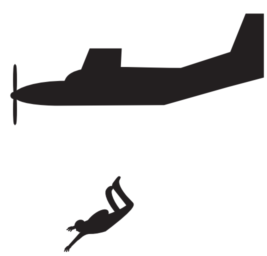


[**Hint:** The component of the tension acting vertically upwards equals the weight force acting downward]

11. What is F in the diagram below if the sum of all the forces in the diagram is zero?



12. A parachutist (mass 100 kg including her parachute) jumps from a height of 200 m out of a small plane. She immediately accelerates downwards at 9.8 m s^{-2}. Air resistance increases as she falls faster and faster until she reaches a terminal velocity of 50 m s^{-1} downwards (she doesn't go any faster due to large frictional forces).



(a) What is the total weight of the parachutist and her parachute?

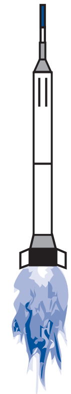
(b) What is the force of air resistance on her at her terminal velocity?

She now pulls her ripcord and as her parachute unfurls, she slows to a steady downward velocity of 5 m s^{-1}. To attain this velocity takes 2 s.

(c) Calculate her deceleration over the 2 s time interval.

(d) Calculate the resultant force that must have acted on her (together with her parachute) to attain a steady downward velocity of 5 m s^{-1}.

13. A liquid fuelled rocket is launched vertically upwards. The initial upward thrust from the rocket propulsion system is 6×10^5 N and its initial weight is 1×10^5 N.



(a) What is the initial mass of the rocket?
(b) What is the initial nett force acting on the rocket?
(c) What is the initial acceleration of the rocket?
(d) As the rocket moves upwards, its particular propulsion system provides a constant upward thrust. During this time, does the acceleration remain constant, increase or decrease as the rocket rises? Explain you answer.

14. A 6 kg mass is acted on by a steady force for 1 minute and acquires a speed of 1 m s^{-1}. What is the value of the force?

15. A nett force of 1 N acts for 1 minute on a 2 kg block. How far will it move from rest?

16. A nett force of 270 N acts on a mass of 1.5 kg for 13 s. If the mass was originally at rest, calculate:

(a) the acceleration.
(b) the velocity after 5 s.
(c) the displacement after 5 s.

17. Calculate the acceleration produced by a resultant force of 6 N acting on a 5 kg mass which is situated on a smooth frictionless horizontal surface.

18. If the resultant force in question 17 is replaced by a resultant force of 18 N, calculate the new acceleration.

19. A body is accelerating on a horizontal surface. A horizontal force of 10 N is applied to it and the friction force is 19.8% of the value of the horizontal force. The object accelerates at 0.22 m s^{-2}. Calculate the mass of the body.

20. What resultant force would be needed to change the velocity of a 240 g mass from 10 cm s^{-1} North to 15 cm s^{-1} North in 6.0 s?

21. A mass of 19.87 kg travels at a constant velocity of 23.47 m s^{-1} for 18.29 s. What is the nett force acting on the mass?

22. A force of 85 N acts on a stationary mass of 17 kg for 6 s. If the average force opposing motion is one tenth of the object's weight during the 6 s time interval, calculate how far the mass moves in 10 s after the force commenced. Assume that for the last 4 s of its motion, frictional force acting on the mass is zero.

23. A particle of mass 2.0×10^{-3} kg travelling East at 4.0 m s^{-1} has its velocity changed to 0.9 m s^{-1} South. If the change took place in 2.0 s, find the average force exerted on the object.

24. A car of mass 950 kg is travelling at 16.5 m s^{-1} when the brakes are applied for 0.025 s. If the retarding force of the brakes is 2.25×10^5 N, find the final velocity of the car.

25. A spring balance reads 1.47×10^2 N. Find the mass of the object hanging on it.

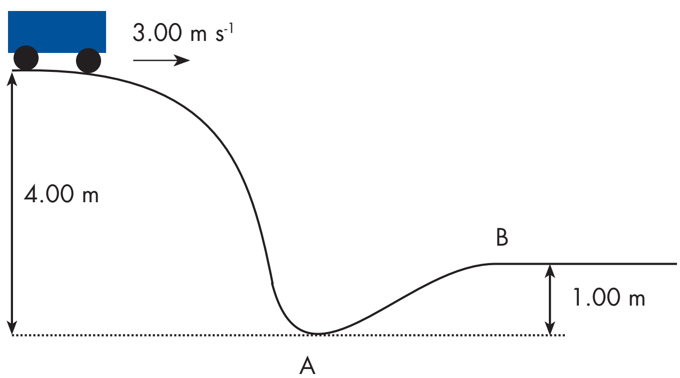
26. A force of 20 N acts on a body of mass 4.0 kg initially at rest, and moving it 2.5 m in the direction of the force. Find the final velocity of the body. (HINT: use the idea that gain in E_k = work done)

27. An object of mass 2.5 kg is moving with a speed of 0.50 m s^{-1}. A force of 10.0 N acts on the object in a direction opposite to its motion. Find the displacement of the object when its velocity is 2.0 m s^{-1} in the direction of the force

28. A cyclist and bike of total mass 90.0 kg moving with a speed of 9.00 m s^{-1} is brought to a stop by a constant force in a distance of 10.0 m.

Calculate:
(a) the loss in kinetic energy of the cyclist
(b) the work done by the force
(c) the magnitude of the force.

29. A cart of mass 4.00 kg is initially moving at 3.00 m s^{-1} on a horizontal frictionless surface. If it then follows the curved track as shown:



Calculate:
(a) its loss of potential energy as it moves to A
(b) its kinetic energy at A
(c) its gain in potential energy as it moves to B
(d) its speed at B.

What assumption did you make in your calculation?

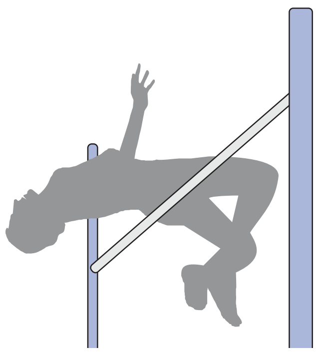
30. How far must a 200 kg pile driver fall if it is to do 1.30×10^4 J of work?

31. Calculate:

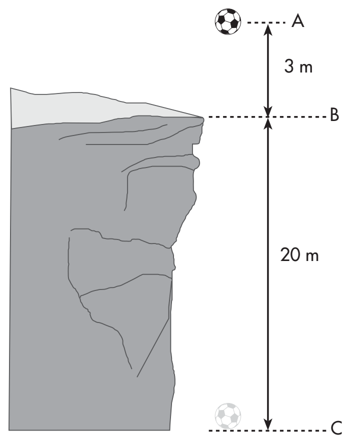
(i) the kinetic energy and

(ii) the velocity required for a 70.0 kg pole vaulter to pass over a 6.0 m high bar.

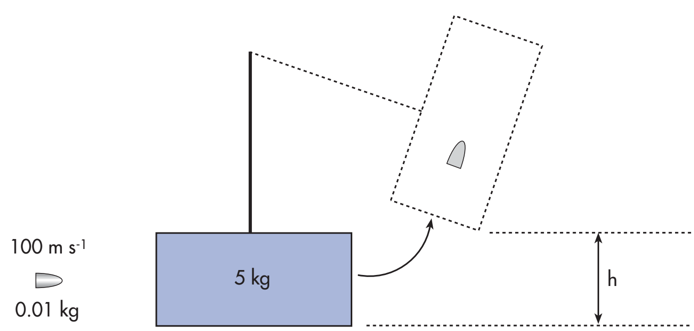
Assume the vaulter's centre of gravity is initially 0.900 m above the ground and that the pole vaulter's centre of gravity just clears the bar itself.



32. A 4.00 kg ball is thrown vertically upward and lands at the base of a 20 m cliff as shown. What is its (a) kinetic energy at A, B and C, (b) potential energy with respect to the base of the cliff, (c) total energy at A, B and C?

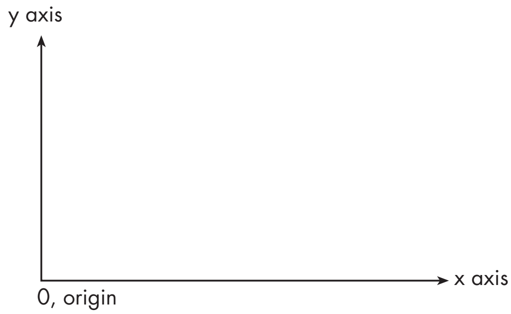


33. A bullet of mass 0.01 kg and speed 100 m s^{-1} strikes a suspended wooden block (5 kg) and embeds in it. The velocity of the block just after the bullet embeds in it is 0.1996 m s^{-1}. How high will the block swing?



GRAPHICAL ANALYSIS

A graph is a powerful means of visually presenting information. A graph shows how one quantity varies with another related quantity. The most common method of showing the relationship between two sets of data is to use a pair of reference axes – these are two lines drawn mutually perpendicular to each other.



The horizontal line is called the **x axis** and the vertical line is called the **y axis**.

The point where x = 0 and y = 0 is called the **origin**.

In addition to axes, scales of measurement must be included on each axis and the axis (inclusive of its units) labelled. The scales of measurement can only be worked out if the data for both variables is known and preferably presented in tabular format.

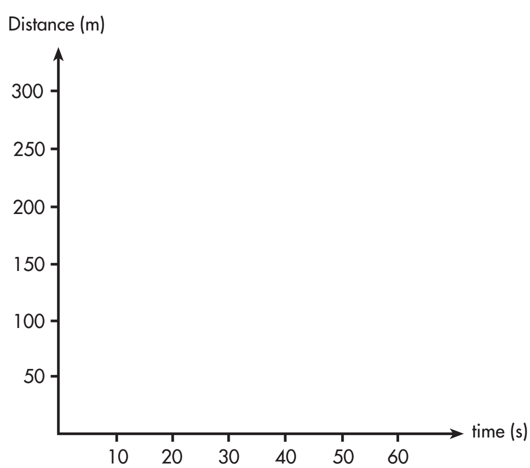
Example: The distances travelled by a truck for certain times are shown in the table below:

Time (s)	Distance travelled (m)
10	50
20	100
30	150
40	200
50	250
60	300

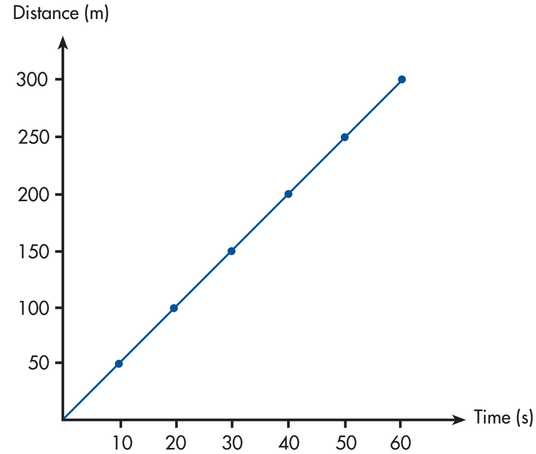
Time will be plotted on the x axis and distance on the y axis. If the graph page has a 10 cm by 10 cm grid , then a choice of scales is possible. It is always advisable to choose scales such that the resulting graph occupies as much of the graph grid as possible.

If we choose a horizontal scale such as '1 cm = 20 s', then the graph will only occupy the left side of the entire grid. Therefore it is preferable to choose a scale such as '1 cm = 10 s'.

Similarly, choosing '1 cm = 50 m' is preferable to choosing '1 cm = 100 m' for the same reason as above. Hence:



The points are plotted with a cross or a large dot and in this case a straight line is drawn through the plotted points.



Note: In some cases a line cannot be drawn through every point – if this occurs, a line of best fit is drawn. This line is visually drawn so that as many points are evenly spaced above the line as are points evenly spaced below the line.

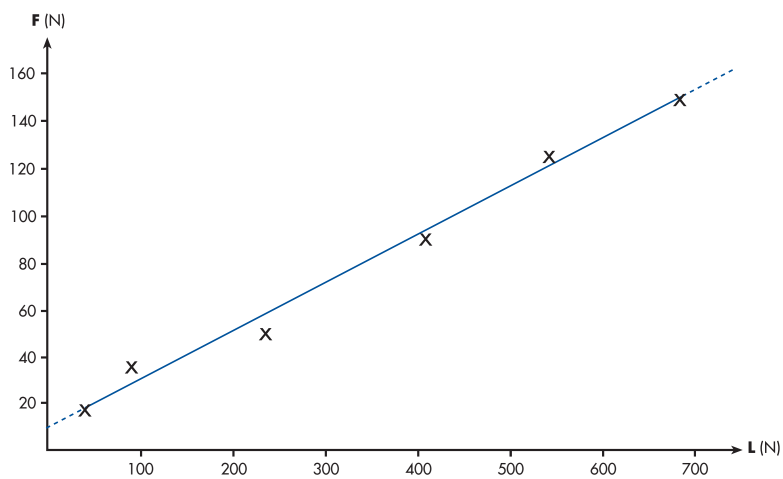
Example 1

A device measures a lifting force **F** required to overcome a load force **L**. The data is shown in the table below:

F (N)	L (N)
19	40
35	120
50	231
92	410
124	540
147	680

(a) Choose appropriate scales (assume you have graph paper with 20 major divisions for both the horizontal and the vertical) and plot L on the horizontal axis and F on the vertical axis. Use crosses as data points.

(b) Draw a line of best fit through the points.



Interpolation

Interpolation is the process of determining the value of say **F** in Example 1 for a value of **L** not in the table of data but having a value for **L** between 40 and 680 N.

Extrapolation

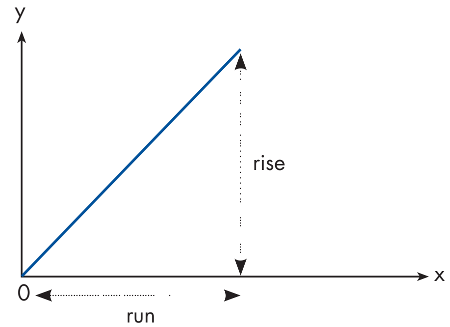
This is the process where, (using Example 1) a value of **F** which lies outside the drawn line of best fit (denoted by a dashed line in previous diagram).

THE DIRECTLY PROPORTIONAL RELATIONSHIP

If two variables **y** and **x** are directly proportional, we say that $y \propto x$

Mathematically, they are related: $y = mx$ where m is a *proportionality constant*

Graphically,



gradient or slope = $\frac{\text{rise}}{\text{run}}$

(in a direct proportionality, the graph starts from the origin; in a indirect proportionality, the graph does not start from the origin)

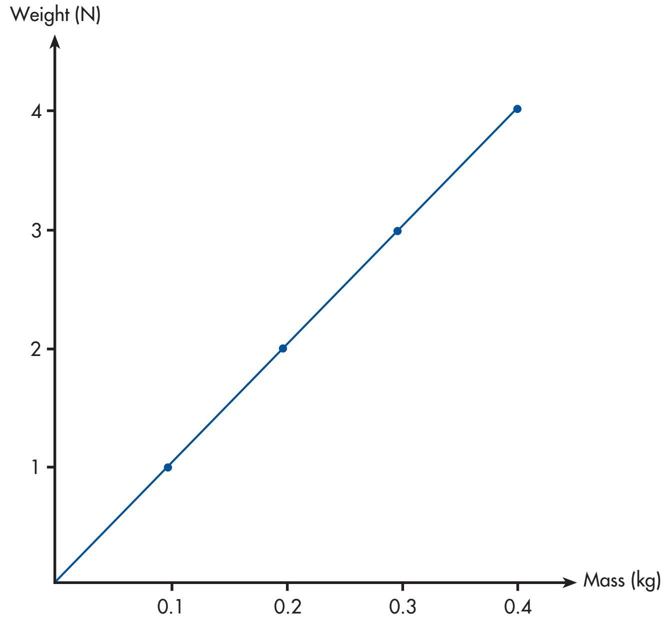
The above graph starts from the origin (0,0). It is worthy to note that the slope can be obtained by using smaller values of rise and run from the graph but the errors are greater. Note also that the rise and run must be determined from the actual scales on the vertical and horizontal axes respectively. The gradient also must have units.

Example 2

The force of gravity on several different masses is measured with a force measuring instrument. The results are shown in the table below:

Weight (N)	Mass (kg)
0.0	0.0
1.0	0.1
2.0	0.2
3.0	0.3
4.0	0.4

The force is graphed on the vertical axis and the mass on the horizontal axis:



The graph is a straight line through the origin (0,0), therefore

Weight is proportional to mass

i.e. $W \propto m$ and the gradient $= \dfrac{rise}{run} = \dfrac{(4 - 0)}{(0.4 - 0)} = 10 \text{ N kg}^{-1}$

Hence the variables are related by the equation:

Weight = 10 × mass where the slope value is 10

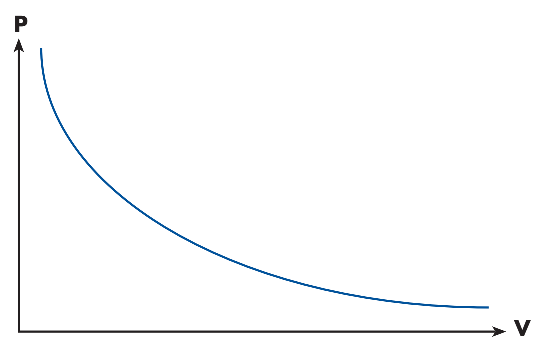
THE INVERSELY PROPORTIONAL RELATIONSHIP

If variables **P** and **V** have an inversely proportional relationship, we write

$$\mathbf{P} \propto \frac{1}{\mathbf{V}}$$

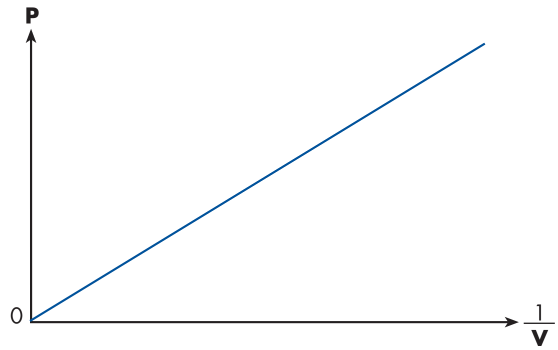
These variables are related by the mathematical formula: $\mathbf{P} \propto \dfrac{k}{\mathbf{V}}$ where k is a constant

A graph of **P** versus **V** has the shape of a hyperbola:



Since the relationship is an inversely proportional one, a second graph may be drawn:

We know that $P \ \alpha \ \frac{1}{V}$ so if we plot P vs the **inverse of** V $\left(\frac{1}{V}\right)$ we get



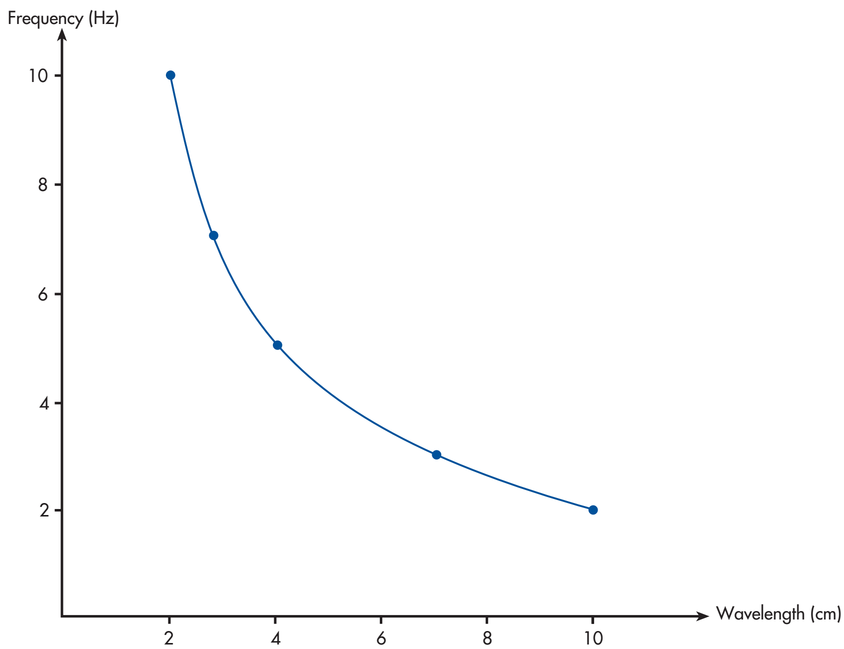
This graph goes through the origin (0,0) and the gradient = k.

Example 3

The wavelength λ of a water wave is measured for different values of frequency f. The results are shown in the table below:

frequency f (Hz)	wavelength λ (cm)
2.0	10.0
4.0	5.0
5.0	4.0
7.0	2.9
10.0	2.0

A graph of f (vertical axis) versus λ (horizontal axis) is:



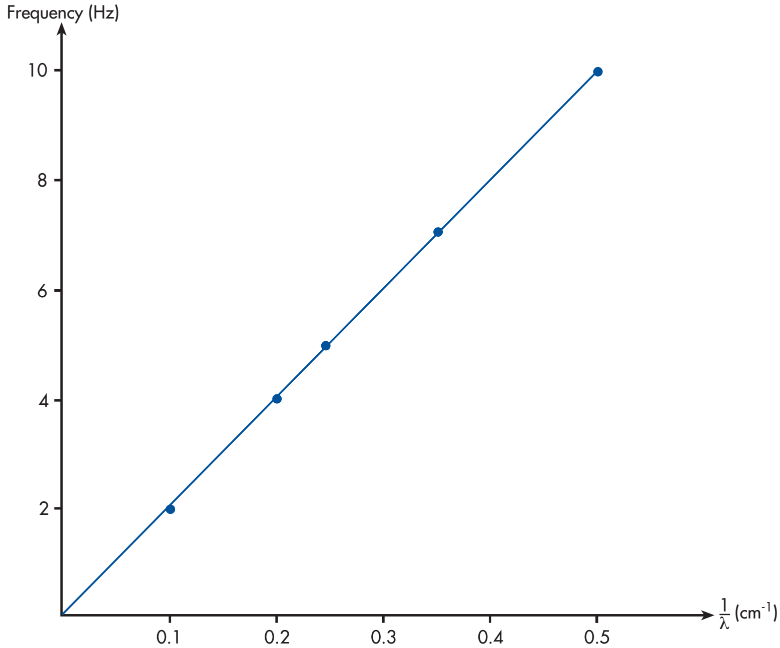
The graph has the shape of a hyperbola.

To check this we can plot a graph of f versus **the inverse of** λ, i.e. $\frac{1}{\lambda}$

Processing the data produces another table or results as follows:

frequency f (Hz)	wavelength (λ) (cm)	$\frac{1}{\lambda}$ (cm^{-1})
2.0	10.0	0.1
4.0	5.0	0.2
5.0	4.0	0.25
7.0	2.9	0.34
10.0	2.0	0.5

If we plot a graph of f versus $\frac{1}{\lambda}$, we get:



The graph is a straight line through the origin (0,0), and this shows that:

f = (constant) ($\frac{1}{\lambda}$) and the slope = $\frac{rise}{run} = \frac{(10 - 0)}{(0.5 - 0)} = 20 \text{ cm s}^{-1}$

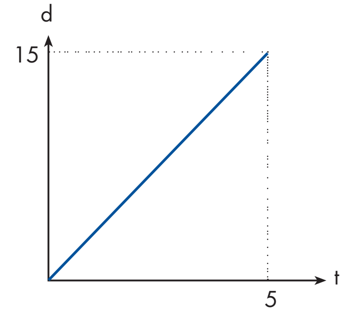
The formula for this relationship is therefore: $f = \frac{20}{\lambda}$

Example 4

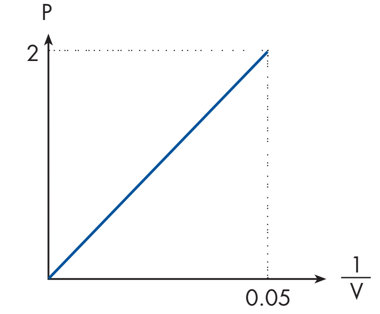
For each of the following graphs:

(a) state the relationship shown
(b) find the constant relating the variables
(c) write an equation.

Graph 1



Graph 2



Answers:

Graph 1

(a) d is directly proportional to t

(b) constant = slope $= \dfrac{15}{5} = 3$

(c) $d = 3\,t$

Graph 2

(a) P is proportional to $\dfrac{1}{V}$

(b) constant = slope $= \dfrac{2}{0.05} = 40$

(c) $P = \dfrac{40}{V}$

Electricity

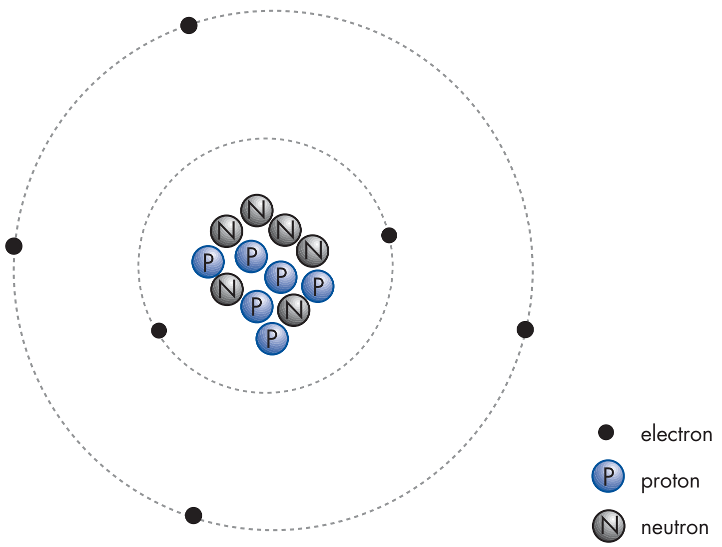
3

3.1 ELECTRIC CHARGE

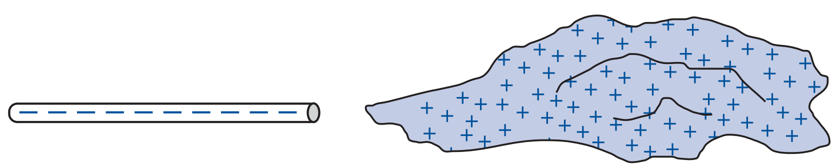
Have you ever experienced any of the following electrical phenomena:

- you have walked on a particular surface and then touched a metal door handle and received a small electric shock.
- you take off a synthetic shirt and you hear or see small sparks.
- you rub your hair on a balloon and your hair stands up.

All of these are examples of friction producing electric charges. It is possible for atoms to gain or lose electrons simply by rubbing two surfaces together. Atoms consist of protons (positive charge), neutrons (no charge) and electrons (negative charge). In a neutral atom, the number of protons always equals the number of electrons (the number of positive charges equals the number of negative charges).

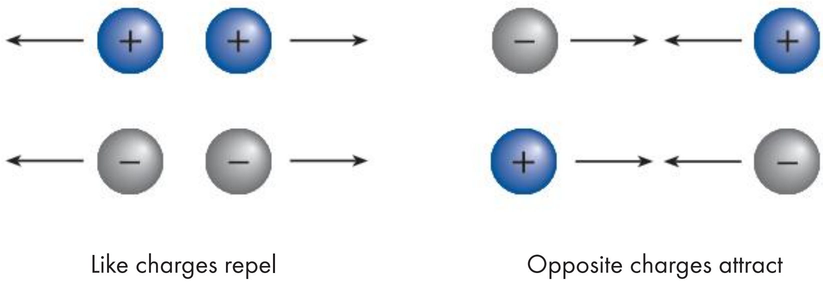


If two different materials are rubbed together (e.g. a polythene rod and a cotton cloth), electrons can be removed. In this case, the cotton loses electrons (and becomes positively charged) and the rod gains electrons and becomes negatively charged.



When a positively charged object is brought near a negatively charged object, attraction occurs. This causes your hair to stand up when rubbed on a balloon since your hair becomes positively charged and the balloon is negatively charged.

CHARGE RULE: Like charges repel, unlike charges attract.



Electric charge is therefore simply an excess or deficiency of electrons on an object.

CHECKPOINT!

3.1 Complete this table:

Atomic particle	Proton	Neutron	Electron
Charge			

3.2 Explain what must happen if an object is to become negatively charged.

____

____

3.3 Explain what must happen if an object is to become positively charged.

____

____

3.4 A van de Graaff generator is a device that uses friction to accumulate charge on a large dome (see photo on page 66). A person who is in contact with the dome also attains the same charge as the dome (usually positive charge). Why does a person's hair then stand up?

____

____

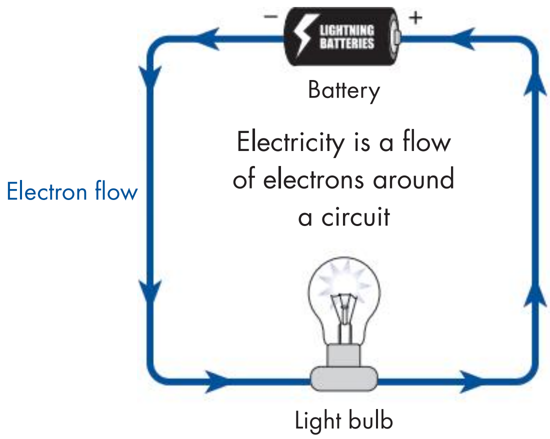
____

3.5 State the charge rule when applied to electric charge.

____

3.2 ELECTRIC CURRENT

Static electricity is basically **electric charge at rest** on the outside of an object as described previously. On the other hand, an **electric current** is an **electric charge which is moving.** Electric currents are produced when electrons move through a metallic conductor like in a simple circuit such as an operating torch. This is simply called **electricity**. Current is measured in a unit called an Ampere (or simply an Amp (A)). Typically, there would be a current of about 4 A flowing in a car headlight circuit. Moving charges in a circuit enable devices to operate (like a light or a TV).



If more electrons move around a circuit, a larger current flows. In fact, current is defined as the amount of charge passing a point in a circuit per second.

$$\textit{current} = \frac{\textit{charge}}{\textit{time}} \qquad I = \frac{q}{t} \quad \text{or} \quad \boxed{q = It}$$

where I is current measured in Amps (A)
q is charge measured in Coulombs (C)
t is time measured in seconds (s)

The movement of electrons around a circuit is called **Electron Current**. A convention (originating with the pioneering electricity scientists) used the idea that positive charges moved around a circuit in the opposite direction to electron current. This does not happen but the convention continues even today. It is called a **Conventional Current.**

Worked Examples

3.1 What current flows in a mobile phone circuit if 10.0 mC of charge pass through each second?

q = 10.0 mC = 0.0100 C
t = 1.0 s
I ?

$$I = \frac{q}{t} = \frac{0.0100}{1.0} = 0.0100 \text{ A}$$

3.2 What charge flows in a TV circuit that is operating with a current of 2.00 A for an hour?

I = 2.00 A
t = 1 hour = 3600 s
q ?

$$I = \frac{q}{t} \text{ or } q = It = 2 \times 3600 = 7200 \text{ C} = 7.20 \times 10^3 \text{ C}$$

Circuits can have currents that flow in one direction only. This is called a **Direct Current (DC)** and electrons move towards the positive terminal of the battery. An **Alternating Current (AC)** has a current that flows in one direction and then the other. Households and industry use AC.

CHECKPOINT!

3.6 Explain the difference between static and current electricity.

____

____

3.7 Convert the following to standard units:

(a) 20.0 mA ______________________________________

(b) 37.8 μC ______________________________________

(c) 1.5 days ______________________________________

(d) 0.0935 kA ______________________________________

3.8 In a torch circuit, what would you expect to see if a larger current flowed?

____

____

3.9 What current flows in a hot water heater circuit operating for 30.0 minutes if 18,000 C of charge passes in that time?

____

____

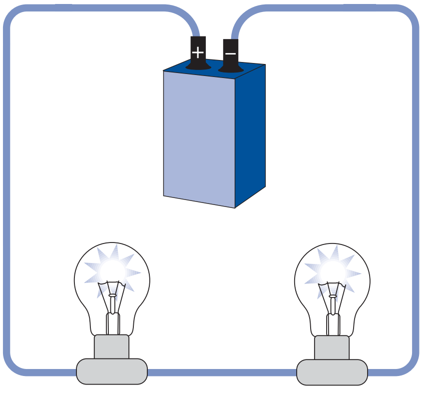
3.10 *(A little harder)* An electron has a charge of 1.60×10^{-19} C. How many electrons flow past a point in the circuit shown if a current of 25.0 mA flows for 10.0 minutes? (See hint below if you are having difficulty).

____

____

____

____



Hint: the number of electrons flowing in a circuit can be determined using the following formula:

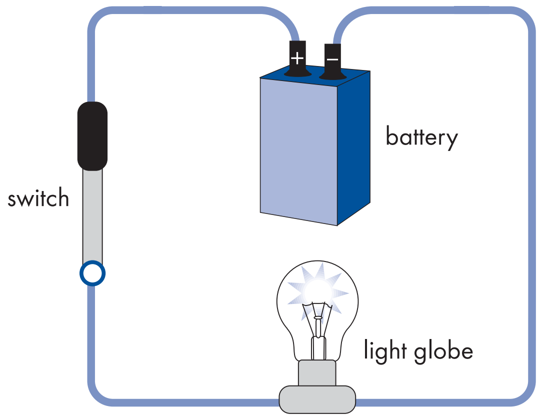
$$\# \text{ electrons} = \frac{q}{1.60 \times 10^{-19}}$$

3.3 ELECTRIC CIRCUITS

V8 Supercars race around a race track. The track is a continuous road and cars may have to do 100 laps. If the track had a large hole in it, the cars could no longer move. An electric circuit is like this except the track is a metallic conductor and the cars are electrons. If there is a break in the circuit, the electrons will not move around the circuit.

An **electric circuit** consists of the following:

Circuit component description	Circuit part
a power supply (to push the electrons along)	a battery
device that will use the electrical energy provided	the light
a continuous conducting track	wire
a device to turn the power off and on	switch



On the diagram above, indicate the direction that you would expect electrons to flow. [Hint: what is the charge on an electron?]

As electrons move around the circuit (towards the positive terminal of the battery) they will do some work, like producing heat and light in the above circuit. All electric circuits are designed to make a device work. Modern households have hundreds of circuits in them in which electrons are doing work from producing light to cooling and heating and making electric motors operate.

3.4 OHM'S LAW

(a) Voltage

What we often call a **battery** is actually incorrect. These are actually **cells**. A battery is multiple cells and in the case for a car battery there are 6 × 2 V cells making a total of 12 V. A cell is indicated in a circuit in the following way:

A cell 

A battery 

A cell in a circuit provides the energy source which makes electrons move. You would have seen cells which have various sizes and voltage ratings. There are many different 1.5 Volt (V) cells AA, AAA, C, D etc. They all do the same job but the bigger batteries have more chemicals that will convert to electrical energy and they will therefore last longer. The voltage rating indicates the electrical 'pressure' that can be used to move electrons. This means that a 9 V cell will move more electrons than a 1.5 V cell. If more electrons move, there will be a greater current flowing in the circuit.

Cells and batteries are also referred to as a source of **electromotive force (EMF)**. An EMF is 'the force that moves electrons.' EMF is measured in Volts (V).

(b) Resistance

There is another factor that affects the flow of electrons in a circuit. If the V8 Supercars are in a race and there was 10 cm of water all over the track, they would be slowed down and there would be less cars going past the start/finish line per second. In an electrical circuit, there is a similar situation to the water on the road. This is called electrical resistance and the unit for resistance is called an **ohm (Ω)**. In a circuit, resistors are indicated by the following symbol:

There are various factors that affect the resistance – the length, thickness, the temperature and type of wire used but also the devices in the circuit that are operating (like a light or TV etc). The greater the resistance in a circuit, the smaller is the flow of electrons.

There is a simple relationship between Voltage, Resistance and Current as indicated by **Ohm's Law**: *'The ratio of the potential difference (voltage) across a conductor to the current flowing in the conductor is a constant at a fixed temperature.'* That constant is the resistance and the relationship can be simply indicated as:

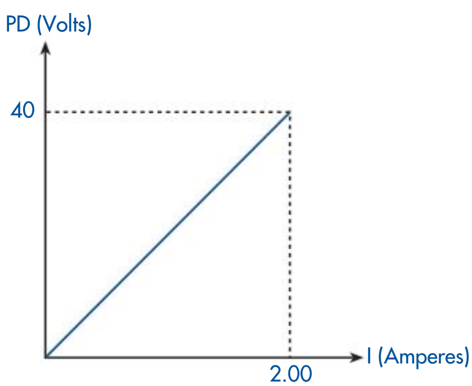
resistance = $\dfrac{\textit{voltage}}{\textit{current}}$ or $R = \dfrac{V}{I}$. Rearranging this formula gives:

$$V = I \times R$$

Where V is the voltage (potential difference or PD) (Volts (V)) across the resistor.
I is the electrical current (Amps (A)) flowing through the resistor.
R is the electrical resistance (Ohms (Ω)).

Worked Examples

3.3



What is the resistance of the load (resistance) in a circuit in which the results are indicated in this graph?

From the graph $V = 40\ V$
$I = 2\ A$
$R = ?$

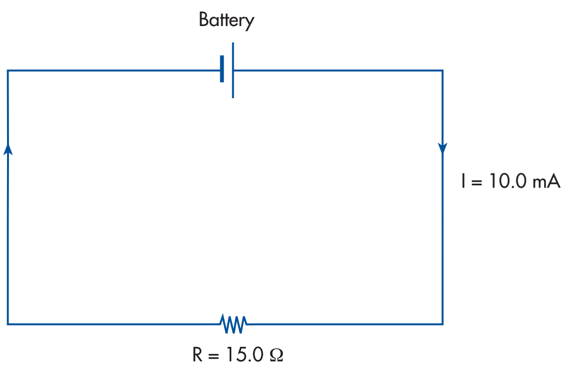
$$R = \frac{V}{I} = \frac{40}{2} = 20.0\ \Omega$$

Another way to do this question is to consider the gradient of the Voltage/Current graph:

The gradient of a voltage/current graph is always equal to the resistance.

$$\text{(resistance) gradient} = \frac{rise}{run} = \frac{40}{2} = 20.0\ \Omega$$

3.4 What is the potential difference across a 15.0 Ω resistor if it has a current of 10.0 mA flowing through it?



$R = 15.0\ \Omega$
$I = 10.0\ mA = 0.0100A$
$V = ?$

$V = I \times R = 0.01 \times 15 = 0.150\ V$

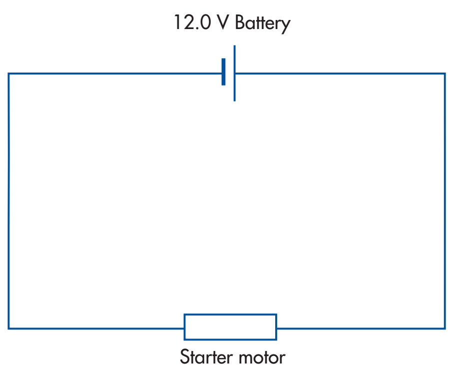
3.5 What current flows through a 10.0 MΩ resistor if there is 25.0 kV voltage drop across it?

$R = 10.0\ M\Omega = 10.0 \times 10^6 = 1.00 \times 10^7\ \Omega$

$V = 25.0 \times 10^3 = 2.50 \times 10^4\ V$

$$I = \frac{V}{R} = \frac{25.0 \times 10^3}{1.00 \times 10^7} = 2.50 \times 10^{-3}\ A$$

3.6 In a car, a 12.0 V battery needs to supply 45.0 A to a starter motor. The wires from the battery to the starter motor are thick to accommodate the large current and have a total resistance of 5.00 mΩ. What is the potential drop across the wires?



$I = 45.0\ A$
$R = 5.00\ m\Omega = 0.00500\ \Omega$
$PD\ (V) = ?$

$V = I \times R = 45.0 \times 0.005 = 0.225\ V$

Note: If there is 0.225 V dropped across the wires, what is the voltage drop across the starter motor? The battery can only supply 12.0 V and if 0.225 V is dropped across the wires, there is only 11.775 V (12 - 0.225) or 11.8 V (3SF) left to drive the starter motor. Voltage drops wherever there is resistance. Current flows through the resistance.

All conductors have some resistance. For example, a piece of wire has less resistance than a light bulb, but both have resistance. A light bulb is a very thin wire surrounded by a glass housing. The high resistance of the filament (small wire) in a light bulb causes the electrons to transfer a lot of their kinetic energy into heat energy. The heat energy is enough to cause the filament to glow white-hot which produces light. The wires connecting the lamp to the cell or battery hardly even get warm while conducting the same amount of current. This is because of their much lower resistance due to their larger cross-section (they are thicker). An important effect of a resistor is that it converts electrical energy into other forms of energy. Light energy is a by-product of the heat that is produced.

CHECKPOINT!

3.11 Describe what is meant by the following terms:

(a) resistance

____

____

(b) voltage

____

____

(c) current

____

____

3.12 State Ohm's Law.

____

____

3.13 In a circuit, state the use of each of the following components:

(a) battery (or cell)

____

____

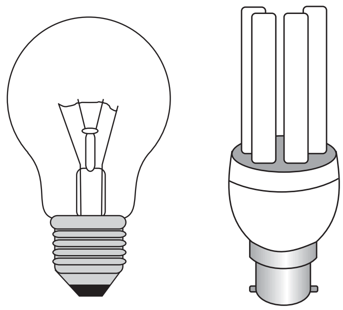
(b) wiring

____

____

(c) switch

(d) a light globe



3.14 Complete the following statement:

Voltage ____________ wherever there is resistance, Current ____________

through the resistance.

3.15 What is the potential difference across a 267 Ω resistor if it has a current of 22.9 A flowing through it?

3.16 What current flows through a 39.5 Ω resistor if there is 29.5 V voltage drop across it?

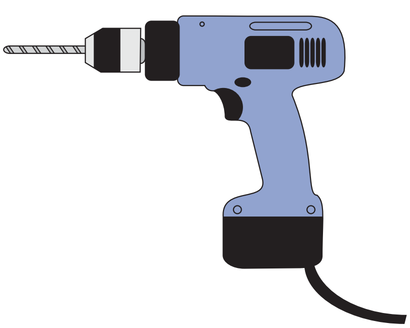
3.17 What is the resistance of a light which has 240 V (AC) dropped across it and a current of 100 mA flowing through it?

3.18 A long extension cord with a total resistance of 500 mΩ is connected to a 240 V (AC) mains supply and to an electric drill. The drill draws a current of 10.0 A. What is the:

(a) voltage drop across the extension cord?

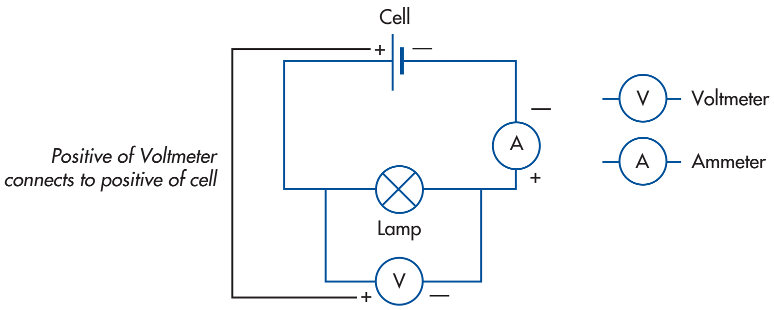
(b) voltage drop across the drill?

[Hint: Draw a circuit diagram first.]



3.5 MEASURING VOLTAGE AND CURRENT

In a circuit, voltage is measured by a **voltmeter** placed around (this is called a **parallel connection**) a resistor or load device (the lamp in the diagram below). Current is measured by a **ammeter** placed within (this is called a **series connection**) a circuit next to the resistor or the load device.

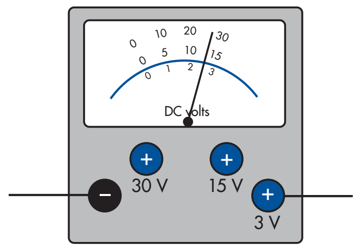


Care must be taken when using analogue devices (pictured) as they are often damaged by students who either put them in a circuit the wrong way or students try to do measurements which exceed the limitations of the devices.

Firstly, they must have the correct polarity. This means that the positive of the device must connect to the positive of the battery and the negative of the device connects to the negative of the battery.

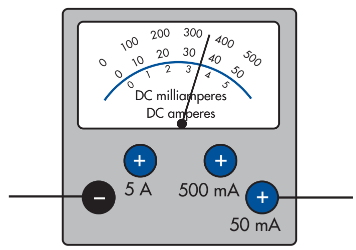
Secondly, there are often multiple scales on these devices (e.g. maximum current reading can be 50 mA, 500 mA or 5000 mA). It is safest to start measurements with the largest scale and if it barely measures any current, then try the next smaller scale etc.

Note the three blue (positive) connectors on the voltmeter and the ammeter indicating three different scales available with these devices. (Note that laboratory ammeters/voltmeters have a red positive terminal).



Voltmeter

This reads 2.6 V (bottom scale)



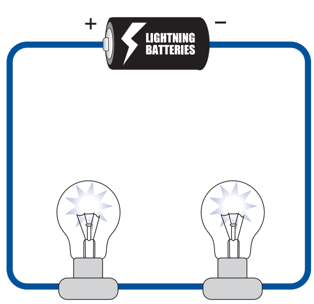
Ammeter

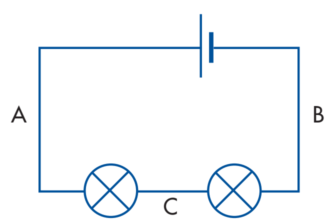
This reads 35 mA (middle scale)

3.6 SERIES AND PARALLEL CIRCUITS

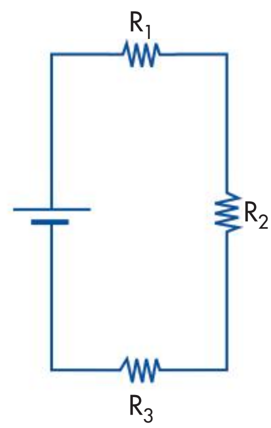
(a) Series circuits

In a series circuit, electrons have only one pathway to go through. Resistors or other load devices are connected simply one after the other as shown in the diagram. This means that since the electrons must follow a single pathway, the current is the same everywhere in the circuit. An ammeter could be positioned at A, B or C and it would measure the same current.





The circuit on the right shows three resistors (R_1, R_2 and R_3) connected in series with a cell. The total resistance (R_T) in circuit is simply the sum of the individual resistors:



$$R_T = R_1 + R_2 + R_3$$

e.g. If $R_1 = 10.0\ \Omega$
$R_2 = 20.0\ \Omega$
$R_3 = 30.0\ \Omega$

then $R_T = R_1 + R_2 + R_3$

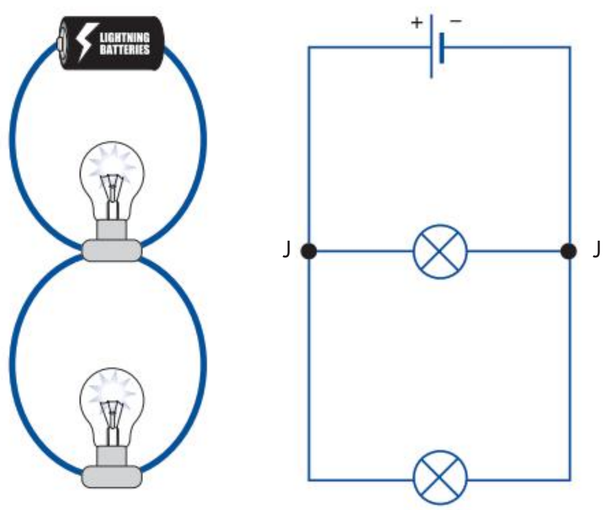
$= 10 + 20 + 30 = 60.0\ \Omega$

(b) Parallel Circuits

In a parallel circuit, electrons have a choice of pathways when they get to a **junction (J)**. The parallel connection is like piggybacking and each lamp or resistor is connected around the previous one.

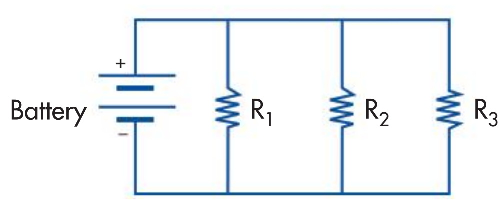
This means that the current will be different in the two lamps (unless they are identical). More current will flow through the smaller resistor.

Parallel circuits are always recognised by the presence of junctions.

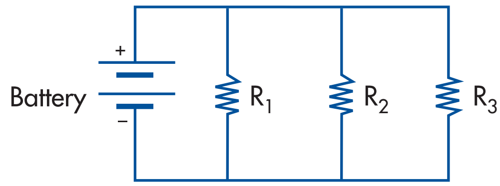


The circuit below shows three resistors (R_1, R_2 and R_3) connected in parallel with each other and the combination is connected in series with a battery. The total resistance (R_T) in circuit is given by the following formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



Worked Examples

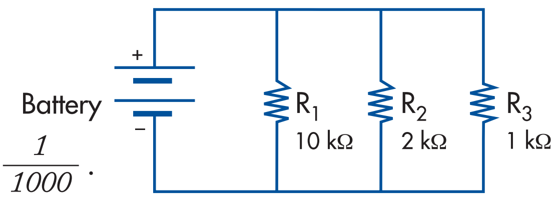


3.7 If $R_1 = 10.0\ \Omega$
$R_2 = 20.0\ \Omega$
$R_3 = 30.0\ \Omega$

then $\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} = \dfrac{1}{10} + \dfrac{1}{20} + \dfrac{1}{30} = \dfrac{11}{60}$

hence $R_T = 5.45\ \Omega$

Parallel circuits are used in households and industry so that individual switches can be used to operate different devices. If every device in a household was connected in series, everything would have to be ON at the same time.



3.8 What is the total resistance in this circuit?

then $\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} = \dfrac{1}{10000} + \dfrac{1}{2000} + \dfrac{1}{1000}$.

$\dfrac{1}{R_T} = 0.00160\ \Omega$ hence $R = 625\ \Omega$

3.9

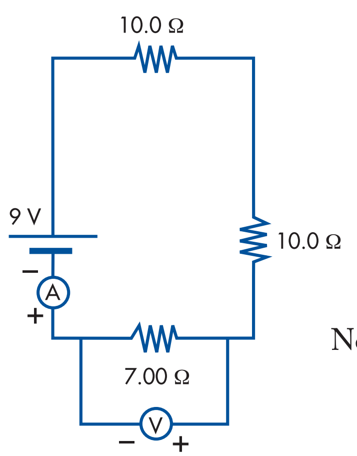
(a) Draw a circuit diagram with following components connected in series: a 9.00 V cell, 2 × 10.0 Ω resistors and a 7.00 Ω resistor. Indicate the position of an ammeter and a voltmeter that will measure the current through and the voltage drop across the 7.00 Ω resistor.

(b) Determine the total resistance in the circuit

(c) Calculate the current through the 7.00 Ω resistor.

(d) Calculate the voltage drop across the 7.00 Ω resistor.

(a)



Note: ammeter could have been anywhere in the series circuit.

(b) $R_T = R_1 + R_2 + R_3$
$= 10 + 10 + 7 = 27.0\ \Omega$

(c) This is a series circuit and the current is the same throughout.

$V_{battery} = 9.00$ V
$R_T = 27.0\ \Omega$
$I_{circuit}$?

$I_{circuit} = \dfrac{V}{R} = \dfrac{9}{27} = 0.333....$ A

(d) $I_{7\Omega}$ = 0.333….A $V = I\,R = 0.333... \times 7.00 = 2.33333... = 2.33$ V
$R_{7\Omega}$ = 7.00 Ω
$V_{7\Omega}$ = ?

Note: The voltage drop across each of the 10.0 Ω resistors would be found in the same way:

$$V = I\,R = 0.333... \times 10.0 = 3.33333... = 3.33 \text{ V}$$

What is the sum of the voltage drops equal to?

This leads to another rule for circuits connected in series: *'The sum of the potential drops around the circuit equals the voltage of the cell (EMF).'*

ΣPD around the circuit = EMF (cell)

[2.33..V + 3.33.. V + 3.33..V = 9.00 V or EMF = $PD_{7\Omega} + PD_{10\Omega} + PD_{10\Omega}$]

CHECKPOINT!

3.19 What is the equivalent resistance to 3 × 10.0 Ω resistors connected in:

(a) series

____

____

(b) parallel

____

____

3.20 If the resistors in question 3.19 were separately connected to the same 12 V battery, which circuit would have the bigger current flowing through it. Explain your answer.

____

____

____

____

____

____

3.21 Draw the circuit indicated in question 3.19(a) with a 36.0 V battery and show an ammeter and voltmeter measuring the current through and the voltage drop on any resistor. Show the correct ± polarity of the battery, the ammeter and the voltmeter.

3.22 *(A little harder)* What is the value of a resistor placed in parallel with a 10.0 Ω resistor to give a equivalent resistance of 5.00 Ω?

ELECTRICITY FACTS

Complete the following matching worksheet by choosing an answer from the list below and writing it in the space provided.

Ampere, charge, electrons, resistance, Volts, voltage, ammeter, $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ *, electrons, current, increases, attract, positive, DC, voltmeter, cells, resistance, Ohm, static electricity, electron current, decrease, Ohm's Law, parallel circuits, alternating currents, electromotive force (EMF), current electricity,* $V = IR$*, series circuits,* $R_T = R_1 + R_2$*, batteries,* $I = \frac{q}{t}$ *, Coulomb, EMF*

1. Like charges repel, unlike charges ______________________.

2. ______________________ is the study of charges at rest.

3. Friction between two surfaces can cause ______________________ to be removed from one surface to the other.

4. ______________________ is the study of charges moving in a circuit.

5. Electric charge is measured in a unit called a ______________________.

6. Electric current is measured in a unit called an ______________________.

7. Electric current can be defined as the rate of flow of ______________________.

   Formula is: ______________________.

8. Conventional current refers to the movement of ______________________ charges in a circuit.

9. In a metal, the only charge that moves are ______________________ .

   This is called an ______________________ .

10. Currents that flow in one direction only are called ______________________.

    This occurs in circuits that contain ______________________.

11. The total resistance ______________________ when resistors are connected in parallel.

12. ______________________ are currents that go one way then the other very rapidly.

13. A battery is actually multiple ______________________.

14. ______________________ is a force that moves electrons. Unit for this is ______________________.

15. In a circuit, ______________________ can reduce the flow of electrons.

    Its unit is an ______________________.

16. 'the ratio of the potential difference (voltage) across a conductor to the current flowing in the conductor is a constant' is statement of ______________________.

    Formula: ______________________.

17. The gradient of a voltage/current graph is equal to______________________.

18. ______________________ drops, ______________________ flows in a circuit.

19. An ______________________ measures current and a ______________________ measures voltage drop in a circuit.

20. ______________________ have only one circuit for electrons to flow through.

    Formula for resistors connected in this way ______________________.

21. ______________________ have a choice of pathways in a circuit.

    Formula for resistors connected in this way ______________________.

22. The sum of the potential drops around a circuit is equal to the ______________________ of a cell.

23. The total resistance ______________________ when resistors are connected in series.

Review Questions

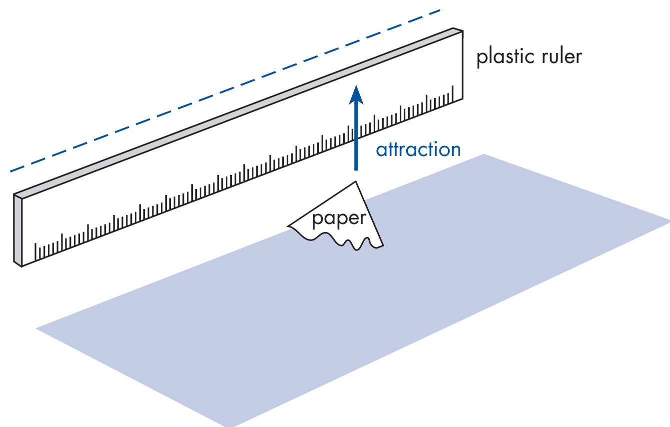
CHAPTER 3: ELECTRICITY

1. (a) Given that the charge on an electron is 1.60×10^{-19} C, how many electrons would be necessary to have an overall charge of 4.00 C?

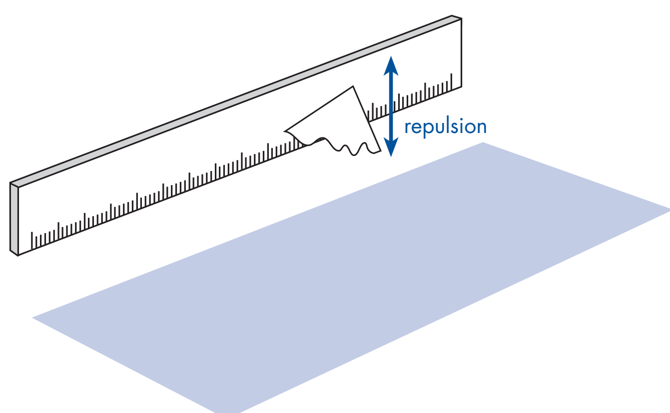
   (b) What current would flow if those electrons went past a point in a circuit in 5.00 s?

2. (a) *[Please try this yourself by rubbing a plastic ruler through your hair]*

   A negatively charged plastic ruler is held near some small pieces of paper. The small pieces of paper are attracted to the ruler. On the diagram below indicate the distribution of charges on the paper that would cause this attraction.

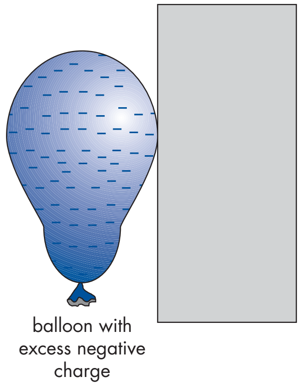


   (b) The piece of paper jumps up to the plastic ruler and remains there for about 10 seconds then drops off. Show on the diagram below the new distribution of charge on the ruler and the paper to show the repulsion causing the paper to fall off.



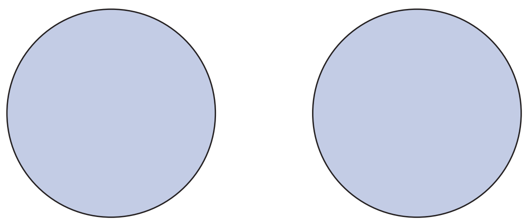
[**Hint:** remember that only electrons can move around]

3. An inflated balloon that is rubbed on some fur (or hair) is attracted to a wall when placed near to the wall. Assuming that the balloon becomes negatively charged, show in the diagram below the distribution of charge on the wall.



4. How long will it take 14.2 C of charge (actually moving electrons) to move through a circuit if the current is 1.50 A?

5. Two small similar light spheres (A and B) are charged such that:
A = + 2.00 nC and
B = - 4.00 nC.



A (+2 nC) B (-4 nC)

(a) The spheres attract. Why?

(b) When they touch, charge is redistributed. What charge is now on each sphere?

(c) What will happen now?

6. What is the difference between a cell and a battery?

7. What does EMF stand for and what does it mean?

8. Explain the difference between electron current and conventional current.

9. Briefly explain the difference between DC and AC.

10. A student was doing an Ohm's Law investigation. He set up a circuit containing the following components:

- 0 - 12 V DC power pack
- wires
- an ammeter
- a voltmeter
- a 5.00 Ω resistor
- a 100 Ω resistor

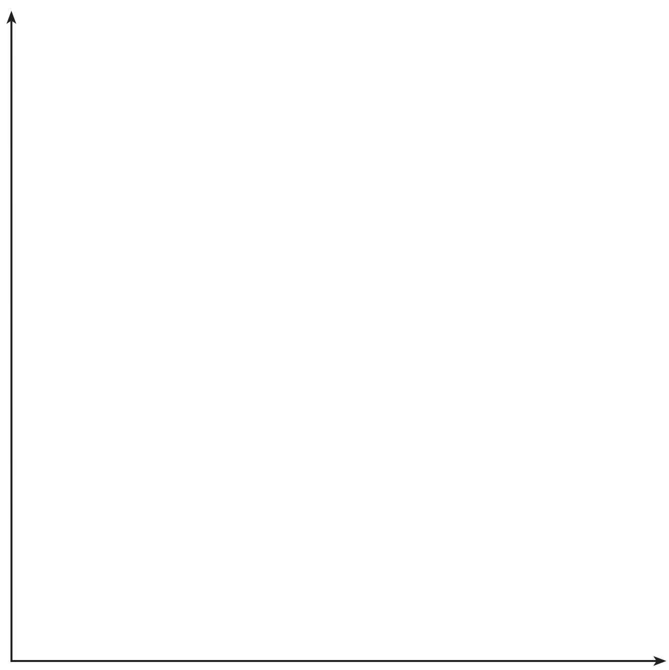
The resistors were connected in series with the power pack. The ammeter and voltmeter were placed in the circuit to measure the current through and the voltage drop across the 5.00 Ω resistor.

(a) Draw the setup for this experiment (the power pack can be indicated as a battery) indicating the correct ± polarity of the power pack, the ammeter and the voltmeter.

(b) By changing the voltage setting on the power pack the student obtained the following results as measured on the voltmeter and the ammeter:

Voltage (V)	0.10	0.20	0.30	0.40	0.50	0.60
Current (mA)	20.0	38.8	57.0	76.2	95.0	112

Graph these results using a line of best fit and with the Voltage on the vertical axis:



Determine the gradient of this graph. What is the significance of this answer?

(c) Considering the definition of Ohm's Law, do these results support Ohm's Law? Explain.

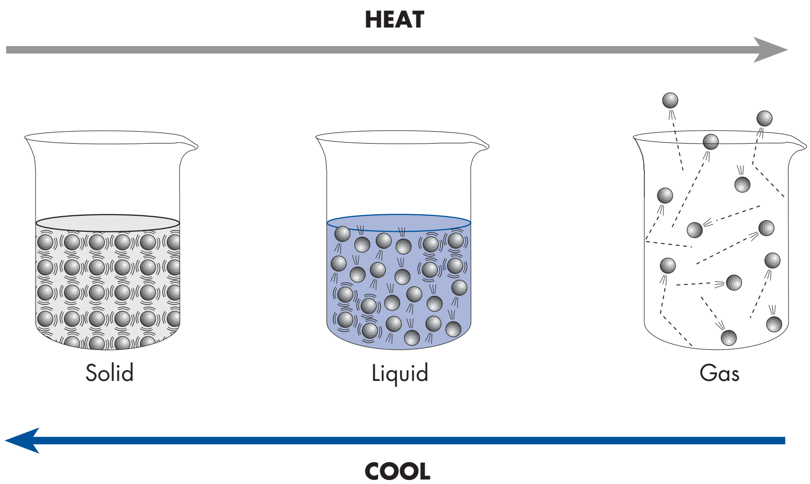
11. Three 5.00 Ω resistors are connected in series and this combination is connected in parallel with three 10.0 Ω resistors which themselves are connected in series. Draw this arrangement and determine the total resistance.

Heating and Cooling

4

4.1 KINETIC THEORY OF MATTER

There are three states of matter: **solids, liquids and gases**.



All matter is made up of **particles*** that are in constant motion. In **solids**, the particles are close together and have relative strong forces binding them together. This is why solids hold their own shape.

When heated, a solid turns to a **liquid**. Energy provided by heat gives the particles increased movement (increased kinetic energy) and causes particles to separate further apart, hence they do not hold their own shape but take up the shape of the container in which they are placed. The forces holding these particles together are weaker than in a solid because they are further apart.

When a liquid is heated, a **gas** is produced. Energy provided by heat causes the liquid particles to move faster and to separate further apart until a gas is formed.

Gases have virtually no forces between the particles to hold them together and hence gases are free to move within their container. You can smell food cooking even if you are not in the kitchen because the gaseous particles can spread throughout the house.

When a gas is cooled it condenses into a liquid and if cooled further it will freeze into a solid. You may have seen frost and ice build up in a freezer. This is caused by gaseous water molecules in the air entering the freezer when it is opened and then solidifying as ice when the freezer is closed.

Particles of a gas travel at high speeds and collide with each other and with the sides of their container. At room temperature the average speed of air particles is about 500 m s^{-1} (≈ 1800 kph). This bombardment of gaseous air particles with the walls of the container creates **gas pressure**.

*[These particles are molecules in covalent molecular substances like water. They are ions in ionic compounds like salt, NaCl, and atoms in metals like aluminium.]

CHECKPOINT!

4.1 Fill in the missing words:

(a) Solid → Liquid ____________________

(b) Liquid → Gas ____________________

(c) Gas → Liquid ____________________

(d) Liquid → Solid ____________________

(Note some solids change directly into gases when heated. This is called ***Sublimation****).*

4.2 Which of the three states of matter has the most energy? Explain your answer.

4.3 Why do solids retain their shape?

4.4 (a) Gaseous pressure may be increased by decreasing volume. Use a diagram to explain why this occurs.

(b) Gaseous pressure may also be increased by increasing the temperature. Explain why this occurs.

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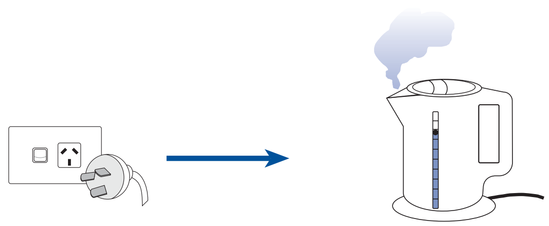
4.2 HEAT IS A FORM OF ENERGY

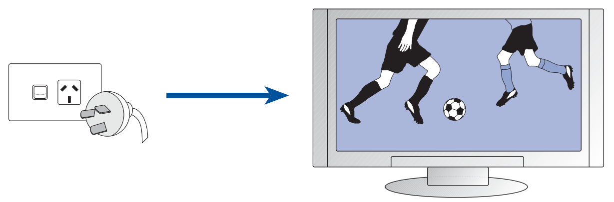
If you are cold, you may rub your hands together. Friction between your hands produces heat. You can produce more heat if you rub your hand faster or push your hands firmly together and then rub. Both of these methods involve you using more energy to produce more heat. Heat is a form of energy that is often produced in **energy transformations**.

Electricity



Movement, heat and sound energy

Electricity

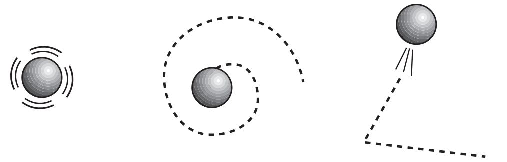


Light, heat and sound energy

Examples:
- hand rubbing: kinetic → heat
- burning petrol: chemical → heat
- striking a match: kinetic → heat → light
- toaster: electricity → heat

All matter have particles that are in motion – i.e. the particles possess kinetic energy. Particles of a liquid or gas can have three different types of kinetic energy:

- **vibrational** (moving back and forth about a point)
- **rotational** (spinning)
- **translational** (moving from place to place)



vibrational rotational translational

[Note that particles of a solid only contain vibrational and some rotational energy.]

Matter can also possess **potential energy** – the energy of position. Just as a ball raised above the ground has potential energy (it can fall and convert this positional energy to kinetic energy), particles of a liquid are further apart than particles in a solid and therefore also possess potential energy. In fact, when a solid is heated at its melting point, heat energy is used to separate the particles further apart to make them into a liquid.

The sum of the kinetic and potential energies of all the particles of an object is called the **Internal Energy.**

Whenever two objects which are at different temperatures are in contact, heat will flow from the hotter to the cooler object. **Heat is defined as the energy that is transferred between objects of different temperature.** Heat is measured in **Joules (J)** – like all forms of energy.

Worked Examples

4.1 A bullet of mass 55.0 g and travelling at 300 m s^{-1} strikes a rock wall and stops immediately transforming all of its kinetic energy to heat. How much heat was produced?

m = 55.0 g = 0.0550 kg
v = 300 m s^{-1}
Heat = ?

Energy transformation:
$E_k \rightarrow$ Heat
Heat = ½ mv^2 = ½ × 0.055 × 300^2 = 2475
= 2.48 × 10^3 J

4.2 A 100 g apple drops 10.0 m from a tree to the ground. If 20.0% of the potential energy converts into sound energy and the rest is converted to heat energy, how much heat is transferred to the apple?

m = 100 g = 0.100 kg
h = 10.0 m
g = 9.80 m s^{-2}

Energy transformation:
80% of E_p = Heat (20% is transferred to sound)
80% x mgh = 0.8 × 0.100 × 9.80 × 10.0 = 7.84 J

CHECKPOINT!

4.5 Why is heat considered to be a form of energy?

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4.6 Why can the particles of solids only have vibrational and rotational energy?

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4.7 (a) Why do liquid water molecules have less potential energy than gaseous water molecules?

(b) Which would be more severe: a burn from boiling water or a burn from the same amount of gaseous water at the same temperature? Explain.

4.8 Describe the three types of kinetic energy that matter in a gas may have.

4.9 Describe the energy transformation that occurs when sunlight shines onto the earth making a tree grow. The wood of this tree is then burned to heat a house.

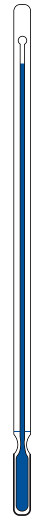
4.10 Define:

(a) Heat

(b) Internal Energy

4.11 A one tonne race car travelling at 175 km h^{-1} hits a safety barrier converting 65.3% of its kinetic energy to heat. How much heat energy is produced in the collision?

4.3 TEMPERATURE



Temperature is a measure of the average kinetic energy of a substance or is simply a measure of how hot an object is. This means that at higher temperatures, particles of matter will be moving faster. If a gas is heated in a confined space, the particles of gas will move faster and therefore they will hit the sides of the container harder and therefore the pressure will increase.

Temperature is measured using a **thermometer**. When heated, the mercury (or other liquids like red coloured alcohol) in the thermometer, expands. The Celsius temperature scale is used to indicate how hot it is. A temperature of 40°C is very hot and on the old Fahrenheit scale is about 105°F.

Another scale used in science to measure temperature is called the Kelvin scale which has a true zero. In fact, zero Kelvin (0 K) is called Absolute Zero because it is the lowest attainable temperature in the universe. It is equivalent to -273°C. At this temperature, particle motion ceases.

i.e. 0 K = -273 °C

To convert Celsius to Kelvin, add 273 to the Celsius temperature.

i.e. 100°C = 373 K

or -50°C = 223 K

Heat and temperature are not the same thing. A 5 g nail at 100°C will transfer less heat to a bucket of cold water at 0°C than 1 kg of steel that is at 20°C. The amount of heat that is transferred between the steel and the water depends on the:

- mass of steel
- temperature of the steel
- nature of material (in this case the steel) [the nature of the material is related to the **Specific Heat**]

Water has a really high specific heat which means that a lot of heat energy must be transferred to it to raise the temperature of the water. In fact, 4180 J of heat energy must be used to raise the temperature of 1 kg of water by 1°C. This is why water is used in a car radiator since water absorbs a lot of heat before the radiator and the water present increase in temperature. This keeps the engine cool.

CHECKPOINT!

4.12 What is the difference between heat and temperature?

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4.13 Convert the following temperatures to Kelvin:

(a) 25˚C = _______ K (b) -25˚C = _______ K (c) -250˚C = _______ K

4.14 Using the definition of temperature, explain why particle motion ceases at Absolute Zero.

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4.15 If you have ever eaten a hot pie, you would notice that the meat/gravy seems to be much hotter than the pastry (even though they have been in the same oven for the same amount of time) and that you need to blow on the meat to cool it down. Which of the two (meat/gravy or the pastry) has the higher specific heat? Explain.

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4.16 Having short showers is an easy way to save money in any household. Give two reasons to support this statement.

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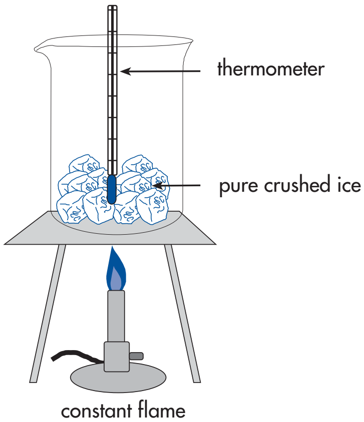
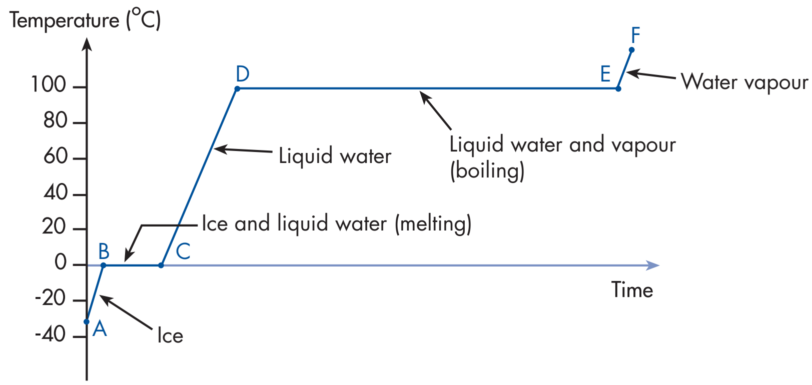
4.4 CHANGING PHASE

Consider ice being heated from -30°C into water vapour (steam) at 125°C as indicated in the graph. This is called a **heating curve**.





A → B: Solid ice is heated and the molecular motion increases and therefore the ice rises in temperature from -30°C to 0°C, i.e. E_k increases, E_p is constant.

B → C: Ice melts. In changing from a solid to a liquid, the molecules of ice separate apart and the ice no longer holds its shape and turns into water. Liquid water molecules are further apart than solid water molecules. Note that during a phase change there is no change in temperature, i.e. E_k (average) is constant, E_p increases.

C → D: Water is heated and the molecular motion increases and therefore the water temperature rises to 100°C, i.e. E_k (average) increases, E_p is constant.

D → E: Water boils. In changing from a liquid to a gas, the molecules of water separate apart further and turn into gaseous water vapour (steam). **Note that during a phase change there is no change in temperature**, i.e. E_k (average) is constant, E_p increases.

E → F: Steam is heated and the molecular motion increases and therefore the vapour temperature rises to 125°C, i.e. E_k (average) increases, E_p is constant.

This means that steam at 100°C has a much more internal energy than water at 100°C because it has the extra potential energy. Therefore more heat can be transferred by the steam than the water at this temperature. This means that a scald from steam would be more severe than a scald from the same mass of boiling water.

The heat energy required to change phase is called **Latent Heat**. Latent means 'hidden'. Even though heat was added there was no change in temperature. The heat was hidden!

The amount of heat energy required to melt 1 kg of ice at 0°C is large (335 000 J) and to change the same amount of water to steam at 100°C requires even more heat energy (2 250 000 J). Remember that it would require about 1 J of energy to raise an apple 1 m above the ground.

CHECKPOINT!

4.17 (a) Describe what happens to water molecules that are being heated from 0°C to 100°C.

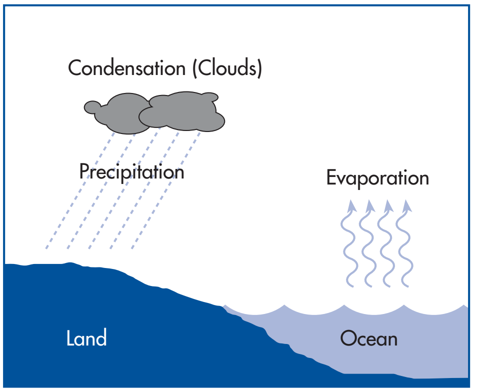
(b) Describe what happens to water molecules that are being heated at 100°C.

4.18 Explain why kinetic energy of water molecules is constant during a phase change.

4.19 Explain why potential energy of water molecules increases during a phase change.

4.20 Look at the graph on the previous page. Why is the section D→E much larger than the section B→C?

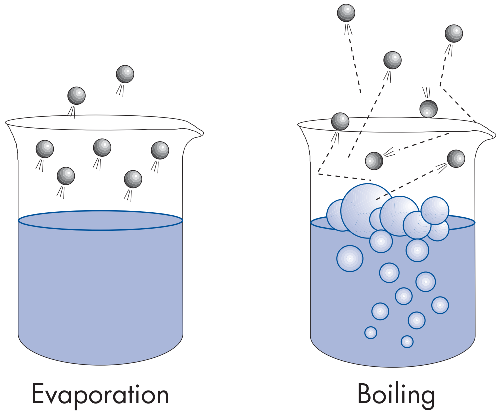
4.5 EVAPORATION



Evaporation is the change in phase from liquid to gas. When it rains, the roads become dry fairly quickly because the water evaporates into the air.

Water that evaporates from the ocean or other water sources, rises into the air to form clouds. The darker a cloud is, the more water vapour it contains. The vapour then can condense and rain may occur.

Evaporation is different to boiling in that boiling only occurs at the boiling point (i.e. 100°C) and occurs **within** the liquid. Evaporation occurs at any temperature and only occurs at the **surface** of a liquid.



Only molecules with high kinetic energy can escape from the surface of the liquid and enter the gaseous phase. Molecules within the liquid are attracted to other liquid molecules and unless they have very high energy, stay in the liquid phase.

We have already indicated that temperature is a measure of the average kinetic energy of a substance. What will happen to the average kinetic energy of a liquid if evaporation occurs? Only the highest kinetic energy molecules have sufficient energy to evaporate. If these molecules leave the liquid, what happens to the average kinetic energy of those that remain?

Of course, the average E_k will decrease and there will be a cooling effect. Therefore, **evaporation causes cooling**.

Evaporation can be increased by:

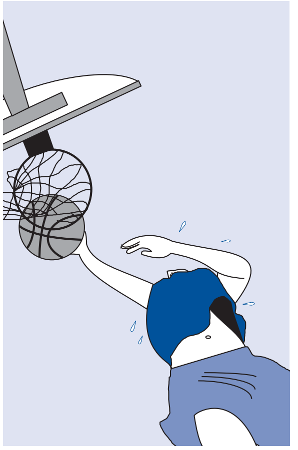
- increasing temperature.
- increasing the air flow over the liquid (wind blowing).
- increasing the surface area of the liquid that is in contact with the air.

Evaporation causing cooling has many applications:

1. Water bag on the front of a car

On a hot day, a hessian water bag was filled with water and hung from the front of a car. Even if it was 40°C, air flow over the bag and the high temperature causes water to evaporate from the hessian bag and cool the remaining water. Warm water could be cooled to below 18°C this way.

2. Human sweat on a hot day



On a hot day we sweat. Heat from our body evaporates the sweat. Heat is transferred to the sweat from our hot bodies and this evaporation causes cooling.

In humid conditions, the air is already saturated with water vapour and the rate of evaporation decreases and we seem to sweat more. This is not the case. Evaporation rate is decreased and we feel less comfortable as our bodies remain covered with sweat. However if we stand in front of a fan, the rate of evaporation increases and we are cooled.

3. Dog panting

Dogs do not sweat. However, if they pant hot air over their tongue and moist mouth parts, evaporation increases and a cooling effect is produced. This has the same effect as a fan on a sweating human.

CHECKPOINT!

4.21 What is the difference between boiling and evaporation?

4.22 Why does evaporation cause cooling?

4.23 On a hot day, you can still feel cold when you get out of the water at the beach if there is a breeze blowing. Explain.

4.24 What conditions would be most suitable if you wished to dry a wet towel as quickly as possible? (No, you cannot put the towel in a dryer!)

4.25 Research how an evaporative air conditioner works. Use a diagram in your answer.

4.6 HEAT TRANSFER

Heat is transferred from one object to another in three main ways:

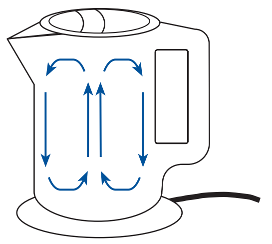
- Convection
- Conduction
- Radiation

(a) Convection

Convection occurs in fluids (liquids and gases). Convection is the circulation of heat in a fluid due to the movement of fluids of varying densities as a result of unequal heating.

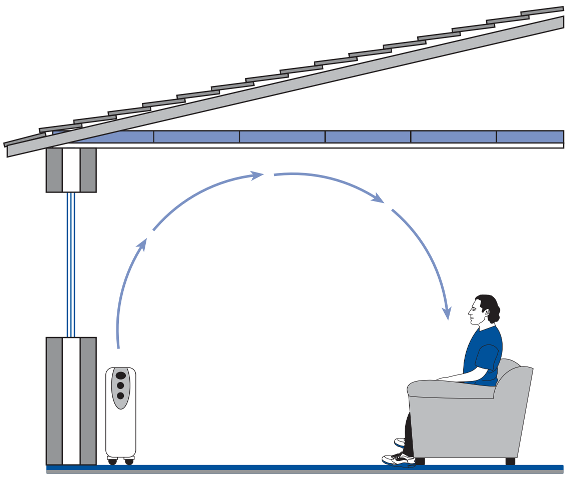
Applications:

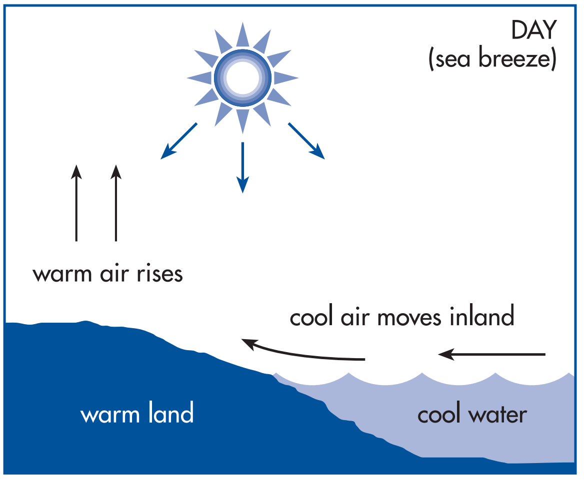
(i) A **kettle** works because as water at the bottom of the kettle is heated, it expands, becomes less dense and rises. (This occurs because any object that is heated expands into a bigger volume and because its mass is unchanged, it must be less dense than before and will therefore rise). Cooler (more dense) water at the top falls to the bottom and is then also heated.

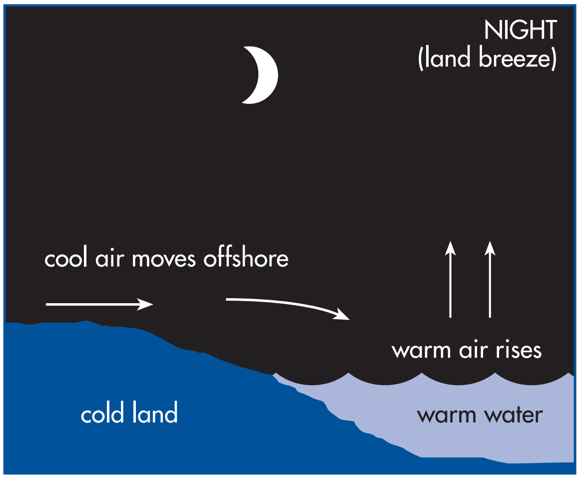


(ii) **Convection heaters**. These work in the same way except that air forms the convection current, not water.

(iii) **Land and Sea Breezes.** During the day, the land heats up more than the ocean (because the water has a higher specific heat than the land). Air over the land is also heated, expands and rises. Cooler air over the sea moves into take the place of this heated air and a sea breeze is produced. The opposite happens at night and a land breeze is produced.

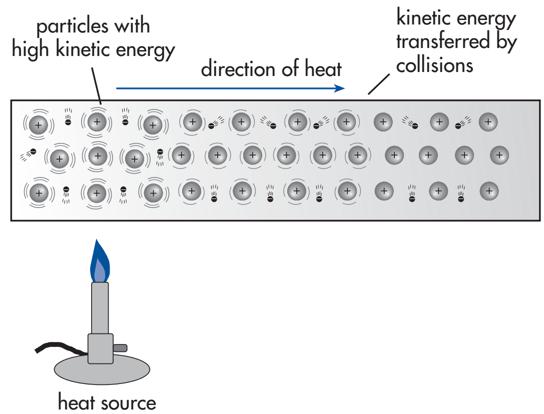






(b) Conduction

Conduction is heat transfer by molecular transference of heat from **hotter to cooler objects that are in contact**. Conduction occurs mainly in solids, somewhat in liquids and very slightly in gases. Materials that allow heat to transfer through them are called **conductors**. Metals are excellent conductors. Materials that do not allow heat to transfer through them are called **insulators**. Air is an excellent insulator and trapping air in between layers of various materials is often used to insulate from cold (e.g. clothing layers, a couple of blankets).



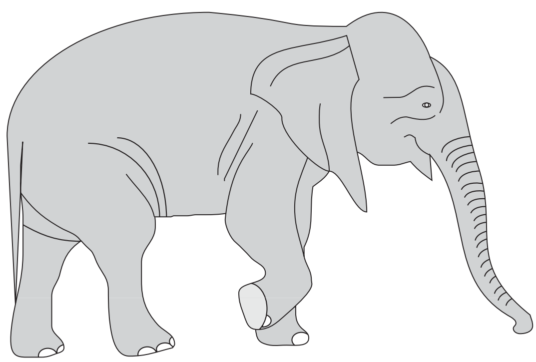
Kinetic Explanation: The higher temperature particles have greater E_k and these particles, impinging on neighbouring particles, transfer energy to them, i.e. heat is transferred without bodily movement of the molecules from one place to another. In metals, kinetic energy is also transferred by electron movement. This is why they are the best conductors of heat.

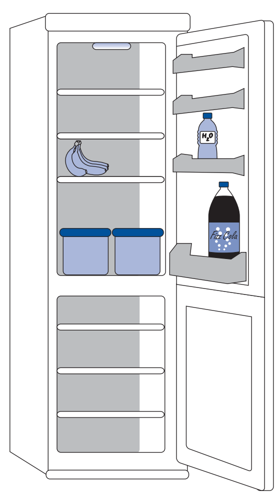
Heat conduction between two objects depends upon:

(i) thermal conductivity of medium (how well it conducts heat)

(ii) surface area of conducting material (e.g. Cooling fins on a refrigerator, car radiator or lawn mower engine, ears on an elephant). A large surface area allows more contact between the two surfaces at different temperatures.

(iii) temperature difference between two surfaces.





Poor Conductors (or Good Insulators) have many uses:

(i) insulating handles (kettles and pots and pans etc).

(ii) lagging (insulation) on hot water pipes.

(iii) insulation in refrigerators, ovens and ceilings etc.

(iv) woollen clothing (due to trapped air pockets).

(c) Radiation

The sun's radiant heat passes through space to warm us on earth. This heat transfer is called **radiation** and heat is transferred by electromagnetic waves of all wavelengths. Electromagnetic radiation include visible light, ultra violet (UV), infra red (IR) and Radio waves. However, infrared radiation can be detected by us 'feeling' the heat produced on your hand. No medium is necessary for this method of heat transfer, i.e. it can pass through a vacuum.

Dark coloured and rough surfaces are better radiators and absorbers of infrared radiation than are light coloured and smooth surfaces (which reflect more radiation than they absorb).

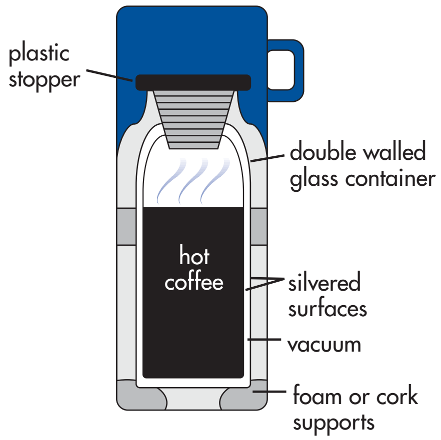
Applications:

(i) Fuel storage tanks – silver or white to reflect heat.

(ii) Car radiators – black to radiate heat away from the radiator.

(iii) Clothing – light colours in tropics, dark colours in cooler climates.

(iv) Vacuum Flask – silvered surfaces to reflect heat.



Worked Example

4.3 How does a vacuum flask keep food/drinks hot?

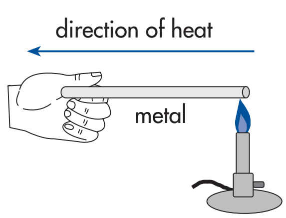
The vacuum flask works in three main ways to reduce heat transfer:

1. Vacuum – cuts down heat losses by conduction and convection.

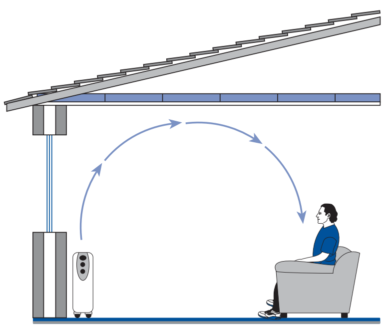
2. Glass, Plastic and Cork – poor conductors of heat.

3. Silvered Surfaces – cut down heat loss by radiation by reflecting the heat.

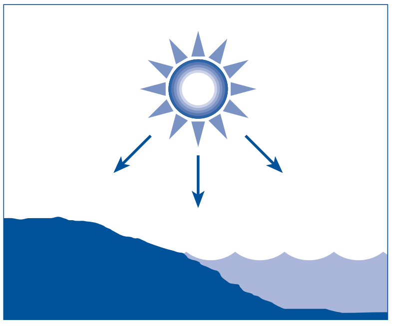
Summary of heat transfer methods:



Conduction



Convection



Radiation

CHECKPOINT!

4.26 Complete this table by indicating the way that heat is transferred in each of the following cases:

Situation	Heat transfer method
1. A kettle is placed on hot coals of a fire.	
(a) the kettle gets hot	
(b) the water in the kettle gets hot	
(c) a person standing nearby is also warmed	
2. Water in a car radiator is heated and cooled as it circulates.	
(a) the water is heated as it passes through the engine block	
(b) the heated water flows to the top of the radiator	
(c) the water is cooled as it flows down through the black, large surface area radiator	

4.27 In an electric kettle, the heating element is always found at the bottom of the kettle. Explain why. Use a diagram in your answer.

4.28 Car radiators and painted black have a large surface area and are metallic. How do these features help to keep a car engine cool?

4.29 Night vision cameras detect infrared radiation. How would they help detect a bandit hiding under thick bush at night?

4.30 List some ways that are used to either reduce heat loss or heat gain in a house.

HEAT FACTS

Complete the following matching worksheet by choosing an answer from the list below and writing it in the space provided.

0°C, convection current, boiling point, constant, close, conduction, conductor, surface area, 100°C, within, cooling, evaporation, windows, convection, convection, condensation, insulation, surface, bottom, radiation, amount of wind, internal energy, temperature, north, temperature, far, heat, melting, specific heat, vibrational, conduction, Joule, 273.

1. Heat energy unit is a ______________________.
2. Solid → liquid ______________________.
3. Liquid → gas ______________________.
4. Gas → liquid ______________________.
5. Melting point of ice ______________________.
6. Temperature remains ______________________ during boiling.
7. Land and sea breezes are an example of a ______________________.
8. Boiling point of water ________
9. Heat can be transferred by ____________, ____________ or ____________.
10. Evaporation causes ______________________.
11. In metals, heat is mainly transferred by ______________________.
12. The sum of the kinetic and potential energy of an object is called the ______________________.
13. 0 K = ________ °C
14. ______________________ is a measure of the average kinetic energy of a substance.
15. Molecules in a solid are very ______________________ together.
16. Molecules in a gas are ______________________ apart.
17. The nature of a material that determines how quickly it changes temperature when

    heated is called the ______________________.
18. Boiling only occurs at the ___________ and occurs ______________________ the liquid.

    Evaporation occurs at any temperature and only occurs at the ______________________ of a liquid.

19. ____________________ kinetic energy is the major type of motion found in the molecules of a solid.

20. The heating element in a kettle is always placed near the ____________________.

21. Rate of evaporation depends on ____________________, ____________________ and ____________________.

22. An energy efficient house should have most windows facing ____________________.

23. To reduce heat loss from a house in winter time, place ____________________ in the ceiling and cover up the ____________________.

24. Since water is a poor____________________, heat is transferred in a kettle by ____________________.

25. ____________________ is defined as the energy that is transferred between objects of different temperature.

Review Questions

CHAPTER 4: HEATING AND COOLING

1. Convert the following temperatures to Kelvin:

    (a) 100°C

    (b) -205°C

    (c) 273°C

2. Explain the following:

    (a) We rub our hands together when it's cold.

    (b) Fans help keep you cool on a hot day (even if the fan blows warm air onto you).

    (c) You can determine the direction that the wind is blowing by wetting your finger and holding it in the air.

    (d) Two thin blankets are better than one thick blanket on a cold night.

3. (a) Draw a temperature versus time graph for ice at -20°C being uniformly heated until it is steam at 120°C.

(b) Indicate the MP (of ice) and BP (of water) on the graph.

(c) On the graph, indicate the position on the graph where:

(i) molecules would have the highest kinetic energy. Label this point A.

(ii) molecules would have the lowest potential energy.
Label this point B.

(iii) there would be a 50% ice, 50% water mix.
Label this point C.

4. List three heat conductors and three insulators found in a kitchen:

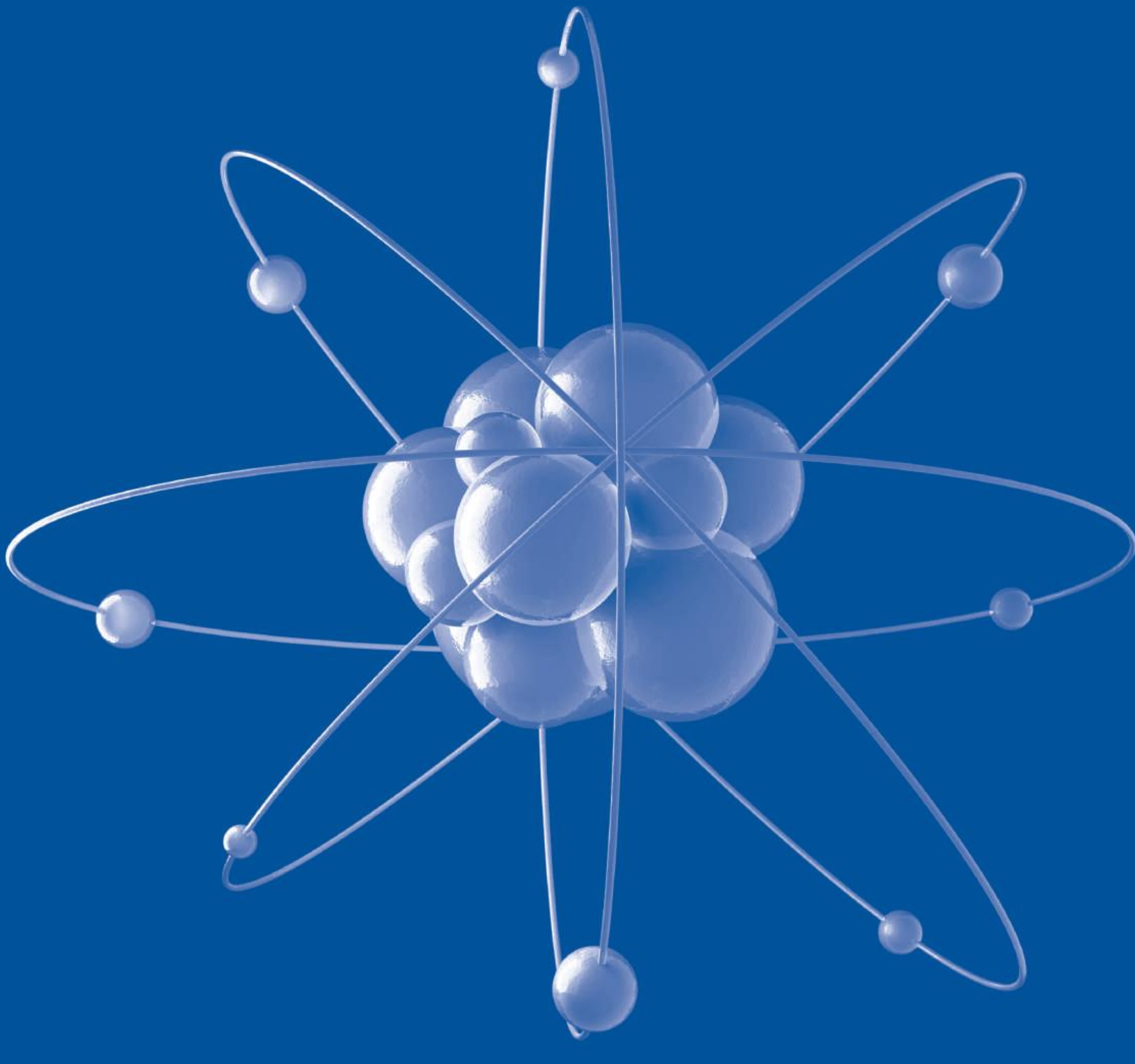
Kitchen Conductors	Kitchen insulators

5. State and describe the difference between the three methods of heat transfer.

6. State the heat transfer process in the following situations:

Situation	Transfer process
(a) Heat enters a house through a closed window.	
(b) Toast is cooked in a toaster.	
(c) Water in a hose left in the sun becomes very hot.	
(d) The tip of a soldering iron is very hot.	
(e) A room is heated by a slow combustion wood fire.	
(f) After a 3 day heat wave, ceilings of insulated houses get hot.	

7. When eating hot soup, we often blow across the surface of the soup to cool it down. Explain how this works.



Nuclear Physics

5

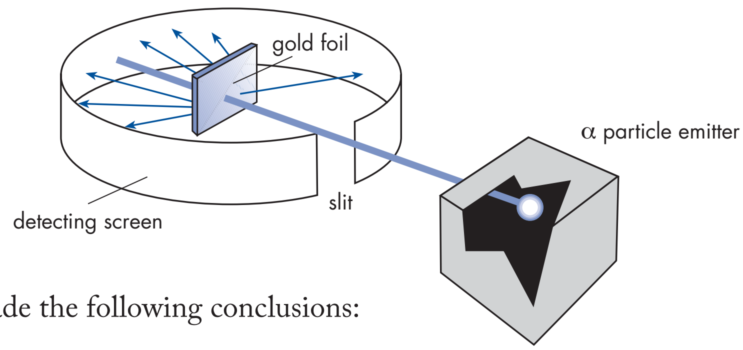
5.1 ATOMIC THEORY

(a) A brief history

1911: Rutherford and Geiger found an irregular deflection pattern of alpha (α) particles (α are helium nuclei) that were fired into gold foil. Rutherford observed that:

(a) most α particles passed straight through the foil;

(b) some were deflected and even reflected.



Rutherford made the following conclusions:

(i) most of the atom is empty space.

(ii) an atom contains a central core with a positive charge. He called this core the **nucleus**.

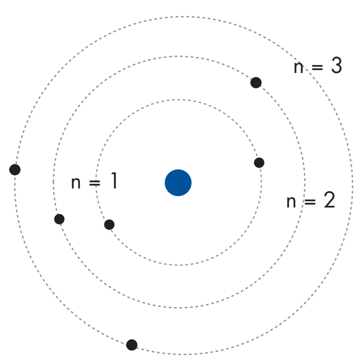
(iii) electrons orbited the nucleus and were held in orbit by electrostatic attraction to the protons.

(iv) the total positive charge (in the nucleus) equals the total negative charge (on the electrons).

1913: Bohr suggested electrons existed in particular energy levels (commonly called electron shells); this conforming with Planck's Quantum Theory of 1900.

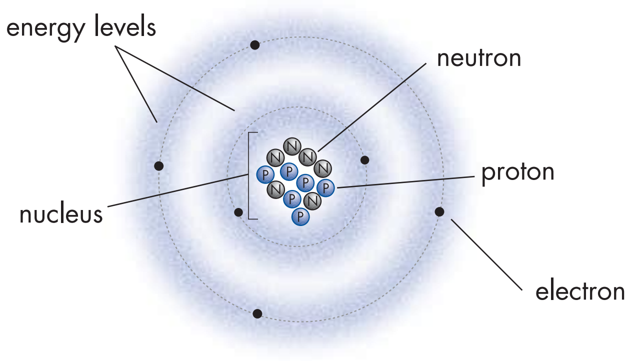
1919: Rutherford suggested existence of neutron.

1932: Chadwick first detected the existence of the neutron.



In Bohr's model electrons can only occupy orbits having integer values of n

The modern model of the atom describes the positions of electrons in an atom in terms of probabilities – not fixed orbits as proposed by Bohr. An electron can be found at any distance from the nucleus, but, depending on its energy level, exists more frequently in a space called an orbital. The orbitals come in a variety of shapes – sphere, dumbbell, torus, etc. with the nucleus in the middle.



PARTICLE	MASS	RELATIVE MASS	CHARGE	RELATIVE CHARGE
electron	9.1091×10^{-31} kg	$\frac{1}{1840}$	-1.602×10^{-19} Coulomb	-1
proton	1.6725×10^{-27} kg	1	$+1.602 \times 10^{-19}$ Coulomb	+1
neutron	1.6748×10^{-27} kg	1	nil	0

Note: m (proton) ~ m (neutron) ~ 1840 × m (electron)

(b) The Nucleus

The nucleus consists of protons and neutrons. The nucleus is tiny when compared to the size of the atom. A comparison in size of a nucleus to its atom is the same as comparing a pea to the size of a football stadium – that is a ratio of about 1:100000.

(i) **The Atomic Number (Z)** is the number of protons in the nucleus of an element.

(ii) **The Mass Number (A)** is the number of protons + neutrons in the nucleus of an element. (Therefore the number of neutrons = A - Z).

(iii) Isotopes of an element contain the same number of protons but different numbers of neutrons. Hence isotopes of an element have the same chemical properties since the number of electrons remain the same – the chemical properties of an element are dependent on the number of protons and electrons in an atom and not the mass of an atom. Neutrons do not affect the chemistry of an element.

(iv) Symbolic Representation is required in order to distinguish between isotopes of an element.

Chemical symbol (for Oxygen)

e.g. $_{8}O^{16}$ mass number (A)

atomic number (Z)

Consider the following table:

Isotope	${}_{6}C^{12}$	${}_{6}C^{14}$	${}_{92}U^{238}$
Number of protons (Z)	6	6	92
Number of protons + neutrons (A)	12	14	238
Number of neutrons	6	8	146

Sub-atomic particles can be represented as:

neutron ${}_{0}n^{1}$
electron ${}_{-1}e^{0}$
proton ${}_{1}p^{1}$ or ${}_{1}H^{1}$ (a hydrogen nucleus is just a proton)

CHECKPOINT!

5.1 One of Rutherford's conclusions was that 'most of an atom is empty space'. How did Rutherford come to that conclusion?

5.2 Another one of Rutherford's conclusions was that 'an atom contains a central core with a positive charge'. How did Rutherford come to that conclusion?

5.3 Complete the following table:

Isotope	${}_{1}H^{1}$	${}_{12}Mg^{24}$	${}_{88}Ra^{226}$
Number of protons (Z)			
Number of protons + neutrons (A)			
Number of neutrons			

5.4 Complete the following table:

Particle	Relative Mass	Relative Charge
electron		
proton		
neutron		

5.5 Draw a labelled diagram to represent the modern representation of an atom.

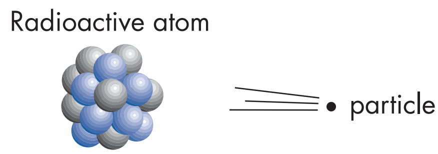
5.2 RADIOACTIVITY

Positive charges (protons) within a nucleus repel each other. This repulsion could destroy an atom. Obviously not all nuclei disintegrate due to this repulsive force. In the nucleus there is a balance between the electrostatic force of repulsion between the protons and a nuclear force of cohesion between all nucleons (protons and neutrons). Only certain combinations of protons and neutrons form stable nuclei. If the balance is upset the nucleus is unstable and will eventually disintegrate in one or more steps until a stable combination of protons and neutrons is achieved. In becoming more stable, a nucleus releases radiation and undergoes a transformation into another isotope or element. Radiation that is released from the nucleus in this process can be:

particles: **alpha** (α) or

beta (β) and

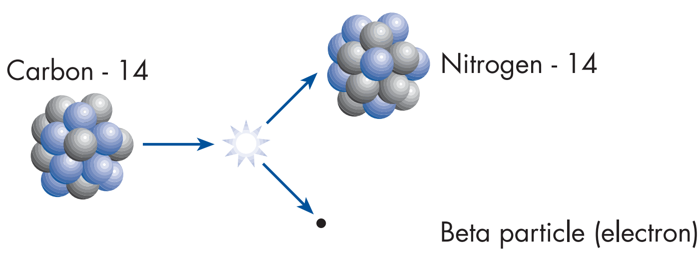
non particles: **gamma** (γ) - electromagnetic radiation



Nuclei that emit radiation are said to be **radioactive**. **Radioactivity** is the term used to describe the decay or disintegration of an unstable nucleus to give a more or completely stable nucleus. Radioactivity was accidentally discovered by Henri Becquerel in 1896.

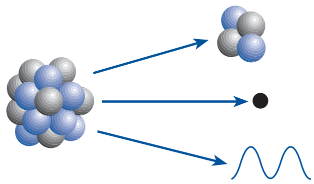
Carbon-12 is stable but carbon-14 is unstable. The combination of 6 protons and 6 neutrons is stable but 6 protons and 8 neutrons is not. To become more stable, a carbon-14 nucleus emits a beta particle and changes to a nitrogen-14 nucleus which is stable. This nuclear reaction can be represented by this nuclear equation:

${}_{6}C^{14} \rightarrow {}_{7}N^{14} + {}_{-1}e^{0}$ This is an example of beta emission.



In a nuclear equation, the atomic numbers (at the bottom) and the mass numbers (at the top) must be equal on both sides of the equation. In the above nuclear reaction, a neutron in the carbon nucleus turns into a proton and emits an electron (beta particle) from the nucleus even though there were not any electrons in the nucleus to begin with. This rearrangement of the nuclear material makes the nucleus more stable.

5.3 TYPES OF RADIATION



(a) Alpha (α) or $_2He^4$

An alpha particle is a helium nucleus ($_2He^4$). It contains 2 protons and 2 neutrons and has a double positive charge. The emission of alpha particles occurs mainly from heavier elements.

Alpha particles are easily absorbed by a few centimetres of air and are also deflected by magnetic and electric fields. They are the most energetic of the radiations. They are considered to be the most dangerous because of their ability to ionise atoms (ionise means to remove electrons from an atom). If living tissue is ionised, the removal of electrons changes the chemistry of the cell and this can lead to abnormality of cells and ultimately cancer.

e.g. $$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_2He^4$$

(b) Beta Particle (β or $_{-1}e^0$)

β particles are high speed electrons from a nucleus. They penetrate approximately 100 times the range of an α particle. Beta radiation causes ionisation but not to the same extent as alpha radiation.

e.g. $$_6C^{14} \rightarrow {}_7N^{14} + {}_{-1}e^0$$

Note: With β emission (i) A unchanged (ii) Z increased by 1

Beta particles are also deflected by magnetic and electric fields.

(c) Gamma Ray (γ)

A nucleus excited by the emission of α particle may rearrange itself to get rid of surplus energy. This energy is emitted as γ radiation. γ rays are an electromagnetic radiation like visible light but with much more energy than visible light. Because they are not particles (and they have no charge), they are not affected by magnetic and electric fields and have enormous penetrating ability.

Property	α	β	γ
Penetration	Few cm of air or thin paper	Thin sheet metal needed to halve radiation intensity	Up to 10 cm of lead, 25 cm of concrete needed to halve radiation intensity
Ionisation of matter	Readily	Some	Slight
Nature of neutrons	$_2He^4$ nucleus	High speed 'nucleus electrons'	Electromagnetic radiation

CHECKPOINT!

5.6 What causes an isotope to be radioactive?

____

____

____

5.7 For each of the following characteristics choose the type of radiation that best fits the description:

Property	Radiation
Strongest ioniser	
Undeflected by an electric or magnetic field	
Highest mass	
Greatest charge	
Highest charge/mass ratio	
Most penetrating	
Least penetrating	

5.8 Identify the missing particle in each of the following nuclear reactions:

(a) ${}_{2}He^{4}$ + ________ $\rightarrow$ ${}_{8}O^{16}$ + γ (remember that γ do not have mass)

(b) ${}_{6}C^{12}$ + ${}_{1}H^{1}$ $\rightarrow$ ________ + γ

(c) ${}_{8}O^{16}$ + ${}_{0}n^{1}$ $\rightarrow$ ________ + ${}_{9}F^{17}$

(d) ${}_{86}Rn^{222}$ $\rightarrow$ ________ + ${}_{2}He^{4}$

(e) ${}_{90}Th^{234}$ $\rightarrow$ ________ + ${}_{91}Pa^{234}$

5.9 Explain how electrons can be emitted from a nucleus during beta decay even though the nucleus does not contain electrons. Show this in a balanced nuclear equation.

____

____

____

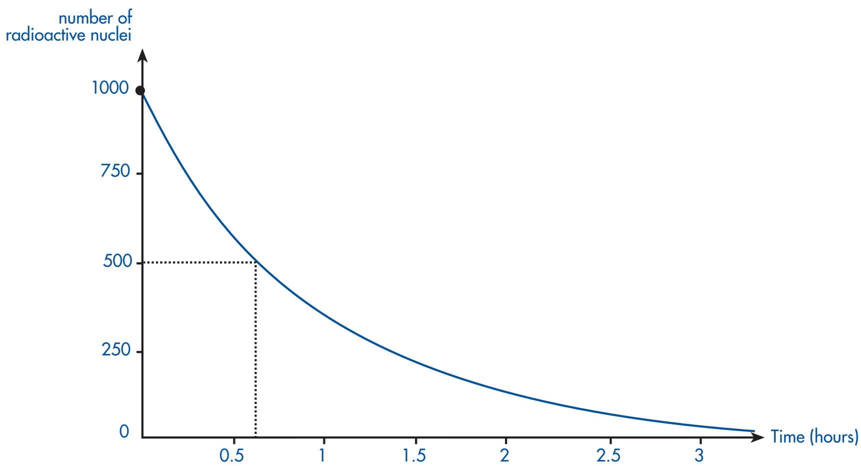
____

5.4 HALF LIFE

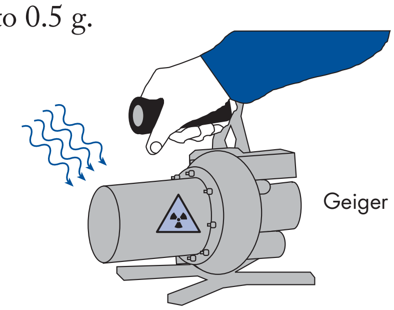
Different radioactive nuclei decay (change and give out radiation) at different rates. The **Activity** of a Radioactive sample is the number of atoms that decay per unit time. Activity is measured in BECQUEREL (Bq). 1 Bq = 1 disintegration s^{-1}.

The **Half-Life** ($T_{½}$) is the length of time during which half a given number of atoms decay or is the **length of time** during which the activity decreases by a half. The graph below is called an exponential decay curve.

From this graph we can see that the time that it takes the number of radioactive nuclei to change from 1000 to 500 is about 0.6 hours. This is the half life.



e.g. After 28.5 years, the activity of 1.0 g of Sr-90 drops from 4000 Bq to 2000 Bq as measured by a Geiger counter. This means that in same time the amount of Sr-90 atoms present drops to 0.5 g.



Worked Examples

5.1 (a) Iodine-131 has a half-life of about 8 days. The initial activity of a sample of $_{53}I^{131}$ is 160 disintegrations per second. What is the activity after 16 days?

# Half lives	Time	Activity	%	Fraction
0	0	160 Bq	100%	1/1
1	8 days	80 Bq	50%	1/2
2	16 days	40 Bq	25%	1/4

Ans = 40 Bq

e.g. (b) After 50 hours, 6.25% of a sample of the radioisotope ${}_{19}K^{42}$ remains undecayed. What is its half-life?

# Half lives	Time (hours)	%
0	0	100%
1		50%
2		25%
3		12.5%
4	50 hours	6.25%

$4 \times (T_{½}) = 50$ hours

$(T_{½}) = 50/4 = 12.5$ hours

CHECKPOINT!

5.10 A radioactive sample emits 720 disintegrations per second. After 8 minutes the count has dropped to 45 per second. What is the half-life?

# Half lives	Time (minutes)	%	Activity (Bq)
0	0	100%	
1		50%	
2		25%	
3		12.5%	
4		6.25%	

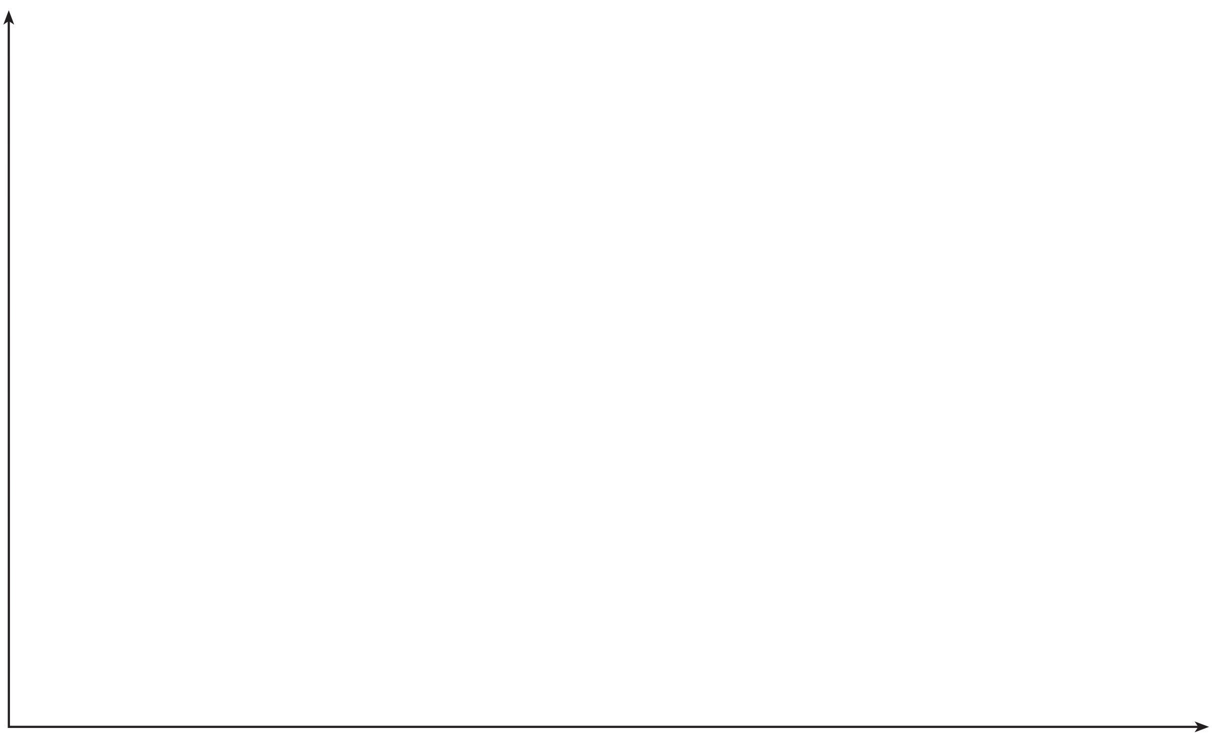
5.11 After 40 seconds the number of disintegrations per second of a radioactive material drops to 1/32 of its initial value. Calculate the half-life.

# Half lives	Time	Fraction
0	0	1/1
1		
2		
3		
4		
5		

5.12 A piece of charcoal from an ancient cave dweller's fire was found to give an average beta count of 2.30 min^{-1}. Identical charcoal of recent origin registers 18.4 counts min^{-1}. If the half life of C-14 is 5730 years, what is the age of the charcoal?

5.13 (i) Plot a graph of the following radioactive decay data:

Activity (Bq)	800	600	450	340	260	200	150	105	80
Time (s)	0	8	16	24	32	40	48	56	64



(ii) Estimate the half life from the graph.

5.5 NUCLEAR REACTIONS

There are two types of nuclear reaction by which nuclear energy can be obtained. They are:

(a) by **Fission Reactions** – in which the heavier nuclei are split into two (or more) lighter nuclei with the release of energy.

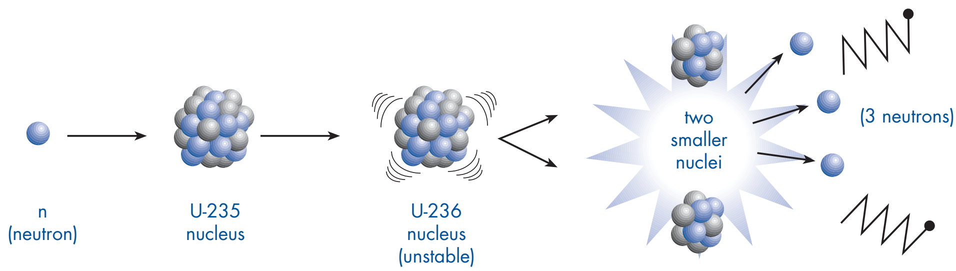
(b) by **Fusion Reactions** – in which the lighter nuclei are combined to form somewhat heavier nuclei.

(i) Fission Reactions (splitting apart heavy nuclei)

Nuclear fission is the process whereby a neutron is captured by a nucleus and the nucleus splits into two approximately equal parts. Fission reactions occur in nuclear power stations and an enormous amount of energy is released during the process.

One of the U-235 fission reactions is:

$${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + \text{Energy}$$

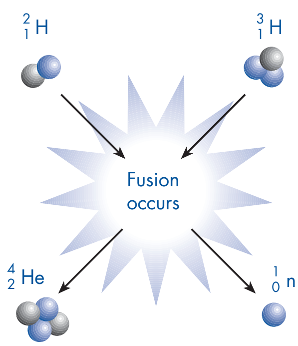


(ii) Fusion Reactions (joining together of lighter nuclei)

Nuclear fusion reactions can be brought about by accelerating protons, deuterons (${}_{1}H^{2}$) etc. and allowing them to collide with various target nuclei of light elements. An alternative method of increasing the kinetic energy is by raising the temperature of the reacting system (thermonuclear reactions). Once the process is initiated the energy produced is sufficient to raise the temperature of other nuclei to that necessary for the reaction to take place. Fusion reactions occur in the sun and provides the earth with enormous amounts of energy to keep us warm, make plants grow and to produce photovoltaic and wind powered energy.

E.g. A fusion reaction (in the hydrogen bomb) is:

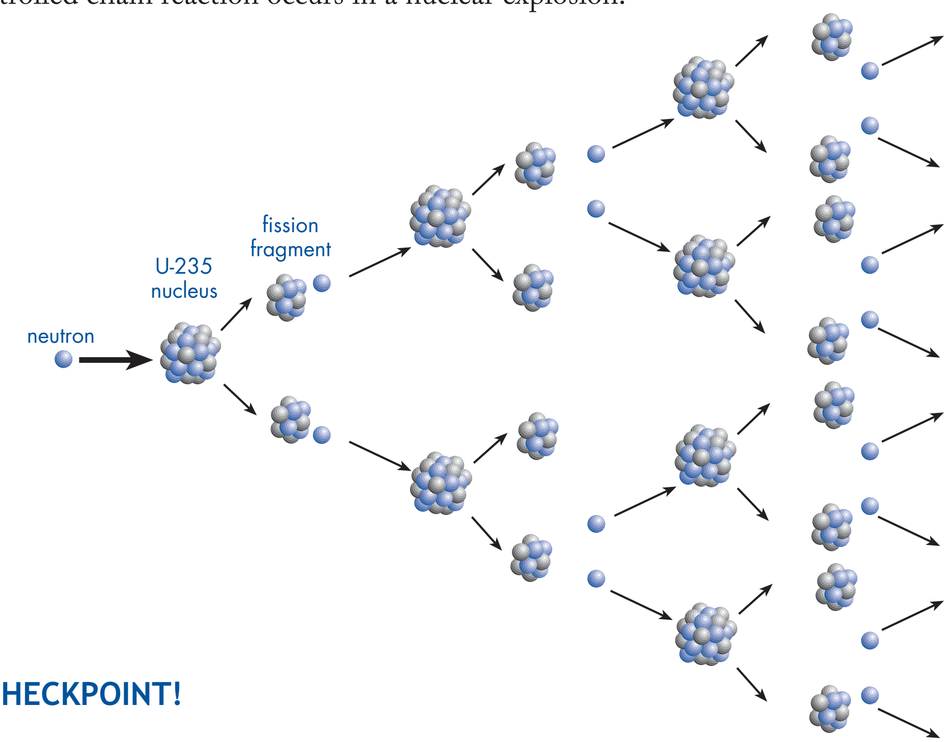
$${}_{1}H^{3} + {}_{1}H^{2} \rightarrow {}_{2}He^{4} + {}_{0}n^{1} + \text{energy}$$



(iii) Fission Chain Reaction

In a nuclear reactor, the fission process is required to be sustained but not becoming uncontrolled. Neutrons released during fission can then be used to split other nuclei. This can then produce a **Chain Reaction**. For a chain reaction to occur, the number of neutrons produced in the fission process must be at least equal to the number absorbed in both fission and non-fission reactions plus the number that escape entirely.

An uncontrolled chain reaction occurs in a nuclear explosion.



CHECKPOINT!

5.14 Distinguish between fission and fusion.

5.15 Write a nuclear equation that occurs between two deuterons ($_1H^2$) producing helium - 3 and a neutron. What type of a nuclear reaction is this?

5.16 In a nuclear reactor it is necessary to have a fission reaction that produces, on average, at least 2.5 neutrons. Why is it necessary to have at least 2.5 neutrons released per reaction when only 1 neutron is needed to cause another fission reaction?

NUCLEAR PHYSICS FACTS

Complete the following matching worksheet by choosing an answer from the list below and writing it in the space provided.

alpha, proton, mass number, ionisation, chain reaction, alpha, electron, 51, Becquerel (Bq) 6 minutes, nucleus, 23, half-life, 3 minutes, beta, alpha, neutron, atomic number, gamma, fission, fusion, 4 minutes, positive, fusion alpha, 28, mass, beta, charge, neutron, isotopes, gamma, activity, energy, alpha

1. The ______________________ contains protons and neutrons.

   Protons have a ______________________ charge.

2. ______________________ of an element have the same number of protons but different numbers of neutrons.

3. The number of protons is called the ______________________ .

4. The number of protons plus neutrons is called the ______________________ .

5. The nucleus, $_{23}V^{51}$ has ________ protons and ________ neutrons.

6. The three types of radiation are ______________________ , ______________________ and ______________________ .

7. ______________________ are helium nuclei.

8. ______________________ are high speed nuclear electrons.

9. ______________________ are electromagnetic radiation.

10. In beta emission, a ______________________ turns into a ______________________ and emits a ______________________ .

11. ______________________ is the removal of electrons by radiation.

    ______________________ cause this to happen most readily.

12. Gamma radiation is highly penetrating in matter because they have no ______________________ or ______________________ .

13. Identify X in this nuclear reaction: $_{92}U^{238} \rightarrow {}_{90}Th^{234} + X$ (______)

14. _________ is the number of nuclei that decay each second.

    Its unit is the ______________________ .

15. The time during which half the atoms in a radioactive sample decay is called the

______________________.

16. ______________________ is the splitting of a heavy nuclei into approximately equal parts.

17. ______________________ is the joining of two light nuclei together. Both this reaction

and the previous reaction produce huge amounts of ______________________.

18. In a nuclear reaction fission occurs continuously due to a ______________________ occurring.

19. The half-life of a radioactive sample which has its activity change from 1000 Bq to 125 Bq

in 12 minutes is ______________________.

20. Identify X in this nuclear reaction: $_{1}H^{2} + {}_{11}Na^{23} \rightarrow {}_{12}Mg^{24} + X$ (______)

21. ______________________ reactions occur in the sun.

22. The type of radiation absorbed by a few cm of air is ______________________ .

Review Questions

CHAPTER 5: NUCLEAR PHYSICS

1. Complete the following table:

Nuclide	$_{8}O^{18}$	$_{35}Br^{80}$	$_{74}W^{184}$
Number of protons (Z)			
Number of protons + neutrons (A)			
Number of neutrons			

2. Identify the following particles:

(i) $_{2}X^{4}$

(ii) $_{1}X^{1}$

(iii) $_{-1}X^{0}$

(iv) $_{0}X^{1}$

3. Complete the following table:

Type of Radiation	Alpha	Beta	Gamma
Symbol			
Nature			
Charge			
Relative mass			
Ionising ability			
How is it stopped			

4. Complete the following table by putting α, β or γ in the last column:

Description of Radiation Type	Radiation Type
Largest mass	
Best ioniser	
Not affected by magnetic fields	
Would be deflected towards the positive plate in an electric field	
No charge	
Will penetrate through the roof of a house	
Travels at the speed of light	
Has the highest mass : charge ratio	

5. Complete the following nuclear reactions:

(a) ${}_{83}Bi^{214} \rightarrow {}_{84}Po^{214} + X$

(b) ${}_{29}Cu^{65} + {}_{0}n^{1} \rightarrow X +$ a proton

(c) ${}_{11}Na^{21} \rightarrow X +$ a beta

(d) ${}_{13}Al^{27} +$ an alpha $\rightarrow X$

(e) In a nuclear reaction, an alpha particle is absorbed by a nitrogen-14 nucleus and a proton and an unknown element are produced.

6. When boron-10 is bombarded with a neutron, the neutron is absorbed and an alpha particle is emitted.

(a) Write an equation to represent this reaction.

(b) Use a periodic table to determine what is the new element formed.

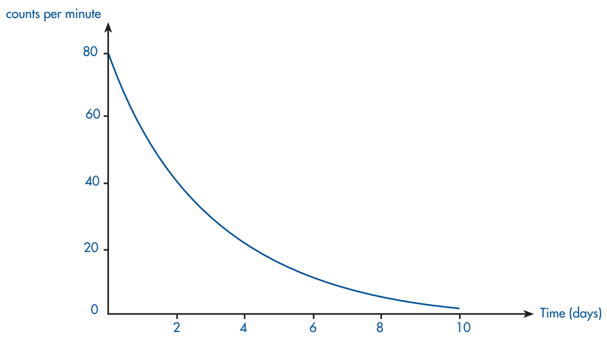
(c) This method is used to detect neutrons since alpha particles are easy to detect. Why are neutrons difficult to detect?

7. (a) The half life of gold - 198 is 2.7 days. How long will it take for the activity to drop to 1/32 of its present activity?

(b) If gold - 198 is a beta emitter, write the equation for its decay.

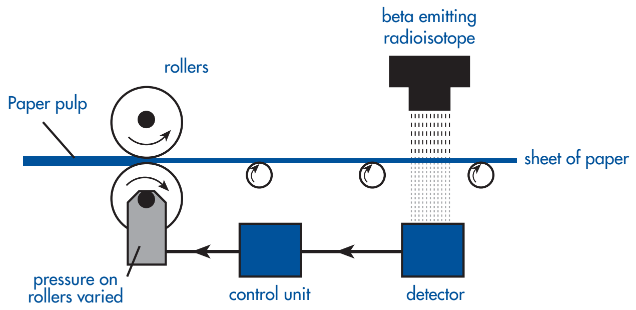
(c) If the original activity is 10 kBq, what is the approximate activity after a week?

8. (a) What half life is indicated in the following decay curve?



(b) Approximately, what would the activity be (in counts per minute) after 8 days?

9. Consider the thickness controller in a paper mill below and explain why it is necessary to use a beta emitter.



Trial Test 1 : Fundamentals and Motion

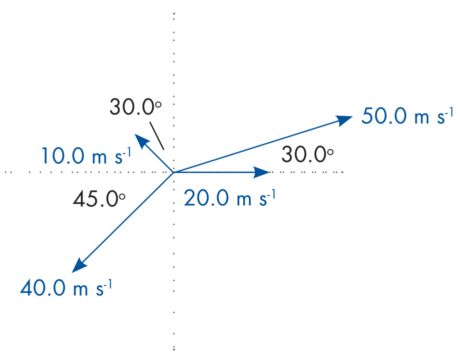
Time allowed: 60 minutes
Total marks: 90

1. Which of the following is the longest length? Show how you obtain your answer.

(a) 227550 pm (b) 122 nm (c) 44.7 μm

[4 marks]

2. In the diagram below, resolve all the vectors in vertical directions (up and down) and also in horizontal directions (left and right).

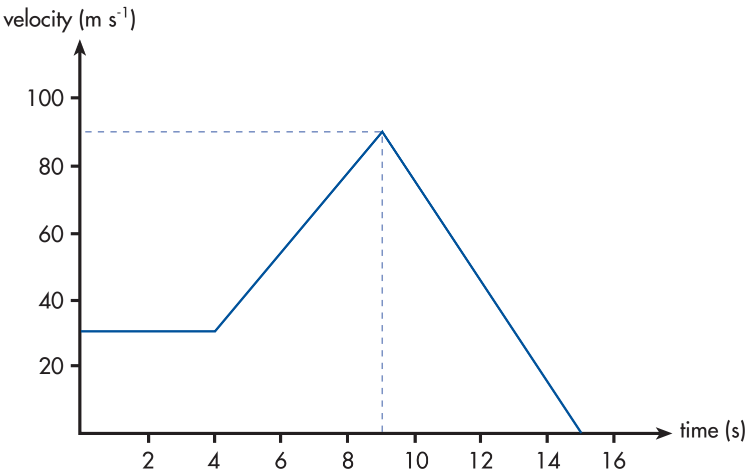


[10 marks]

3. Add the horizontal components in Question 2. Then add the vertical components and finally find the resultant of all the vectors.

[8 marks]

4. The graph below shows the velocity of a motorbike plotted as a function of time.



(a) What is the instantaneous acceleration at t = 3 s, t = 7 s and t = 11 s?

[3 marks]

(b) How far does the motorbike travel in the first 4 s?

[2 marks]

(c) What total distance has been covered at the end of the fifteenth second?

[5 marks]

5. A car is travelling with a velocity of 14.5 m s^{-1}. It then experiences a uniform acceleration of 4.80 m s^{-2} for 6.50 s. Finally it decelerates at a rate of 10.5 m s^{-2} until it comes to a stop.

(a) Draw a velocity vs time graph for the car while the velocity is changing.

[8 marks]

(b) From the graph, how far has the car travelled while the velocity was changing?

[3 marks]

6. A car covered 1.6 km in 40 s in an attempt at the world speed record in 1904.

(a) What was its speed in km h^{-1}?

[2 marks]

(b) Assuming the car travelled at constant speed, how much time elapses (in s) until it reaches the 1 km mark?

[2 marks]

7. Ernesto was driving to the local country convenience store when a kangaroo jumped out onto the road 170 m in front of his car. The kangaroo became dazzled by the car headlights and stopped. Ernesto at the time was travelling at 16.5 ms^{-1} and took 0.15 s to apply the car brakes with a deceleration of 0.85 m s^{-2}. Calculate the distance he travelled during the time from when he saw the kangaroo to when he stopped. Did he hit the kangaroo?

[4 marks]

8. An archer on the wall of a building that is 45 m above the ground fires his arrow with a speed of 25 m s^{-1} vertically upwards so that it rises, momentarily stops and then falls down to the ground below the wall of the building.

(a) How long does it take the arrow to reach the ground?

[5 marks]

(b) With what velocity does the arrow strike the ground?

[3 marks]

9. A meteor of mass 115 kg hits the Earth and decelerates from 270 m s^{-1} to rest over a distance of 30.0 cm.

(a) What is the retarding force exerted by the Earth?

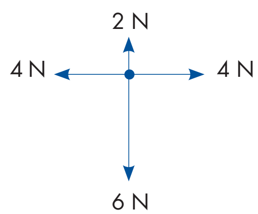
[4 marks]

(b) What work is expended?

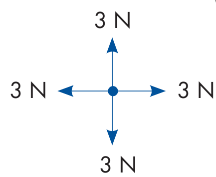
[1 mark]

10. Which object can be moving with a constant speed in a straight line if only the forces acting are those shown in the diagram?

(a)



(b)



(c)

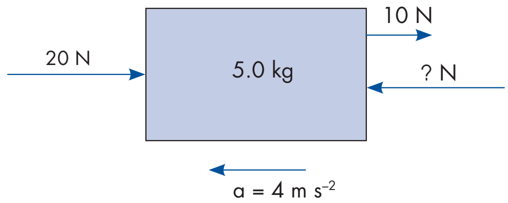
[1 mark]

11. A certain force, **F** will give a mass **m** an acceleration of **a** m s^{-2}.
Therefore, force **F** will give a mass of **2 m** an acceleration of

(a) 2**a** (b) **a** (c) $\frac{\mathbf{a}}{2}$ (d) $\frac{\mathbf{a}}{4}$

[1 mark]

12. Calculate the missing force in the diagram below:



[3 marks]

13. A 9.90 kg object resting on a horizontal surface has a horizontal force of 18.0 N applied to it. The frictional force is 4.00 N. Calculate the acceleration of the object.

[4 marks]

14. A lumberjack is exerting a force of 400 N on a rope so he can tow a large log along the ground. If the log pulls on the rope with a force also equal to 400 N, explain why the forces do not cancel each other out and why the log actually moves forward.

[3 marks]

15. A force of 500 N acts on an object of mass 3.00 kg, moving it 8.00 m from rest. Find:

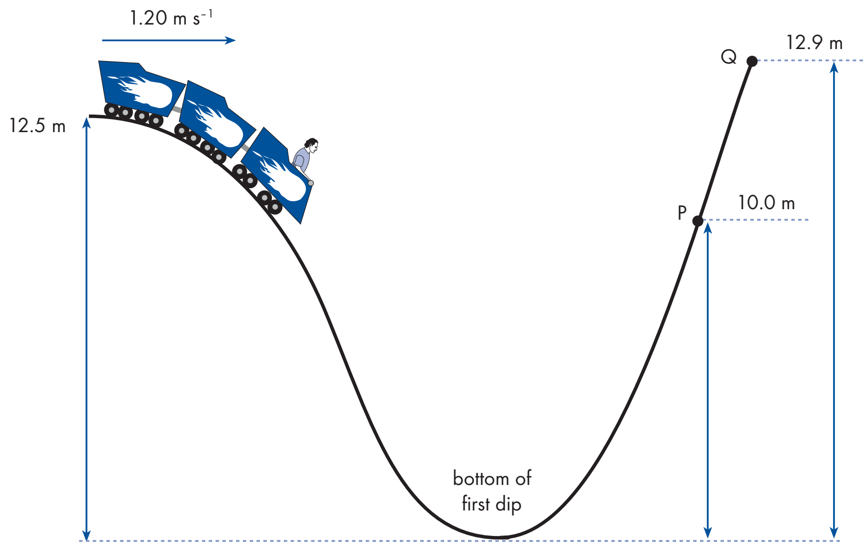
(a) the work done by the force

(b) the kinetic energy gained by the object

(c) the final velocity of the object.

[4 marks]

16. A roller coaster starts at the top of a ride with a speed of 1.20 m s^{-1}. The 3.00 tonne roller coaster then plummets 12.5 m down a steep incline as shown below:



Calculate (neglect friction throughout):

(a) the speed of the coaster at the bottom of the first dip

(b) the speed at point **P**

(c) the speed at point **Q**

[10 marks]

END OF TEST - TOTAL 90 MARKS

Trial Test 2: Electricity, Heating & Cooling, Nuclear Physics

Time allowed: 60 minutes
Total marks: 50

1. A circuit contains a 12.0 V cell, a 12.0 Ω resistor, a 24.0 Ω resistor connected in series, an ammeter measuring the circuit current and a voltmeter measuring the voltage drop across the 12.0 Ω resistor.

   Draw a diagram of electric circuit. Show polarity of the ammeter and voltmeter.

[3 marks]

2. Using the kinetic theory, explain why evaporation causes cooling.

[2 marks]

3. Using an example, describe a cooling effect produced from evaporation.

[2 marks]

4. Balance the following nuclear equations by identifying X:

(a) $_{92}U^{235}$ + $_{0}n^{1}$ → $_{56}Ba^{141}$ + $_{36}Kr^{92}$ + X (____________)

(b) $_{88}Ra^{226}$ → $_{86}Rn^{222}$ + X (_____)

(c) $_{82}Pb^{210}$ → $_{83}Bi^{210}$ + X (_____)

[3 marks]

5. A isotope has two more neutrons than protons and has a mass number ten times that of a alpha particle. How many protons and how many neutrons does the isotope have?

____

____

____

____

[2 marks]

6. (a) Use a diagram to show the arrangement of molecules in a solid, liquid and a gas.

[2 marks]

(b) Explain why, at the same temperature, liquids contain more internal energy than solids.

____

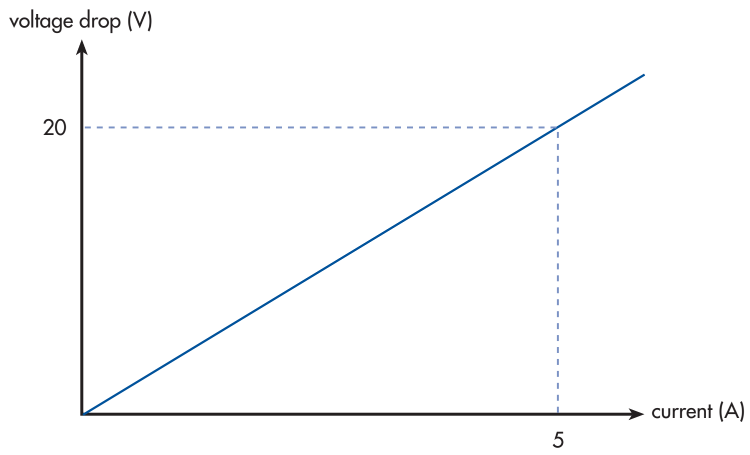
____

____

____

[2 marks]

7. Determine the resistance in a circuit where the voltage drop across the resistor and current through the resistor were measured and graphed as indicated below. Show any working.



[2 marks]

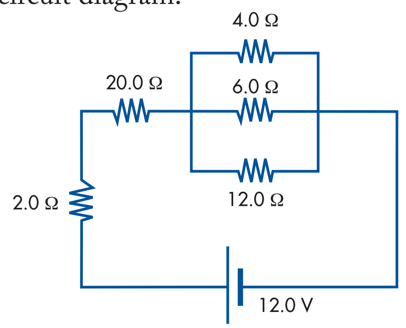
8. What is meant by the term ionising radiation? Which form of radiation causes the most ionising?

[2 marks]

9. Considering that the charge on one electron is -1.60 × 10^{-19} C, how many electrons are flowing past a point in a circuit that has a current of 5.00 A flowing for 2.00 hours?

[3 marks]

10. Consider the following circuit diagram:



(a) Circle the resistors connected in series. [1 mark]

(b) Put a rectangle around the resistors connected in parallel. [1 mark]

(c) Find the total resistance for series resistors.

[2 marks]

(d) Find the total resistance for the parallel resistors.

[2 marks]

(e) Find the total resistance for the circuit.

[1 mark]

(f) Find the circuit current.

[2 marks]

11. Explain each of the following:

(a) Car radiators are coloured black, consist of a thin metal with a large surface area and have a fan blowing on them.

Description	Explanation
Black coloured	
Thin metal with a large surface area	
Fan blowing on them	

[3 marks]

(b) Steam burns are more severe than boiling water burns.

[2 marks]

(c) Evaporative air conditioning works very well on a hot dry day but is less effective when the humidity is high.

[2 marks]

(d) Solar hot water systems are placed on north facing sloping roofs and have the cold water intake at the bottom and hot water outlets at the top of the black coloured copper heat collectors.

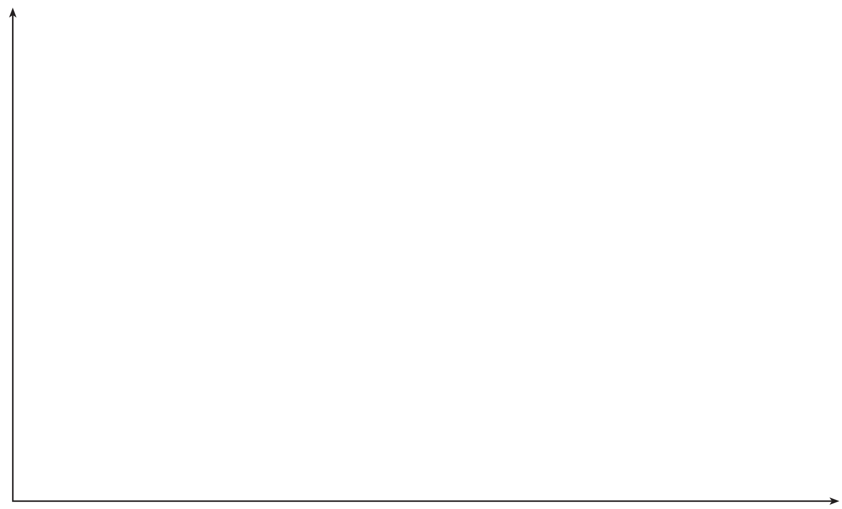
Description	Explanation
North facing **sloping** roof	
The cold water intake is at the **bottom**	
Hot water outlets at the **top**	
Black coloured **copper** heat collectors	

[4 marks]

12. A radioisotope has its radiation detected by a geiger counter over an hour. The recorded count rate is shown below:

Activity (Bq)	4000	2800	2000	1400	1000	700	500
Time (min)	0	10	20	30	40	50	60

(a) Plot a graph of activity versus time.



[2 marks]

(b) Use your graph to estimate the activity after 25 minutes.

____

[1 mark]

(c) Determine the half-life of the radioisotope from:

(i) the graph ______________________________

(ii) other means (e.g. the table) ______________________

[Show your reasoning]

[2 marks]

(d) If originally there was 50.0 g of the radioisotope, what mass remains after 2 hours?

____

____

[2 marks]

END OF TEST - TOTAL 50 MARKS

Checkpoint Answers

CHAPTER 1: PHYSICS FUNDAMENTALS

1.1

(a) $\frac{10000}{60} = 166.7\ min$

(b) $1\ Ms = 10^6\ s = \frac{10^6\ h}{60^2} = 277.8\ h$

$3\ ks = 3 \times 10^3\ s = \frac{3 \times 10^3}{(60)(60)(24)}$

$= 3.47 \times 10^{-2}\ days$

1.2

(a) $4.4\ km = 4.4 \times 10^3\ m$

$= (4.4 \times 10^3) \times 10^2\ cm$

$= 4.4 \times 10^5\ cm$

(b) $3.8 \times 10^{10} g = \frac{3.8 \times 10^{10}}{10^3}\ kg$

$= 3.8 \times 10^7\ kg$

$= (3.8 \times 10^4) \times 10^3\ kg$

$= 3.8 \times 10^4\ tonne$

(c) $0.00567\ mm = 0.00567 \times 10^{-3}\ m$

$= 5.67 \times 10^{-6}\ m$

(d) $7.2\ kWh = 7.2 \times (3.6 \times 10^6)\ J = 2.6 \times 10^7\ J$

(e) $761\ nm = 761 \times (10^{-9})\ m = 7.61 \times 10^{-7}\ m$

(f) $13\ pm = 13 \times (10^{-12})\ m = 13 \times 10^{-12} \times (10^9)\ nm = 1.3 \times 10^{-2}\ nm$

1.3

(a) $0.0008 = 8 \times 10^{-4}$

(b) $0.20321 = 2.0321 \times 10^{-1}$

(c) $29678 = 2.9678 \times 10^4$

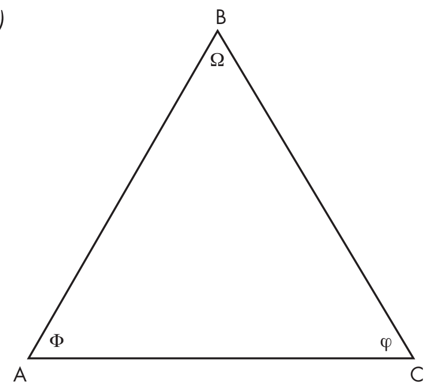
(d) $14 \times 10^3 = 1.4 \times 10^4$

(e) i) $Volume = (6.3)(12.1)(0.84) = 6.4 \times 10^1\ cm^3$

ii) $Volume = \frac{6.3}{10^2}\ m \times \frac{12.1}{10^2}\ m \times \frac{0.84}{10^2}\ m =$

$\frac{6.40 \times 10^1}{10^6}\ m^3 = 6.4 \times 10^{-5}\ m^3$

1.4 (a)



(b) $(AB)^2 = (AC)^2 + (BC)^2 - 2\,(AC)(BC)\cos\varphi$

$(BC)^2 = (AB)^2 + (AC)^2 - 2\,(AB)(AC)\cos\Phi$

$(AC)^2 = (AB)^2 + (BC)^2 - 2\,(AB)(BC)\cos\Omega$

(c) $\frac{\sin\Phi}{BC} = \frac{\sin\Omega}{AC} = \frac{\sin\varphi}{AB}$

1.5 $TW = \sqrt{(ST)^2 + (SW)^2 - 2(ST)(SW)\cos 30.0^o}$

$= \sqrt{(23.3)^2 + (9.8)^2 - 2(23.3)(9.8)\cos 30.0^o}$

$= 15.6$

$\frac{\sin(angle\ STW)}{9.8} = \frac{\sin(30.0^o)}{15.6}$

$\therefore$ $angle\ STW = \sin^{-1}(0.314\ldots) = 18.3^o$

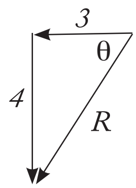
Since all the angles add up to 180°, the angle $TWS = 180^o - [30.0^o + 18.3^o]$

$= 131.7^o$

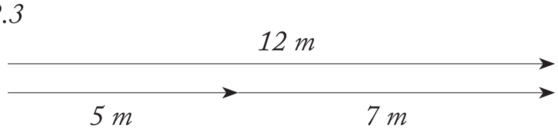
CHAPTER 2: MOTION

2.1 *Ans = (ii)*

2.2 *By Pythagoras,* $R = 5$ *and* $\theta = \tan^{-1}\left(\frac{4}{3}\right) = 53.1^o$
hence answer is (iii)

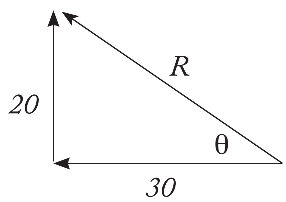


2.3



Hence angle = 180º, answer (v)

2.4

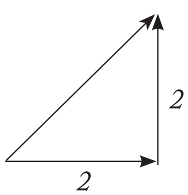


Resultant = 36 km h^{-1}
W33.7^o *N or N 56.3*^{o} *W*

2.5 *Horizontal Forces, nett force is 2 N to the right*

Vertical Forces, nett force = 2 N upwards

Therefore:

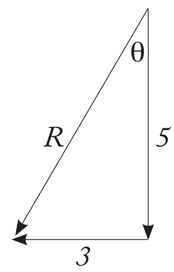


Answer is (ii).

2.6 $3\ m\ N - 4\ m\ N$
$= 3\ m\ N + 4\ m\ S$
$= 1\ m\ S$

2.7 $3\ m\ S - 4\ m\ N$
$= 3\ m\ S + 4\ m\ S$
$= 7\ m\ S$

2.8 $5.0\ m\ s^{-1}\ S - 3.0\ m\ s^{-1}\ E$
$= 5.0\ m\ s^{-1}\ S + 3.0\ m\ s^{-1}\ W$



$R = \sqrt{5^2 + 3^2} = 5.83$, $\theta = \tan^{-1}\left(\frac{3}{5}\right) = 31^o$

Answer: $5.83\ ms^{-1}$ *S 31*^{o} *W or W 59*^{o} *S*

2.9

$\Delta\mathbf{v} = \mathbf{v} - \mathbf{u} = 15\ m\ s^{-1}\ S - 40\ m\ s^{-1}\ S$
$= 15\ m\ s^{-1}\ S + 40\ m\ s^{-1}\ N$
$= 25\ m\ s^{-1}\ N$

2.10

$\Delta\mathbf{v} = \mathbf{v} - \mathbf{u} = (-35) - (25)$
if direction towards bat is taken to be positive
$= -60\ m\ s^{-1}$ *i.e. away from the bat*

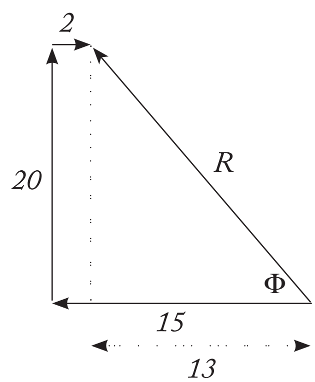
OR

$\Delta\mathbf{v} = \mathbf{v} - \mathbf{u} = (35) - (-25)$
if direction away from bat is taken to be positive
$= 60\ m\ s^{-1}$ *i.e. away from the bat*

2.11

(a) distance = 15 km + 20 km + 2 km = 37 km

(b)



$R = \sqrt{20^2 + 13^2} = 23.85$, $\Phi = \tan^{-1}\left(\frac{20}{13}\right) = 57^o$

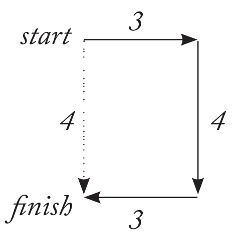
Answer: 23.85 km W 57^o *N or N 33*^{o} *W*

2.12

(a) $\text{average speed} = \dfrac{\text{total distance}}{\text{total time}} = \dfrac{3+4+3}{5+8+2}$

$= \left(\dfrac{10}{\frac{15}{60}}\right) = 40 \text{ km h}^{-1}$

(b) total displacement is shown below:



Answer = 4 km South.

$\text{Average velocity} = \dfrac{\text{total displacement}}{\text{total time}} = \dfrac{4 \text{ km}}{\frac{15}{60} \text{ hr}}$

$= 16 \text{ km h}^{-1}$

2.13

Non rest time total

$= 2 + 2 + 2 + 1.25 = 7.25 \text{ hrs}$

$\text{Total distance travelled} = 7.25 \times 4 = 29 \text{ km}$

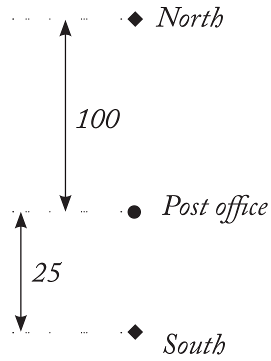
2.14

$\text{Average speed} = \dfrac{\text{total distance}}{\text{total time}}$

$= \dfrac{(15)(15) + (20)(15)}{30}$

$= 17.5 \text{ m s}^{-1}$

2.15



$\text{speed} = \dfrac{\text{distance}}{\text{time}}$

$\therefore \text{time} = \dfrac{\text{distance}}{\text{speed}} = \dfrac{(25+100)}{15} = 8.33 \text{ s}$

2.16

(a) $\text{speed} = \dfrac{\text{distance}}{\text{time}} = (0.5)\dfrac{2\pi r}{t} = \dfrac{\pi(36.0)}{18}$

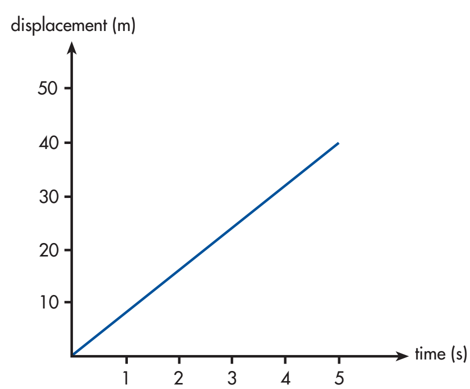
$= 6.28 \text{ m s}^{-1}$

(b) $\text{velocity} = \dfrac{\text{displacement}}{\text{time}} = \dfrac{72.0 \text{ m}}{18 \text{ s}}$

$= 4 \text{ m s}^{-1}$ from A to B

2.17 $v = \dfrac{40}{5} = 8 \text{ m s}^{-1}$

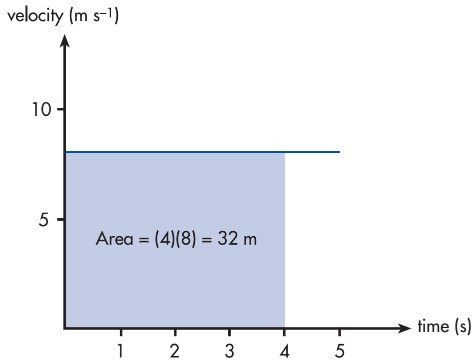
t	s (= vt)
0	0
1	8
2	16
3	24
4	32
5	40



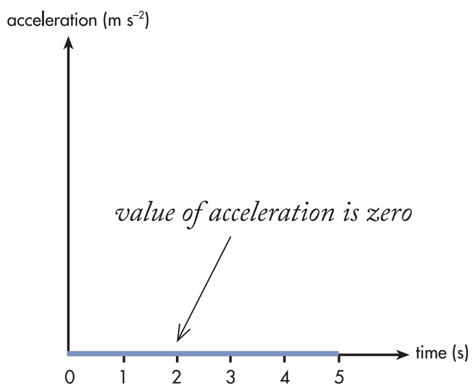
$\text{slope} = \dfrac{\text{rise}}{\text{run}} = \dfrac{40}{5} = 8 \text{ m s}^{-1}$

therefore velocity vs time graph is:

(a)



(b)



2.18

(a) $u = 0$ $\quad s = ?$
$t = 10$ $\quad v = ?$
$a = 3$

$s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(3)(10)^2$

$= 150\ m$

(b) $v = u + at$
$= 0 + (3)(10)$
$= 30\ m\ s^{-1}$

2.19

(a) $u = 0$ $\quad a = ?$
$t = 5$
$v = 30$

$a = \frac{v - u}{t}$

$= \frac{30 - 0}{5}$

$a = 6\ m\ s^{-2}$ *in direction of motion*

(b) $s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(6)(5)^2$

$= 75\ m$

OR rearrange

$v^2 = u^2 + 2as$ *to get s:*

$s = \frac{(v^2 - u^2)}{2a}$

$= \frac{(30^2 - 0)}{2(6)}$

$= 75\ m$

2.20 $u = 0$ $\quad s = ?$
$a = 9.8$ $\quad v = ?$
$t = 3$

(a) $s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(9.8)(3)^2$

$= 44.1\ m$

(b) $v = u + at$

$= 0 + (9.8)(3)$

$= 29.4\ m\ s^{-1}$

OR $v^2 = u^2 + 2as$

$\therefore v = \sqrt{0 + 2(9.8)(44.1)}$

$= 29.4\ m\ s^{-1}$

2.21 $u = 0$ $\quad t = ?$
$a = 9.8$

$s = 49000$

$s = ut + \frac{1}{2}at^2$

$49000 = 0 + \frac{1}{2}(9.8)(t)^2$

$\therefore$ $t = 100\ s$
(In this problem the initial downward vertical velocity is zero).

2.22

(a) *velocity = value of v at the end of the first three second interval*

$= u + at$
$= 0 + (12)(3)$
$= 36 \text{ m s}^{-1}$

(b) *maximum velocity will occur after (3 + 2 + 4) seconds from the beginning*

for the t = 4 s interval:

$u = 36 \text{ m s}^{-1}$ $v = ?$
$a = 6$
$t = 4$

$v = u + at$
$= 36 + (6)(4)$
$= 60 \text{ m s}^{-1}$

FIRST THREE SECONDS

time (s)	velocity (m s^{-1})
0	0
1	u + at = 0 + (12)(1) = 12
2	u + at = 0 + (12)(2) = 24
3	u + at =0 + (12)(3) = 36

NEXT TWO SECOND INTERVAL

t (s)	velocity (m s^{-1})
3	36
4	36
5	36

THIRD TIME INTERVAL

time (s)	velocity (m s^{-1})
5	36
6	u + at =36 +(6)(1)=42
7	u + at =36 +(6)(2)=48
8	u + at =36 +(6)(3)=54
9	u + at =36 +(6)(4)=60

LAST SIX SECONDS

Need to find the value of the deceleration (negative acceleration)

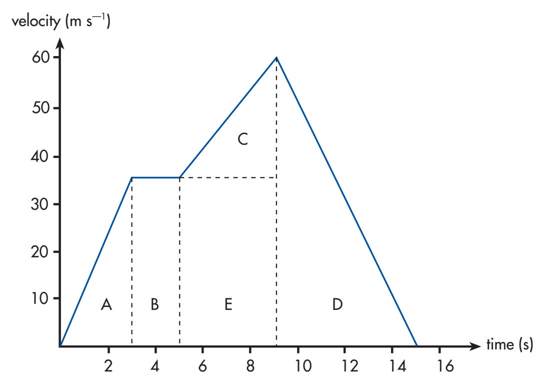
$u = 60$ $a = ?$
$t = 6$
$v = 0$

$$a = \left(\frac{v - u}{t}\right)$$
$$= \left(\frac{0 - 60}{6}\right)$$
$$= -10 \text{ m s}^{-2}$$

Therefore for the last six seconds:

time (s)	velocity (m s^{-1})
9	60
10	u + at =60 +(-10)(1) = 50
11	u + at =60 +(-10)(2) = 40
12	u + at =60+(-10)(3) = 30
13	u + at =60+(-10)(4) = 30
14	u + at =60 +(-10)(5) = 10
15	u + at =60 +(-10)(6) = 0

(c)



From the graph, distance = total area under shape

$= A + B + C + D + E$

$= \frac{1}{2}(3)(36) + (2)(36) + \frac{1}{2}(4)(60 - 36) +$

$\frac{1}{2}(6)(60) + (4)(36) = 498 \text{ m}$

Retardation = slope of last downhill section on the graph

$= \text{absolute value of } \dfrac{rise}{run}$

$= \dfrac{60}{6}$

$= 10\ m\ s^{-2}$ OR acceleration $= -\ 10\ m\ s^{-2}$

2.23.

(a) $u = 0$ $s = ?$

$a = 0.25$

$t = (2)(60) = 120$

$$s = ut + \frac{1}{2}at^2$$

$$= 0 + \frac{1}{2}(0.25)(120)^2$$

$$= 1800\ m$$

(b) $s = 1000\ m$ $v = ?$

$u = 0$

$a = 0.25$

$$v^2 = u^2 + 2as$$

$$v = \sqrt{0 + 2(0.25)(1000)}$$

$$= 22.36\ m\ s^{-1}$$

2.24 $s = 1.5\ km$ $t = ?$

$u = 360\ km\ h^{-1}$

$v = 0$

Need to first find a:

$$v^2 = u^2 + 2as$$

rearranging:

$$a = \frac{(v^2 - u^2)}{2s}$$

$$= \frac{0 - 360^2}{2(1.5)}$$

$$= -\ 4.32 \times 10^4\ km\ h^{-2}$$

(or 3.33 $m\ s^{-2}$ if converting all original quantities to $m\ s^{-1}$)

to find t: $t = \dfrac{(v - u)}{a}$

$$= \frac{0 - 360}{-4.32 \times 10^4}$$

$= 8.33 \times 10^{-3}\ h$ or $0.5\ min$ or $30\ s$

2.25 First 5.00 s

$u = 0$ $v = ?$

$t = 5.00$

$a = 3$

(a) $v = u + at = 0 + (3)(5.00)$

$= 15\ m\ s^{-1}$ North

(b) $u = 15\ m\ s^{-1}$ East

(assume plane changes direction instantly)

$v = ?$

$a = 4\ m\ s^{-2}$ East

$t = 7$

$$v = u + at$$

$$= 15 + 4(7)$$

$= 43\ m\ s^{-1}$ East

2.26 $a = 9.8$ $s = ?$

$u = 0$

$t = 4$

(a) $s = ut + \dfrac{1}{2}at^2$

$$= 0 + \frac{1}{2}(9.8)(4)^2$$

$$= 78.4\ m$$

(b) *After $t = 5$ s,*

$$s = ut + \frac{1}{2}at^2$$

$$= 0 + \frac{1}{2}(9.8)(5)^2$$

$$= 122.5\ m$$

(c) *In the 5th second,*

distance travelled = distance travelled after 5 s – distance travelled after 4 s

$$= 122.5 - 78.4$$

$$= 44.1\ m$$

(d) $s = 850$ $t = ?$
$u = 0$
$a = 9.8$

$$s = ut + \frac{1}{2}at^2$$

$$850 = 0 + \frac{1}{2}(9.8)(t)^2$$

$\therefore t = 13.2\ s$

(e) $u = 0$ $v = ?$
$a = 9.8$
$s = 850$

$$v^2 = u^2 + 2as$$

$$v = \sqrt{0 + 2(9.8)(850)}$$

$$= 129\ m\ s^{-1}$$

OR $v = u + at = 0 + 9.8(13.2)$

$$= 129\ m\ s^{-1}$$

2.27

(a) $p = mv = (0.5)(7) = 3.5\ kg\ m\ s^{-1}$ NNE

(b) $p = mv = (20 \times 10^{-3})(1 \times 10^{-3})$

$= 2 \times 10^{-5}\ kg\ m\ s^{-1}$ in direction of snail's motion

(c) $p = mv = (1.5 \times 10^3)(\dfrac{120 \times 10^3}{60^2})$

$= 5.0 \times 10^4\ kg\ m\ s^{-1}$ in direction of motion

2.28 $\Delta p = m\Delta v$

$= 0.45[22–0]\ kg\ m\ s^{-1}$ East

$= 9.9\ kg\ m\ s^{-1}$ East

2.29

$$p = m_{total}v$$

$= [45 + 75 + 2.1 \times 10^3](\dfrac{36 \times 10^3}{60^2})\ kg\ m\ s^{-1}$ West

$= 2.22 \times 10^4\ kg\ m\ s^{-1}$ West

2.30

(a) $v = \dfrac{p}{m} = \dfrac{90}{85} = 1.06\ m\ s^{-1}$ to the right

(b) $v = \dfrac{p}{m} = \dfrac{90}{0.45} = 200\ m\ s^{-1}$ to the right

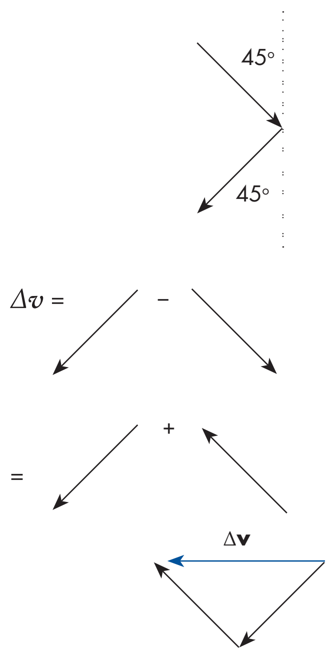
2.31

elephant	bullet
$p = mv$	$p = mv$
$= (2 \times 10^3)(0.85)$	$= (20 \times 10^{-3})(450)$
$= 1700\ kg\ m\ s^{-1}$ in direction of motion	$= 9\ kg\ m\ s^{-1}$ in direction of motion

Therefore the elephant has the greater momentum

2.32

Must first calculate Δv



$$\Delta v = \sqrt{900^2 + 900^2}$$

$= 1273\ m\ s^{-1}$ at 90° to the armour plated tank

therefore: $\Delta p = m\Delta v$

$= 0.250\ (1273)$

$= 318\ kg\ m\ s^{-1}$ at 90° to the surface of the armour plated tank

2.33 $m = \dfrac{\Delta p}{\Delta v}$

$= \dfrac{2.63 \times 10^3 \text{ kg m s}^{-1} \text{ upwards}}{18.0 \text{ m s}^{-1} \text{ upwards}}$

$= 146$ kg

2.34

$\Delta p = m\Delta v$

$= (3.80 \times 10^4 + 4.25 \times 10^3)(0 - \dfrac{70 \times 10^3}{60^2})$

$= -8.22 \times 10^5$ kg m s^{-1} southbound

$= 8.22 \times 10^5$ kg m s^{-1} northbound

CHAPTER 3: ELECTRICITY

3.1

Atomic particle	Proton	Neutron	Electron
Charge	+1	0	-1

3.2 The object must have gained electrons.

3.3 The object must have lost electrons.

3.4 When the person touches the dome, electrons from the person move to the dome, i.e. the person gains a positive charge. Charge accumulates on the outside of the person, i.e. it accumulates on their hair. Hair is fine and light and since like charges repel, hair tends to stand up.

3.5 Like charges repel, unlike charges attract.

3.6 Static electricity is electric charge at rest or nearly at rest. Current electricity is a flow of charge (electrons usually) in a conductor.

3.7 (a) $\dfrac{20.0}{1000} = 0.0200$ A

(b) $\dfrac{37.8}{1000000} = 0.0000378$ A

$= (3.78 \times 10^{-5}$ A$)$

(c) $1.5 \times 24 \times 60 \times 60 = 1.3 \times 10^5$ s

(d) $0.0935 \times 1000 = 93.5$ A

3.8 The light would glow brighter OR the globe would 'blow' if the current was too large.

3.9 t = 30.0 minutes = 30×60 = 1800 s
q = 18,000 C

$I = \dfrac{q}{t} = \dfrac{18000}{1800} = 10.0$ A

3.10 I = 25.0 mA = .025 A

t = 10.0 min = 10×60 = 600 s

$q = It = .025 \times 600 = 15$ C

electrons $= \dfrac{q}{1.60 \times 10^{-19}}$

$= \dfrac{15}{1.60 \times 10^{-19}}$

$= 9.38 \times 10^{19}$

3.11

(a) **Resistance:** Restricts the flow of current through a circuit.

(b) **Voltage:** A voltage drop is needed across a resistor to make electrons flow through the resistor. Voltage is supplied by a battery (power pack etc) to provide electrical energy to a circuit.

(c) **Current:** The rate of flow of charge in a conductor.

3.12 **Ohm's Law:** The ratio of the potential drop across a resistor to the current flowing through the resistor is a constant.

3.13

(a) **Battery (or cell):** Provides the electrical energy to move electrons through the circuit.

(b) **Wiring:** Provides a conducting path for electrons to flow through.

(c) **Switch:** Allows the flow of electrons to start or stop.

(d) **A light globe:** The light globe has resistance that produces heat (and therefore light) as electrons move through it.

3.14 *Voltage* ***drops*** *wherever there is resistance, Current* ***flows*** *through the resistance.*

3.15 $R = 267\ \Omega$

$I = 22.9\ A$

$PD\ (V) = ?$

$$V = IR = 22.9 \times 267 = 6.11 \times 10^3\ V$$

3.16 $R = 39.5\ \Omega$

$PD\ (V) = 29.5\ V$

$I = ?$

$$I = \frac{V}{R} = \frac{29.5}{39.5} = 0.747\ A$$

3.17 *[Ohm's Law still applies for AC]*

$PD\ (V) = 240\ V$

$I = 100\ mA = 0.100\ A$

$R = ?$

$$R = \frac{V}{I} = \frac{240}{0.100} = 2.40 \times 10^3\ \Omega$$

3.18

(a) $R = 500\ m\Omega = 0.500\ \Omega$

$I = 10.0\ A$

$PD\ (V) = ?$

$$V = IR = 10.0 \times 0.500 = 5.00\ V$$

(b) *There is 240 V supplied by mains power but there is a voltage drop across the long extension cord of 5.00 V. Therefore, there is 235 V left to drop across the drill to make it operate.*

[EMF (mains) = Σ voltage drop in a circuit.
240 = 5 + voltage drop across the drill]

3.19

(a) $R_T = R_1 + R_2 + R_3 = 10.0 + 10.0 + 10.0 = 30.0\ \Omega$

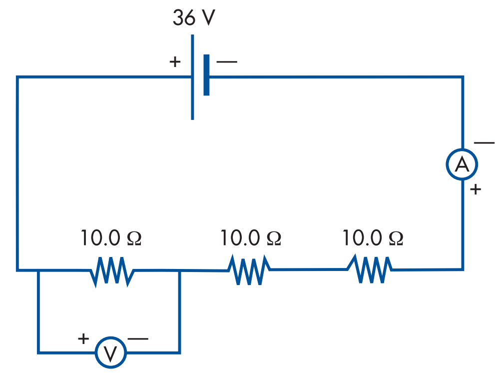
(b) $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10} + \frac{1}{10} + \frac{1}{10} = \frac{3}{10}$$

$R_T = 3.33\ \Omega$

3.20 *Because the series circuit has a larger resistance, it will have a smaller current flowing through it.*

$[I = \frac{V}{R}]$

3.21



3.22

$R_1 = 10.0\ \Omega$

$R_T = 5.00\ \Omega$

$R_2 = ?$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_2} = \frac{1}{R_T} - \frac{1}{R_1} = \frac{1}{5.00} - \frac{1}{10.0}$$

$$\frac{1}{R_2} = \frac{1}{10.0}$$

$R_2 = 10.0\ \Omega$

CHAPTER 4: HEATING AND COOLING

4.1

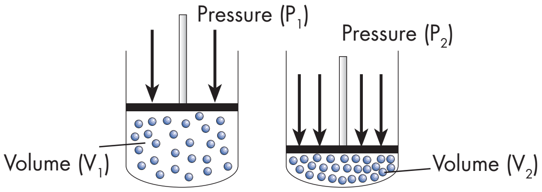
(a) *melting*
(b) *boiling/evaporation*
(c) *condensing*
(d) *solidifying*

4.2 *Gases have the most energy because it requires energy to change a solid to a liquid and to change a liquid to a gas. Gases possess large amounts of potential energy.*

4.3 *Solid particles are relatively close together and have relatively strong attractive forces between them. They do not have sufficient kinetic energy to break away from the rigid structure present in a solid.*

4.4

(a) If a gas is compressed, the particles become closer together and will collide with the sides of the container more frequently and hence pressure will increase.



(b) If temperature increases, the average kinetic energy of the particles will also rise. This means that the particles are travelling faster and will collide with the sides of the container more often and with more force creating higher pressure.

4.5 Heat is a form of energy because it can be used to do work. It can be transformed into other forms of energy, e.g. a steam engine transforms heat to kinetic energy or a kettle transforms electrical energy → heat energy.

4.6 Particles in a solid are very close together and have relatively large attractive forces between them. Hence these particles are not free to translate except as the temperature approaches MP.

4.7

(a) Gaseous molecules are very separated from each other whereas liquid molecules are relatively close together. Lots of energy must be supplied to a liquid at its BP to convert it into a gas. The extra energy given to the liquid molecules is potential energy.

(b) A burn from gaseous water is far more severe since the gaseous water molecules have far more internal heat – lots of energy must be supplied to a liquid at its BP to convert it into a gas. Hence the gas can transfer more energy to the object it is in touch with – like your hand.

4.8 Gases may have:

(a) vibrational energy – molecules vibrate about a fixed spot.

(b) rotational energy – molecules can spin like a top.

(c) translational energy – molecules can move from one place to another.

4.9 Solar energy (in the form of visible light) → stored chemical energy (the wood) → heat, light and some sound as the wood burns.

4.10

(a) Heat is defined as the energy that is transferred between objects of different temperature. Heat is measured in Joules (J).

(b) The sum of the kinetic and potential energy of all particles in an object is called the Internal Energy.

4.11

$m = 1 \text{ tonne} = 1000 \text{ kg}$

$v = 175 \text{ km h}^{-1} = \dfrac{175}{3.6} = 48.6....\text{m s}^{-1}$

Heat energy $= 0.653 \times E_k = 0.653 \times \frac{1}{2} \times mv^2$

$= 0.653 \times \frac{1}{2} \times 1000 \times (48.6...)^2 = 7.72 \times 10^5 \text{ J}$

4.12 Temperature is a measure of how hot an object is. Temperature (in Kelvin) is proportional to the average kinetic energy of the particles in a body. Heat is the energy transferred from a hot object to a cooler object.

4.13 (a) 25°C = 298 K (b) –25°C = 248 K
(c) –250°C = 23 K

4.14 Temperature is proportional to the average kinetic energy. If the temperature is 0 K (zero Kelvin) the average kinetic energy must also be zero, i.e. there is no motion.

4.15 The meat/gravy has a much higher specific heat (due to the water content). This means that it has a much higher heat content than the pastry and hence will stay hotter for longer.

4.16 Water has a high specific heat and it requires a relatively large amount of energy to increase the temperature of water. Money can be saved in two ways:

a) the water itself costs money

b) the heating of the water costs money.

Therefore if you have short showers you will save some money.

4.17

(a) As heat is applied to water at 0°C, the molecules will gain kinetic energy and hence move faster and increase in temperature up to 100°C. There is an increase in the kinetic energy but the potential energy is constant.

(b) When the temperature reaches 100°C, the applied heat energy is used to separate the molecules to change the liquid into a gas. There is an increase in the potential energy but the kinetic energy is constant.

4.18 At a phase change, all the applied heat is used to separate the molecules further apart. This means that the potential energy increases but the kinetic energy stays constant. If kinetic energy is constant, so is the temperature.

4.19 At a phase change, all the applied heat is used to separate the molecules further apart. The basic difference between the different phase is the distance of separation between the molecules. Greater separation between molecules means higher potential energy. This means that the potential energy increases but the kinetic energy stays constant.

4.20 The phase change from liquid to gas requires that the molecules are separated by a relatively large amount compared to the separation that occurs during the solid to liquid phase change. Hence far more energy (about ten times more) is required for this phase change.

4.21 Both boiling and evaporation are a phase change from liquid to gas but boiling only occurs at the BP and occurs anywhere within the liquid. Evaporation occurs at any temperature but only at the surface of a liquid.

4.22 Only the most energetic water molecules have sufficient energy to leave the liquid phase and enter the gaseous phase. If the most energetic water molecules are removed the average kinetic energy of the remaining molecules must be less. If average kinetic energy is less, temperature must be reduced.

4.23 Evaporation causes cooling. The blowing breeze increases evaporation by removing gaseous water molecules from around your body to allow more energetic liquid water molecules to undergo the phase change. Heat from your body helps water molecules make the change. Heat is therefore removed from your body at an increasing rate when there is a breeze blowing and you feel cool.

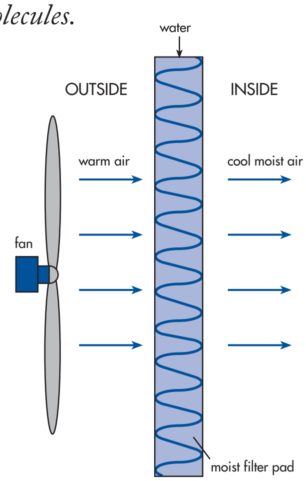
4.24

(a) Spread the towel out by hanging on a line (increases the surface area).

(b) Place in warm/hot place like in the sun (increases the temperature).

(c) Put in a windy place (this removes the layer of gaseous water molecules from around the towel and allows the liquid to gas phase change occur more readily).

4.25 Hot air is blown through a moist pad. Some of the water evaporates and cools the air. The cool air is filtered and blown into a house to cause cooling. These air conditioners are very effective in dry climates but are less effective where humidity is high because less evaporation occurs when the air is already laden with water molecules.

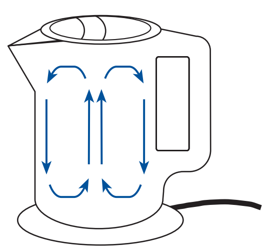


4.26

1. (a) Conduction
(b) Conduction and convection
(c) Radiation

2. (a) Conduction
(b) Convection
(c) Conduction and radiation.

4.27 The heating element is at the bottom of the kettle because the heat transfer method in fluids is convection. Water around the element is heated by conduction but this heated water expands, becomes less dense and rises. Cooler water at the top of the kettle falls and, in turn, is heated by the element.



4.28

Feature	Explanation
Black	Radiates more heat to cool quicker
Large surface area	Radiates more heat to cool quicker
Copper metal	Conducts heats to the surroundings to cool quicker.

4.29 *The bandit would be hotter than the surrounding bush and would therefore radiate infra-red radiation that could be detected by the camera.*

4.30 (a) *insulation in ceilings and walls*
(b) *window covering (curtains/blinds)*
(c) *double glazing windows*
(d) *thick concrete slab that the house is built on.*
(e) *carpet or floor coverings.*

CHAPTER 5: NUCLEAR PHYSICS

5.1 *Most of the alpha particles passed through unaffected by any matter. For this to occur, most of the atom must be empty space.*

5.2 *Some of the alpha particles were deflected or reflected. The core must be positive to cause the positively charged alpha particles to behave in this way.*

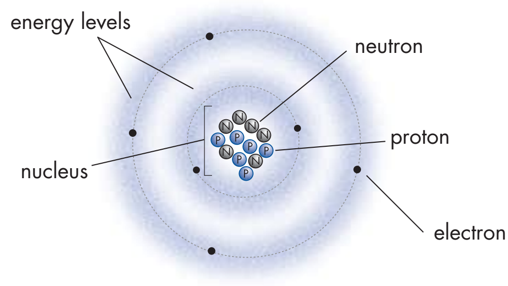
5.3

Isotope	$_{1}H^{1}$	$_{12}Mg^{24}$	$_{88}Ra^{226}$
Number of protons (Z)	1	12	88
Number of protons + neutrons (A)	1	24	226
Number of neutrons	0	12	138

5.4

Particle	Relative Mass	Relative Charge
electron	1/1840	-1
proton	1	+1
neutron	1	0

5.5



5.6 *When the electrostatic repulsion between protons is greater than attractions between the nucleons, the nuclear material rearranges itself by emitting radiation and therefore being radioactive.*

5.7

Property	Radiation
strongest ioniser	alpha
Undeflected by an electric or magnetic field	gamma
Highest mass	alpha
Greatest charge	alpha
Highest charge/mass ratio	beta
Most penetrating	gamma
Least penetrating	alpha

5.8
(a) $_{6}C^{12}$ (b) $_{7}N^{13}$ (c) $_{-1}e^{0}$

(d) $_{84}Po^{218}$ (e) $_{-1}e^{0}$

5.9 *In beta decay, a neutron turns into a proton and releases an electron.*

$$_{0}n^{1} \rightarrow {}_{1}H^{1} + {}_{-1}e^{0}$$

5.10

# Half lives	Time	%	Activity
0	0	100%	720
1		50%	360
2		25%	180
3		12.5%	90
4	8 min	6.25%	45

$4 \times T_{½} = 8$ *min, therefore* $T_{½} = 2.00$ *min*

5.11

# Half lives	Time	Fraction
0	0	1/1
1		1/2
2		1/4
3		1/8
4		1/16
5	40	1/32

$5 \times T_{½} = 40$ s, therefore $T_{½} = 8.00$ s

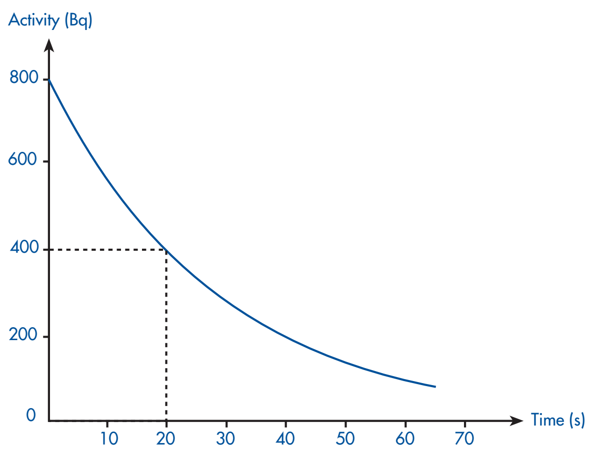
5.12

# Half lives	Time	Activity (counts min^{-1})
0	0	18.4
1		9.2
2		4.6
3		2.3

$3 \times T_{½} = 3 \times 5730 = 17190 = 1.72 \times 10^4$ years

5.13

(i)



(ii) $T_{½} = 20.0$ s

5.14 *Fission is the splitting of heavy nuclei into roughly equal parts achieved by neutron collision. Fusion is the joining together of light nuclei to form a heavier nuclei. Both nuclear reactions produce large amounts of energy.*

5.15 ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1$ (Fusion)

5.16 *In a chain reaction, some neutrons escape through the surface of the radioactive material and some do not have the right energy to cause fission. Therefore extra neutrons are needed to sustain the reaction.*

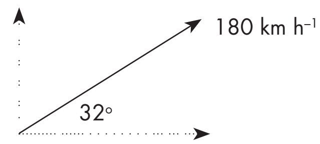
Review Question Answers

CHAPTER 1: PHYSICS FUNDAMENTALS

No Review Questions.

CHAPTER 2: MOTION

1.



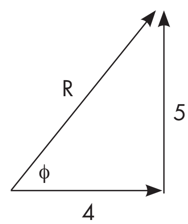
Vertical component $= 180 \cos 58^{\circ} = 95.38$

Since speed $= \dfrac{\textit{distance}}{\textit{time}}$

Then time $= \dfrac{\textit{distance vertically upwards}}{\textit{speed vertically upwards}}$

$= \dfrac{1\ km}{95.38\ km\ h^{-1}} = 1.05 \times 10^{-2}\ h = 37.7\ s$

2.

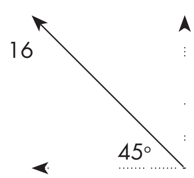


$R = \sqrt{4^2 + 5^2}$

$= 6.40, \quad \phi = \tan^{-1}\left(\frac{5}{4}\right) = 51.3^{\circ}$

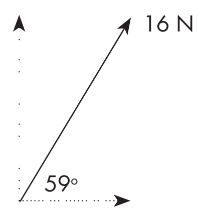
Answer: 6.4 N at an angle of ϕ *as shown.*

3.



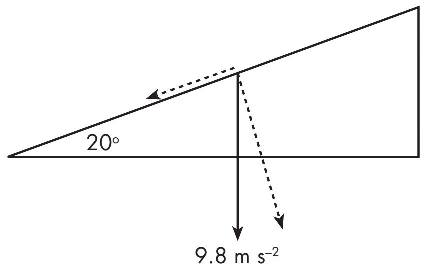
northerly component $= 16 \cos 45^{\circ} = 11.3\ m\ s^{-1}$

4.



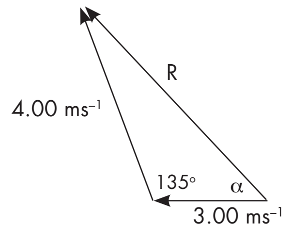
horizontal component $= 16 \cos 59^{\circ} = 8.24\ N$

5.



acceleration down incline $= 9.8 \cos 70^{\circ} = 3.35\ m\ s^{-2}$

6.



$R = \sqrt{3.00^2 + 4.00^2 - 2(3.00)(4.00)\cos 135^{\circ}} = 6.48$

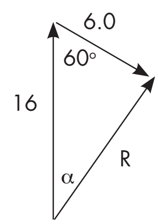
To find α

$= \dfrac{\sin \alpha}{4.00} = \dfrac{\sin 135^{\circ}}{6.48}$

$\alpha = 25.9^{\circ}$

Answer: 6.48 $m\ s^{-1}$ *inclined at* 25.9° *to the 3.00* $m\ s^{-1}$ *vector as shown.*

7.



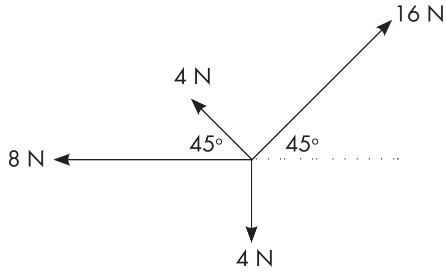
$R = \sqrt{16^2 + 6^2 - 2(16)(6)\cos 60^{\circ}} = 14$

and $\dfrac{\sin \alpha}{6.0} = \dfrac{\sin 60^{\circ}}{14}$

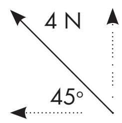
$\therefore \sin^{-1}(0.371\ldots) = 21.8^{\circ}$

Answer: 14 $km\ h^{-1}$ *N* 21.8° *E or E* 68.2° *N*

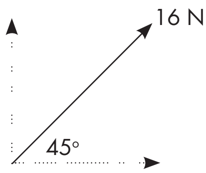
8.



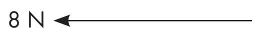
Consider each of the vectors separately:



(i) horizontal component left = 4 cos 45° = 2.83 N
(ii) vertical component upwards = 4 cos 45° = 2.83 N



(iii) upwards vertical component =16 cos 45°= 11.3 N
(iv) horizontal component right = 16 cos 45° = 11.3 N



(v) has only itself acting to the left = 8 N

(vi) has only itself acting vertically downwards = 4 N

Σ(horizontal components left) = (i) + (v) = 2.83 + 8 = 10.83 N
Σ(horizontal components right) = (iv) = 11.3 N

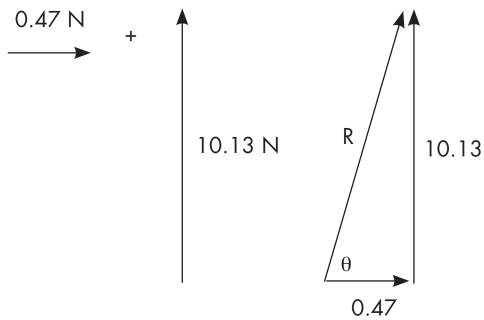
(vii) Nett vector horizontally =(11.3-10.83)= 0.47 N to the right

Similarly:

Σ(vertical components upwards) = (ii) + (iii) = 2.83 + 11.3 = 14.13 N
Σ(vertical components downwards) = (vi) = 4 N

(viii) Therefore nett vector acting vertically = (14.13 – 4) = 10.13 N upwards

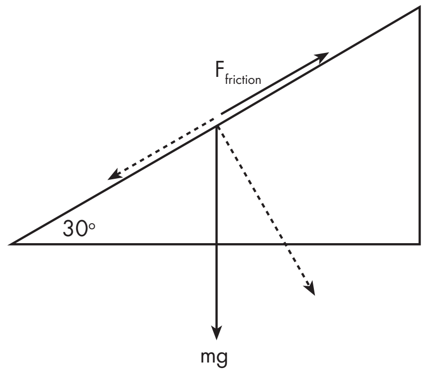
The entire problem simplifies to finding the vector sum of:



$R = \sqrt{0.47^2 + 10.13^2} = 10.14$ *and* $\theta = \tan^{-1}\left(\frac{10.13}{0.47}\right) = 87.3°$

Answer: 10.14 N E 87.3° N or N 2.7° E

9.

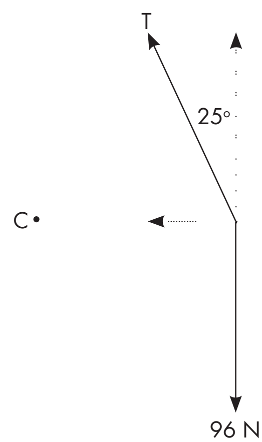


$F_{friction}$ = *same magnitude as the component of the weight force down and parallel to the incline*

= mg cos 60°
= 0.5 mg

Answer: Frictional force is half the car's weight

10.



Component of tension that acts towards the centre C = T cos 65°

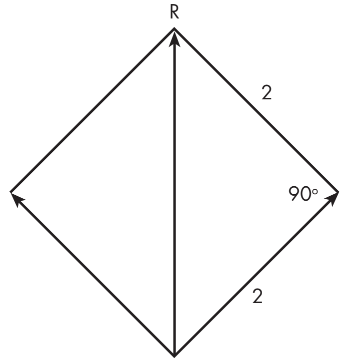
It is necessary to first find T:

The upwards component of T is exactly balanced by the object's weight

$\therefore\ T\cos 25^o = 96$
$\therefore\ T = 105.9$

hence $T\cos 65^o = 105.9\cos 65^o = 44.8\ N$

11.



$R = \sqrt{2^2 + 2^2} = 2.83\ N$
R acts directly upwards,
hence $F = 2.83\ N$ *acting downwards*

12.
(a) *weight* $= m_{total}g = 100(9.8) = 980\ N$ *acting towards Earth's centre*

(b) *at terminal velocity, nett force = 0*
therefore force of air resistance = weight force = 980 N

(c) $u = 50$ $a = ?$
$v = 5$
$t = 2$

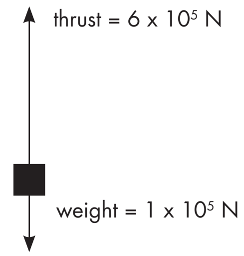
$$a = \frac{v-u}{t} = \frac{5-50}{2} = -22.5\ m\ s^{-2}$$

therefore deceleration $= 22.5\ m\ s^{-2}$

(d) *Since* $a = -22.5\ m\ s^{-2}$,
$F_{nett} = ma$
$= (100)(-22.5)$
$= -2.25 \times 10^3\ N$

Resultant force on parachutist $= 2.25 \times 10^3\ N$ *acting vertically upwards*

13.



(a) $m = \dfrac{weight}{g} = \dfrac{1 \times 10^5}{9.8} = 1.02 \times 10^4\ kg$

(b) $F_{nett} = (6 \times 10^5) - (1 \times 10^5) = 5 \times 10^5\ N$ *acting upwards*

(c) $a = \dfrac{F_{nett}}{m} = \dfrac{5 \times 10^5}{1.02 \times 10^4} = 49\ m\ s^{-2}$

(d) *If thrust is constant, acceleration will increase since there is a mass loss due to combustion of liquid fuel.*

14. $m = 6$ $F = ?$
$t = 60$ $a = ?$
$u = 0$
$v = 1$

First find a :

$$a = \frac{v-u}{t} = \frac{1-0}{60} = 1.66\ldots \times 10^{-2}\ m\ s^{-2}$$

Therefore $F = ma = (6)(1.66.. \times 10^{-2}) = 0.1\ N$ *in direction of motion*

15. $u = 0$ $s = ?$
$F_{nett} = 1$ $a = ?$
$t = 60$
$m = 2$

First find a :

$$a = \frac{F_{nett}}{m} = \frac{1}{2} = 0.5\ m\ s^{-2}$$

then $s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(0.5)(60)^2$

$= 900\ m$

16. $F_{nett} = 270$ $a = ?$
$m = 1.5$ $v = ?$
$t = 5$ $s = ?$
$u = 0$

(a) $a = \frac{F_{nett}}{m} = \frac{270}{1.5} = 180 \text{ m s}^{-2}$

(b) $v = u + at$

$= 0 + (180)(5)$

$= 900 \text{ m s}^{-1}$

(c) After $t = 5$ s,

$s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(180)(5)^2$

$= 2250 \text{ m}$

17. $F_{nett} = 6$ $a = ?$
$m = 5$

$a = \frac{F_{nett}}{m} = \frac{6}{5} = 1.2 \text{ m s}^{-2}$

18. $F_{nett} = 18$ $a = ?$
$m = 5$

If the nett force is tripled, so is the acceleration, since $a \propto F_{nett}$

OR $a = \frac{F_{nett}}{m} = \frac{18}{5} = 3.6 \text{ m s}^{-2}$

19. $F_{nett} = 10 - \frac{19.8}{100}(10) = 8.02 \text{ N}$

$m = ?$
$a = 0.22$

$m = \frac{F_{nett}}{a} = \frac{8.02}{0.22} = 36.45 \text{ kg}$

20. $u = 10 \text{ cm s}^{-1}$ North $= 0.1 \text{ m s}^{-1}$ North
$v = 15 \text{ cm s}^{-1}$ North $= 0.15 \text{ m s}^{-1}$ North

$m = 0.240 \text{ kg}$ $F = ?$
$t = 6.0 \text{ s}$

$F = ma$
$= 0.240\left(\frac{v - u}{t}\right)$
$= \frac{0.240(0.15 - 0.1)}{6.0}$
$= 2.00 \times 10^{-3} \text{ N}$ North

21. Since $a = 0$, then $F_{nett} = 0$

22. $u = 0$

$F_{nett} = 85 - \frac{1}{10}(mg)$

$= 85 - \frac{1}{10}(17 \times 9.8)$

$= 68.34 \text{ N}$

$m = 17$

For the first 6 s: $a = \frac{F_{nett}}{m} = \frac{68.34}{17} = 4.02 \text{ m s}^{-2}$

$s = ut + \frac{1}{2}at^2$

$= 0 + \frac{1}{2}(4.02)(6)^2$

$= 72.36 \text{ m}$

The velocity acquired after $t = 6$ s is given by:

$v = u + at$
$= 0 + 4.02(6)$
$= 24.12 \text{ m s}^{-1}$

In the next 4 s, $a = 0$

Therefore must use formula : $s = vt$
$= 24.12(4)$
$= 96.48 \text{ m}$

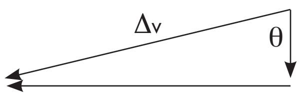
Total distance travelled in $t = 10$ s is :

$72.36 + 96.48 = 168.84 \text{ m}$

23. $m = 2 \times 10^{-3}$ $\quad F_{nett} = ?$
$u = 4.0\ m\ s^{-1}$ East
$v = 0.9\ m\ s^{-1}$ South

$v - u =$ 

$=$ 

$=$ 

$\theta = tan^{-1}\left(\frac{4}{0.9}\right) = 77.3^o$

Therefore $\Delta v = \sqrt{0.9^2 + 4^2} = 4.1\ m\ s^{-1}$ S 77.3^o W

$F_{nett} = \frac{m\Delta v}{t}$

$= \frac{(2 \times 10^{-3})(4.1)}{2.0}$

$= 4.1 \times 10^{-3}$ N acting S 77.3^o W

24. $m = 950$ $\quad v = ?$
$u = 16.5$ $\quad a = ?$
$t = 0.025$

$F_{nett} = -2.25 \times 10^5$

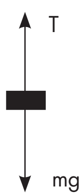
First find a: $a = \frac{F_{nett}}{m} = \frac{-2.25 \times 10^5}{950}$

$= -2.368 \times 10^2\ m\ s^{-2}$ (car decelerates)

$\therefore\ v = u + at$

$= 16.5 + (-2.368 \times 10^2)(0.025)$

$= 10.6\ m\ s^{-1}$

25. 

$T = mg = weight = 147\ N$

$m = \frac{weight}{g} = \frac{147}{9.8} = 15\ kg$

26. ΔEk = work done = Fs

$\therefore\ (\frac{1}{2}mv^2 - 0) = Fs$

$\therefore\ [\frac{1}{2}(4.0)v^2 - 0] = (20)(2.5)$

$\therefore\ v = 5.0\ m\ s^{-1}$ in direction of the force

27. $u = 0.5$ $\quad s = ?$
$v = -2.0$ $\quad a = ?$
$F = -10$
$m = 2.5$

First find a : $a = \frac{F}{m} = \frac{-10}{2.5} = -4\ m\ s^{-2}$

Use $v^2 = u^2 + 2as$ and rearrange to find s :

$s = \frac{v^2 - u^2}{2a}$

$= \frac{(-2.0)^2 - (0.5)^2}{2(-4)}$

$= -0.47\ m$ i.e. 0.47 m in the direction of the applied retarding force

28.
(a) $m = 90$
$u = 9$
$v = 0$
$s = 10$

$|\Delta E_k| = |\frac{1}{2}m(0)^2 - \frac{1}{2}m(9)^2|$

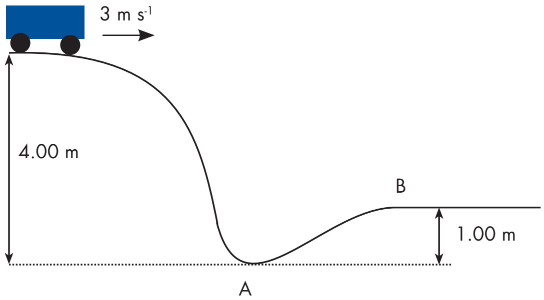
$= \frac{1}{2}(90)(9)^2$

$= 3.645 \times 10^3\ J$

(b) ΔE_k = work done = $3.645 \times 10^3\ J$

(c) therefore $F = \frac{W}{s} = \frac{3645}{10} = 364.5\ N$

29.
(a)



At the top of the hill:

$E_{total} = E_p + E_k$

$= mgh + \frac{1}{2}mv^2$

$= (4)(9.8)(4) + \frac{1}{2}(4)(3)^2$

$= 174.8\ J$

At A: E_p *loss* $= mgh$
$= (4)(9.8)(4)$
$= 156.8\ J$

(b) *Also at A:* $E_{total} = 174.8\ J$ *since energy is conserved and* $E_p = 0$

$\therefore E_k = 174.8\ J$

(c) E_p *gain* $= mgh$
$= (4)(9.8)(1.00)$
$= 39.2\ J$

(d) *At B,* $E_{total} = 174.8\ J$ *and* $E_p = 39.2\ J$

$\therefore E_k = 174.8 - 39.2 = 135.6\ J$

i.e. $\frac{1}{2}mv^2 = 135.6$

$\therefore \frac{1}{2}(4)(v)^2 = 135.6$

$\therefore v = 8.23\ m\ s^{-1}$

The assumption made was that air resistance was negligible.

30. *Loss in* E_p = *Work done*

$\therefore mgh = 1.30 \times 10^4$

$\therefore h = \dfrac{1.30 \times 10^4}{(2 \times 10^2)(9.8)} = 6.63\ m$

31. E_p *gain* $= E_k$ *loss*

$\therefore mgh = E_k$ *loss*

$\therefore (70)(9.8)(6.0 - 0.9) = E_k$ *loss*

$\therefore 3.498... \times 10^3\ J = E_k$ *loss*

$\therefore \frac{1}{2}(m)(v)^2 = 3.498\ldots \times 10^3$

$\therefore (35)(v)^2 = 3.498\ldots \times 10^3$

$\therefore v = 10.0\ m\ s^{-1}$

32. *At A,* $E_P = mgh$

$= (4)(9.8)(23) = 901.6\ J$

$E_k = 0$ *(momentarily stationary)*

$E_{total} = 901.6\ J$

At B, $E_P = mgh$
$= (4)(9.8)(20)$
$= 784\ J$

$E_{total} = 901.6\ J$

$\therefore E_k = 901.6 - 784 = 117.6\ J$

At C, $E_P = 0$

$\therefore E_k = E_{total} = 901.6\ J$

33. E_k *loss* $= E_P$ *gain*

$\therefore \frac{1}{2}(m)(v)^2 = mgh$

$\therefore \frac{1}{2}(5.0 + 0.01)(0.1996)^2 = (5.0 + 0.01)(9.8)\ h$

$\therefore \frac{1}{2}(0.1996)^2 = (9.8)\ h$ *(the mass cancels out)*

$\therefore h = \dfrac{0.5(0.1996)^2}{9.8} = 2.03 \times 10^{-3}\ m$

(or 2.03 mm)

CHAPTER 3: ELECTRICITY

1.

(a) $\# \text{ electrons} = \dfrac{q}{1.60 \times 10^{-19}} = \dfrac{4.00}{1.60 \times 10^{-19}}$

$= 2.50 \times 10^{19}$

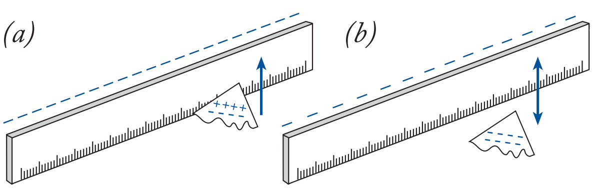
(b) $q = 4.00\ C$
$t = 5.00\ s$
$I = ?$

$$I = \frac{q}{t} = \frac{4.00}{5.00} = 0.800\ A$$

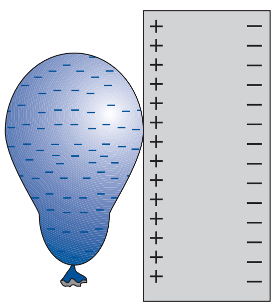
2.

(a) *The charged ruler induces an opposite charge (positive) on the surface of the paper nearest the ruler. Attraction between opposite charges results (see (a) below).*

(b) *While the paper is in contact with the ruler some negative charges from the ruler transfer to the paper. Repulsion between like charges results (see (b) below).*



3.



4. $t = \dfrac{q}{t} = \dfrac{14.2}{1.50} = 9.47\ s$

5.

(a) *Opposite charges attract each other.*

(b) *The opposite charges will cancel each other but there will be an excess of – 2.00 nC which will distribute over the 2 spheres. The charges redistribute so that there would now be –1.00 nC on each sphere.*

(c) *Like charges will now repel and the two charges would separate again.*

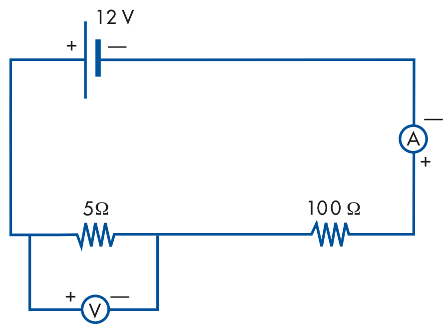
6. *A battery is multiple cells, e.g. 12 V car battery is actually 6 × 2 V cells.*

7. *EMF is the Electromotive Force and is the force in a power supply (or battery) that moves electrons in a circuit.*

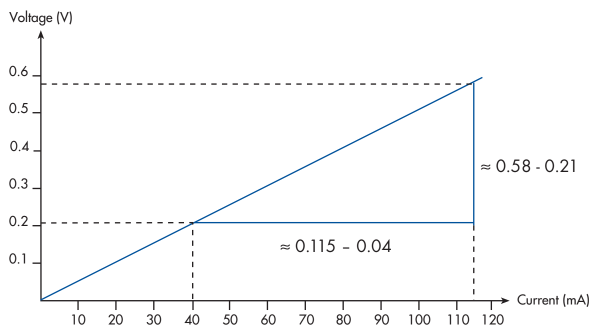
8. *Electron current is the flow of electrons in a circuit. The electrons will flow to the positive electrode of a battery. Conventional current is the fictitious flow of positive charges in a circuit towards the negative terminal of a battery.*

9. *Direct current is the flow of charge in one direction. AC occur in mains power circuits. The electrons in these circuits flow in one direction and then the other. In Australia, this occurs 50 times per second (i.e. frequency is 50 Hz).*

10. (a)



(b)



$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{0.58 - 0.21}{0.115 - 0.04} = 5.1\ V\,A^{-1}$$

This represents the resistance in the circuit ($R = 5.00\ \Omega$) [Note: $V.A^{-1} = \Omega$]

(c) *Yes. Within experimental error, the Voltage drop vs current graph is linear and the gradient is close to the stated value of resistance.*

11. *For each 5.00 Ω resistors in series:*

$$R_{T1} = R_1 + R_2 + R_3 = 5.00 + 5.00 + 5.00 = 15.0\ \Omega$$

For the 10.0 Ω resistors in series:

$$R_{T2} = R_1 + R_2 + R_3 = 10.0 + 10.0 + 10.0 = 30.0\ \Omega$$

For these to now be connected in parallel:

$$\frac{1}{R_T} = \frac{1}{R_{T1}} + \frac{1}{R_{T2}} = \frac{1}{15} + \frac{1}{30} = \frac{3}{30}$$

$R_T = 10.0\ \Omega$

CHAPTER 4: HEATING AND COOLING

1. (a) 373 K (b) 68 K (c) 546 K

2.

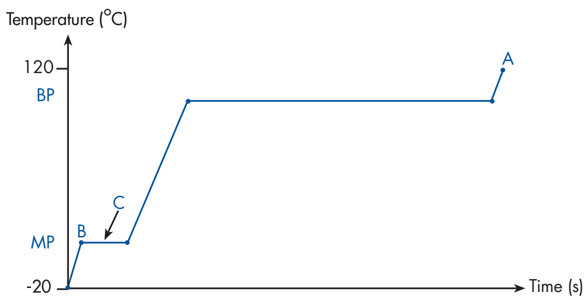
(a) *Friction between our hands creates heat and it warms our hands.*

(b) *The movement of air over our body increases the rate of evaporation by removing the layer of moist air from around your body. More sweat can now evaporate. Heat from your body is used to evaporate the sweat and so that faster evaporation occurs. Evaporation causes cooling so your body is cooled.*

(c) *The moisture will evaporate faster on the side of your finger facing the wind and produces a greater cooling effect. The coolest part of your finger points to the direction the wind is blowing from.*

(d) *Two thin blankets trap a layer of air between them. This air is an excellent insulator that stops body heat from escaping and stops cold air from reaching your body. One thicker blanket will not trap the air as well.*

3.



4.

Kitchen Conductors	Kitchen insulators
Frying pan	Frying pan handle
Electric stove heating element	Fabric pot holder
Metal hot plate	Insulation in a fridge

5.

(a) *Conduction is heat transfer by molecular transference of heat from hotter to cooler objects that are in contact. In metals, electrons transfer heat. Conduction occurs mainly in solids, somewhat in liquids and very slightly in gases. Materials that allow heat to transfer through them are called conductors.*

(b) *Convection occurs in fluids (liquids and gases). Convection is the circulation of heat in a fluid due to the movement of fluids of varying densities as a result of unequal heating.*

(c) *Radiation is a heat transfer system that does not require a medium. The sun's radiant heat passes through space to warm us on earth. Heat is transferred by electromagnetic waves of all wavelengths from a hot object to any cooler objects surrounding it. Electromagnetic radiation includes visible light, ultra violet (UV), infra red (IR) and Radio waves. However, infra-red radiation can be detected by us 'feeling' the heat produced on our bodies.*

6.

Situation	Transfer process
(a) Heat enters a house through a closed window.	Radiation
(b) Toast is cooked in a toaster.	Radiation
(c) Water in a hose left in the sun becomes very hot.	Conduction
(d) The tip of a soldering iron is very hot.	Conduction
(e) A room is heated by a slow combustion wood fire.	Radiation Convection
(f) After a 3 day heat wave, ceilings of insulated houses get hot.	Conduction

7. *Blowing across the soup can cause the heated, moist air above the soup to be removed and hence more liquid molecules can escape the liquid phase and enter the gaseous phase, i.e. the rate of evaporation increases and a cooling effect results.*

CHAPTER 5: NUCLEAR PHYSICS

1.

Nuclide	$_{8}O^{18}$	$_{35}Br^{80}$	$_{74}W^{184}$
Number of protons (Z)	8	35	74
Number of protons + neutrons (A)	16	80	184
Number of neutrons	8	45	110

2. *(i) alpha* *(ii) proton* *(iii) electron* *(iv) neutron*

3.

Type of Radiation	Alpha	Beta	Gamma
Symbol	α	β	γ
Nature	He nucleus	Nuclear electron	Electromagnetic radiation
Charge	+2	-1	0
Relative mass	4	$\frac{1}{1840}$	0
Ionising ability	high	lower	lowest
How is it stopped	Few cm air	Thin alfoil	Thick concrete or lead

4.

Description of Radiation Type	Radiation Type
Largest mass	α
Best ioniser	α
Not affected by magnetic fields	γ
Would be deflected towards the positive plate in an electric field	β
No charge	γ
Will penetrate through the roof of a house	γ
Travels at the speed of light	γ
Has the highest mass : charge ratio	α

5.

(a) X = *beta*
(b) $X = {}_{28}Ni^{65}$ *(see periodic table)*
(c) $X = {}_{12}Mg^{21}$ *(see periodic table)*
(d) $X = {}_{15}P^{31}$ *(see periodic table)*
(e) ${}_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{1}H^{1} + {}_{8}X^{17}$
($X = {}_{8}O^{17}$ *see periodic table)*

6.

(a) ${}_{5}B^{10} + {}_{0}n^{1} \rightarrow {}_{2}He^{4} + {}_{3}X^{7}$ *(*$X = {}_{3}Li^{7}$ *see periodic table)*
(b) ${}_{3}Li^{7}$ *(lithium 7)*
(c) Neutrons do not have a charge and are therefore harder to detect.

7.

(a)

# Half lives	Time	Fraction
0	0	1/1
1	2.7	1/2
2	5.4	1/4
3	8.1	1/8
4	10.8	1/16
5	13.5 days	1/32

(b) ${}_{79}Au^{198} \rightarrow {}_{80}Hg^{198} + {}_{-1}e^{0}$

(c)

# Half lives	Time	Fraction	Activity
0	0	1/1	10 kBq
1	2.7	1/2	5
2	5.4	1/4	2.5
3	8.1	1/8	1.25

Therefore after 7 days the activity would be approx. 1.5 kBq.

8.

(a) $T_{½}$ *= 2 days (activity drops from 80 to 40 Bq in that time).*
(b) From the graph it would be about 5 Bq.

9. *Alpha radiation would not penetrate the paper and gamma would be unaffected by the thin paper. Only beta would be affected to indicate a sufficient change that would register on the detector to cause a change in the pressure on the rolling device.*

Solutions to Trial Tests

TRIAL TEST 1: FUNDAMENTALS & MOTION

1.

(a) $227550\ pm = 2.22755 \times 10^5\ pm = 2.22755 \times 10^5 \times 10^{-12}\ m = 2.2755 \times 10^{-7}\ m$

(b) $122\ nm = 122 \times 10^{-9}\ m = 1.22 \times 10^{-7}\ m$

(c) $44.7\ \mu m = 44.7 \times 10^{-6}\ m = 4.47 \times 10^{-5}\ m$

The longest length is therefore 44 .7 μm

2.

Vector (m s⁻¹)	Horizontal components left (m s⁻¹)	Horizontal components right (m s⁻¹)	Vertical components up (m s⁻¹)	Vertical components down (m s⁻¹)
50		50 cos 30° = 43.30	50 cos 60° = 25.0	
20		20.0		
40	40 cos 45° = 28.28			40 sin 45° = 28.28
10	10 cos 60° = 5.00		10 cos 30° = 8.66	

3. *Sum of horizontal components to the left =* $28.28 + 5.00 = 33.28\ m\ s^{-1}$

Sum of horizontal components to the right = $43.30 + 20.0 = 63.30\ m\ s^{-1}$

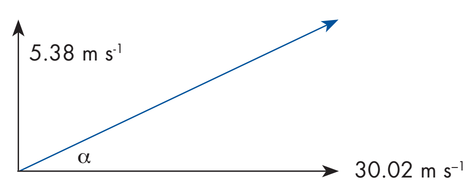
(i) *Nett sum of vectors =* $63.30 - 33.28 = 30.02\ m\ s^{-1}$ *to the right*

Sum of vertical components upwards = $25.0 + 8.66 = 33.66\ m\ s^{-1}$

Sum of vertical components downwards = $28.28\ m\ s^{-1}$

(ii) *Nett sum of vectors =* $33.66 - 28.28 = 5.38\ m\ s^{-1}$ *upwards*

Resultant vector can be found using the Pythagorean relationship in the diagram below (involving (i) and (ii) from above)



Resultant $= \sqrt{5.38^2 + 30.02^2} = 30.5\ m\ s^{-1}$

$\alpha = \tan^{-1}\left(\frac{5.38}{30.02}\right) = 10.2^o$

4.

(a) *At* $t = 0$ *s, acceleration = slope =* $0\ m\ s^{-2}$

At $t = 7$ *s, acceleration = slope =* $\frac{90 - 30}{9 - 4} = 12\ m\ s^{-2}$

At $t = 11$ *s, acceleration = slope =* $-\left(\frac{90 - 0}{15 - 9}\right) = -15\ m\ s^{-2}$ *(bike is decelerating)*

(b) *Distance travelled = area =* $30 \times 4 = 120\ m$

(c) *Distance travelled = total area =* $30(9) + \frac{1}{2}(9-4)\times(90-30) + \frac{1}{2}(15-9)(90-0) = 690\ m$

5. (a) *First 6.50 s:*

time (s)	velocity (m s⁻¹)
0	14.5
1	v = u + at = 14.5 + 4.80 (1) = 19.3
6.5	v = u + at = 14.5 + 4.80 (6.50) = 45.7

Two points are sufficient to establish a line.

Subsequent motion

After 6.50 s , velocity = $45.7\ m\ s^{-1}$

The bike then decelerates:

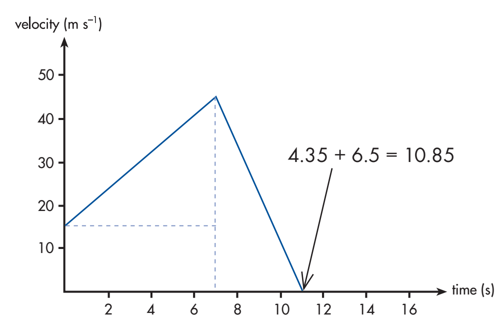
$u = 45.7\ m\ s^{-1}$

$v = 0$

$a = -10.5\ m\ s^{-2}$

$t = ?$

from $a = \frac{v - u}{t}$, $t = \frac{v - u}{a} = \frac{0 - 45.7}{-10.5} = 4.35\ s$



(b) Distance travelled = total area under shape = $14.5(6.5)+\frac{1}{2}(6.5)(45.7-14.5)+\frac{1}{2}(45.7)(4.35)$
$= 295$ m

6.

(a) $40\ s = \frac{40}{60^2}\ h = 1.11\ldots \times 10^{-2}\ h$

$$speed = \frac{distance}{time} = \frac{1.6}{1.11\ldots \times 10^{-2}}$$

$= 144$ km h^{-1}

(b) $$t = \frac{distance}{speed} = \frac{1}{144}\ h = \left(\frac{1}{144}\right)(60^2)\ s$$

$= 25$ s

7. During the 0.15 s interval:
$s = vt = 16.5(0.15) = 2.475$ m

While decelerating:
$u = 16.5$

$$s = \frac{(v^2 - u^2)}{2a} = \frac{0^2 - 16.5^2}{2(-0.85)} = 160.1\ m$$

$v = 0$

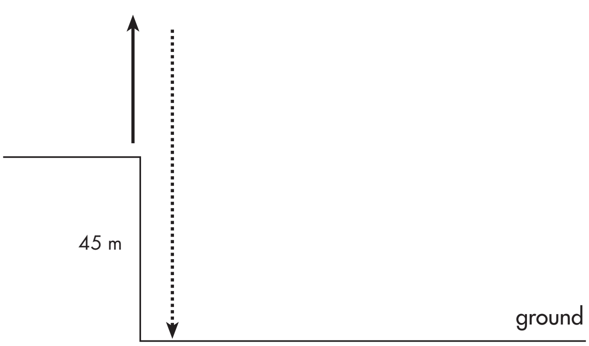
$a = -0.85$

Total distance travelled by Ernesto
$= 2.475 + 160.1$ m $= 162.6$ m

Thus he did not hit the kangaroo (misses it by 7.4 m)

8.

(a) s = vertical displacement = 45 m
$u = -25\ ms^{-1}$
$a = 9.8\ ms^{-2}$
$t = ?$



To find the total time, first find the time for the arrow to reach its maximum height, find the displacement of the arrow from the ground, and then find the time taken for the arrow to fall from its maximum height to the ground. Finally, the total flight time can be found.

At the top of the flight path, the final velocity of the arrow is zero.

$v = 0$ $$t = \frac{v - u}{a} = \frac{0 - (-25)}{9.8} = 2.55\ s$$

$u = -25\ m\ s^{-1}$
$a = 9.8\ ms^{-2}$
$t = ?$

The displacement of the arrow relative to its projection point can be found as follows:

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - (-25)^2}{2(9.8)} = -31.9\ m$$

From the top of the arrow's flight path to the ground, the displacement is:

(45 + 31.9) m or 76.9 m

The time for the arrow to travel 76.9 m can be found using:

$$s = ut + \frac{1}{2}at^2$$

i.e. $76.9 = 0(t) + \frac{1}{2}(9.8)t^2$
(the initial velocity at the top of the path, i.e. at max height is zero)

$76.9 = 4.9\ t^2$
$t = 3.96$ s

Total flight time is $(2.55 + 3.96) = 6.51$ s

NOTE: part (a) could be solved using $s = ut + at^2$, where s = total displacement = 45 m, $u = -25\ ms^{-1}$, $a = 9.8\ m\ s^{-2}$, and the unknown variable is t. This involves solving a quadratic equation which may be beyond your mathematical scope at this stage. If you can set up and solve a quadratic equation then this method is a great deal shorter than the method used above to find the total flight time.

(b) $v = u + at = -25 + 9.8(6.51) = 38.8\ m\ s^{-1}$

OR $v = \sqrt{u^2 + 2as} =$

$\sqrt{(-25)^2 + 2(9.8)(45)} = 38.8\ m\ s^{-1}$

9.

(a) $v = 0$, $m = 115\ kg$

$u = 270\ m\ s^{-1}$

$$a = \frac{v^2 - u^2}{2s} = \frac{0^2 - 270^2}{2(0.30)}$$

$= -1.215 \times 10^5\ m\ s^{-2}$

$F = ?$

$F = ma = (115)(-1.215 \times 10^5)$

$= -1.40 \times 10^7\ N$

Retarding force $= 1.40 \times 10^7\ N$

(b) $W = F\,s = 1.40 \times 10^7\ (0.30) = 4.19 \times 10^6\ J$

10. Answer: (b), constant speed means zero nett force.

11. Answer is (c), since acceleration is inversely proportional to mass (Newton's Second Law)

12. $F_{nett} = ma = 5(4) = 20\ N$ acting to the left

Therefore (? N) – (20 +10) = 20 N acting to the left

Hence (? N) = 50 N

13.

$$a = \frac{F_{nett}}{m} = \frac{18.0 - 4.00}{9.90} = 1.41\ m\ s^{-2} \text{ to the right}$$

as in the diagram.

14. The two equal and opposite forces (400N) acting on the rope do cancel resulting in a zero force on the rope. This means that the rope does not move relative to the lumberjack and the log. However, the rope also exerts a force of 400N on the log. This causes the log to move as presumably the force of friction acting on the log is less than 400N.

15.

(a) $u = 0$ $a = ?$ $W = ?$

$F = 500\ N$

$m = 3.00\ kg$

$s = 8.00\ m$

Work done $= Fs = 500(8.00) = 4.00 \times 10^3\ J$

(b) K.E gained = Work done $= 4.00 \times 10^3\ J$

(c) K.E gained = change in K.E.

$= \frac{1}{2}mv^2 - 0 = 4.00 \times 10^3\ J$

$$v^2 = \frac{2(4.00 \times 10^3)}{m} = \frac{2(4.00 \times 10^3)}{3.00}$$

$v = 51.6\ m\ s^{-1}$

16.

(a) At the start, $E_{total} = E_k + E_p$

$= \frac{1}{2}(3.00 \times 10^3)(1.20)^2 + (3000)(9.8)(12.5)$

$= 3.6966 \times 10^5\ J$

At the bottom of the first dip, $E_p = 0$,

therefore $E_k = E_{total} = 3.6966 \times 10^5\ J$

$\frac{1}{2}(3000)v^2 = 3.6966 \times 10^5$

$v = 15.7\ m\ s^{-1}$

(b) at point P:

$E_{total} = E_k + E_p$

$3.6966 \times 10^5 = mgh + \frac{1}{2}mv^2$

$3.6966 \times 10^5 = (3000)(9.8)(10.0) + 0.5(3000)(v)^2$

$v = 7.10\ m\ s^{-1}$

(c) *At point Q,*
$E_p = mgh = (3000)(9.8)(12.9) = 3.7926 \times 10^5\ J$

this cannot exceed the original energy of $3.6966 \times 10^5\ J$

Therefore the roller coaster does not make it to point Q

The highest point it gets to on the last incline can be calculated as follows:

At its highest point on the last incline, its kinetic energy is zero. Therefore the energy at this point will only be potential energy, value of $3.6966 \times 10^5\ J$

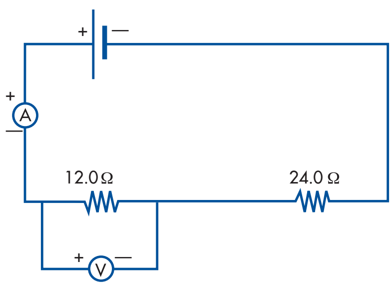
$mgh = 3.6966 \times 10^5$

$(3000)(9.8)(h) = 3.6966 \times 10^5$

$h = 12.6\ m$

TRIAL TEST 2: ELECTRICITY, HEATING & COOLING, NUCLEAR PHYSICS

1.



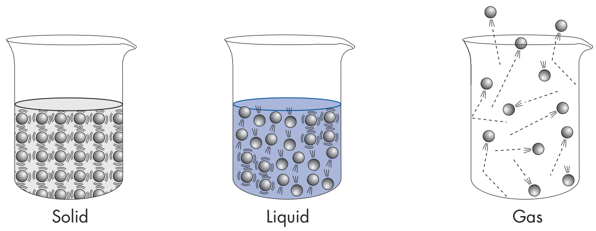
2. *Evaporation causes cooling. Only the most energetic water molecules have sufficient energy to leave the liquid phase and enter the gaseous phase. If the most energetic water molecules are removed from a pool of water, the average kinetic energy of the remaining molecules must be less. If average kinetic energy is less, temperature must be reduced.*

3. *Example: water bag on the front of a car. Evaporation causes cooling. The blowing breeze increases evaporation by removing gaseous water molecules from around the hessian bag and allows more energetic liquid water molecules to undergo the phase change. If the most energetic water molecules are removed from the water, the average kinetic energy of the remaining molecules must be less. Therefore the water is cooled.*

4. (a) ${}_0X^3$ *(X = 3 neutrons)*
(b) ${}_2X^4$ *(X = alpha)*
(c) ${}_{-1}X^0$ *(X = beta)*

5. *let # protons = x*
therefore, # neutrons = x + 2
A(isotope) = 10 × 4 = 40 (# protons + neutrons)
i.e. $x + x + 2 = 40$
$2x = 38$
$x = 19$
 # protons = 19, # neutrons = 21

6.
(a)



(b) *In a solid the molecules are very close together. This means that they do not possess much potential energy. The molecules in a liquid are far more spaced out and therefore possess more potential energy. Energy must be provided to the solid to change it to the liquid phase. Since the solid and the liquid are at the same temperature, they both possess the same kinetic energy. Internal energy is the sum of the potential and kinetic energy and therefore the liquid has a higher internal energy.*

7. *The slope of a voltage (drop) versus current graph equals the resistance.*

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{20}{5} = 4\ \Omega$$

8. *Ionising radiation removes electrons from atoms in matter. Alpha particles are the best ionisers.*

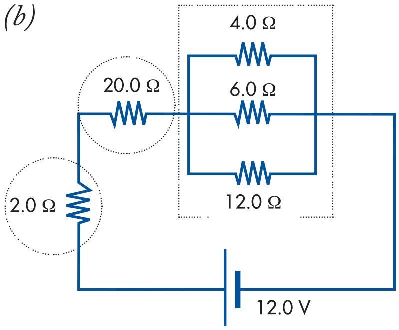
9. $I = 5.00\ A$
$t = 2.00\ \text{hours}$
$= 2 \times 60 \times 60 = 7200\ s$

$q = It = 7200 \times 5 = 3.60 \times 10^4\ C$

$$\#\ \text{electrons} = \frac{q}{1.60 \times 10^{-19}}$$

$$= \frac{36000}{1.60 \times 10^{-19}} = 2.25 \times 10^{23}\ \text{electrons}$$

10. (a),(b)



(c) $R_{T1} = R_1 + R_2 = 2.0 + 20.0 = 22.0\ \Omega$

(d) $\dfrac{1}{R_{T2}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} = \dfrac{1}{4.0} + \dfrac{1}{6.0} + \dfrac{1}{12.0}$

$= \dfrac{6}{12}$

$R_{T2} = 2.00\ \Omega$

(e) $R_T = R_{T1} + R_{T2} = 2.0 + 22.0 = 24\ \Omega$

(f) $I = \dfrac{EMF\ (V)}{R} = \dfrac{12}{24} = 0.50\ A$

11. (a)

Description	Explanation
Black coloured	Black coloured objects radiate more heat to the surroundings than other colours and therefore the radiator (and water) will be cooled faster.
Thin metal with a large surface area	The thin metal will conduct heat well and the heat will be transferred to the air faster because of the large surface area in contact with the air.
Fan blowing on them	Air blowing over the radiator will remove the hot layer of air around the radiator. The temperature difference between the cooler air and the radiator increases the heat transfer between the radiator and the air.

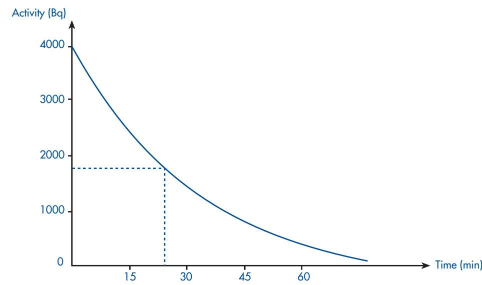
(b) *Steam has extra potential energy than water at the same temperature because the molecules are more separated. Hence the steam will transfer more heat to the person and inflict a more severe burn.*

(c) *Evaporation causes cooling by removing the most energetic liquid water molecules. The rate of evaporation depends on the amount of water vapour in the air. On a dry day when humidity is low, the rate of evaporation is high and hence the evaporative air conditioner works well. However, when the humidity is high, the air is saturated with water vapour and hence only a little amount of evaporation can occur and therefore there is no cooling effect. In fact all the air conditioner will do is to make it more humid and less comfortable. On such a day, it is better to run fans only – no cooling.*

(d)

Description	Explanation
North facing **sloping** roof	This maximises the heat transferred to the panels from the sun by having the panels perpendicular to the sun.
The cold water intake is at the **bottom**	Water in the panels will rise as they are heated due to convection. This heated water is pumped into a holding tank. Cold water is added through a bottom inlet so that it does not cool the already heated water.
Hot water outlets at the **top**	Water in the panels will rise as they are heated due to convection. This heated water is pumped into a holding tank.
Black coloured **copper** heat collectors	Dark coloured copper collectors absorb more heat than light coloured collectors. Copper is used because it is an excellent conductor that will transfer heat to the water.

12. (a)



(b) *Approximately 1700 Bq.*

(c) *i) $T_{1/2}$ = 20 min (activity drops from 4000 Bq → 2000 Bq)*

(ii)

# Half lives	Time	Activity
0	0	4000
1	20	2000
2	40	1000

$T_{1/2}$ = 20 min

(d)

# Half lives	Time	Mass
0	0	50
1	20	25
2	40	12.5
3	60	6.25
4	80	3.125
5	100	1.5625
6	120	0.78125

Mass would be 0.781 g.

Facts Answers

ELECTRICITY FACTS (CHP 3)

1. *Like charges repel, unlike charges* ***attract****.*
2. ***Static electricity*** *is the study of charges at rest.*
3. *Friction between two surfaces can cause* ***electrons*** *to be removed from one surface to the other.*
4. ***Current electricity*** *is the study of charges moving in a circuit.*
5. *Electric charge is measured in a unit called a* ***Coulomb****.*
6. *Electric current is measured in a unit called an* ***Ampere****.*
7. *Electric current can be defined as the rate of flow of* ***charge****. Formula is:* $I = \frac{q}{t}$
8. *Conventional current refers to the movement of* ***positive*** *charges in a circuit.*
9. *In a metal, the only charge that moves are* ***electrons****. This is called an* ***electron current****.*
10. *Currents that flow in one direction only are called* ***DC****. This occurs in circuits that contain* ***batteries****.*
11. *The total resistance* ***decreases*** *when resistors are connected in parallel.*
12. ***Alternating currents*** *are currents that go one way then the other very rapidly.*
13. *A battery is actually multiple* ***cells****.*
14. ***EMF*** *is a force that moves electrons. Unit for this is* ***volts****.*
15. *In a circuit,* ***resistance*** *can reduce the flow of electrons. Its unit is an* ***Ohm****.*
16. *'The ratio of the potential difference (voltage) across a conductor to the current flowing in the conductor is a constant' is statement of* ***Ohm's law****. Formula:* $V = IR$.
17. *The gradient of a voltage/current graph is equal to* ***resistance****.*
18. ***Voltage*** *drops,* ***current*** *flows in a circuit.*
19. *An* ***ammeter*** *measures current and a* ***voltmeter*** *measures voltage drop in a circuit.*
20. ***Series circuits*** *have only one circuit for electrons to flow through. Formula for resistors connected in this way:* $R_T = R_1 + R_2$
21. ***Parallel circuits*** *have a choice of pathways in a circuit. Formula for resistors connected in this way:* $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
22. *The sum of the potential drops around a circuit is equal to the* ***EMF*** *of a cell.*
23. *The total resistance* ***increases*** *when resistors are connected in series.*

HEAT FACTS (CHP 4)

1. *Heat energy unit is a* ***Joule****.*
2. *Solid → liquid:* ***melting.***
3. *Liquid → gas:* ***evaporation.***
4. *Gas → liquid:* ***condensation****.*
5. *Melting point of ice:* $\boldsymbol{0^oC}$
6. *Temperature remains* ***constant*** *during boiling.*
7. *Land and sea breezes are an example of a* ***convection current****.*
8. *Boiling point of water:* $\boldsymbol{100^oC}$
9. *Heat can be transferred by* ***conduction****,* ***convention*** *or* ***radiation****.*
10. *Evaporation causes* ***cooling****.*
11. *In metals, heat is mainly transferred by* ***conduction****.*
12. *The sum of the kinetic and potential energy of an object is called the* ***internal energy****.*
13. $0\ K = 273^oC$
14. ***Temperature*** *is a measure of the average kinetic energy of a substance.*
15. *Molecules in a solid are very* ***close*** *together.*
16. *Molecules in a gas are* ***far*** *apart.*
17. *The nature of a material that determines how quickly it changes temperature when heated is called the* ***specific heat****.*
18. *Boiling only occurs at the* ***boiling point*** *and occurs* ***within*** *the liquid. Evaporation occurs at any temperature and only occurs at the* ***surface*** *of a liquid.*
19. ***Vibrational*** *kinetic energy is the major type of motion found in the molecules of a solid.*
20. *The heating element in a kettle is always placed near the* ***bottom****.*
21. *Rate of evaporation depends on* ***surface area****,* ***amount of wind*** *and* ***temperature****.*
22. *An energy efficient house should have most windows facing* ***north****.*
23. *To reduce heat loss from a house in winter time, place* ***insulation*** *in the ceiling and cover up the* ***windows****.*
24. *Since water is a poor* ***conductor****, heat is transferred in a kettle by* ***convection****.*
25. ***Heat*** *is defined as the energy that is transferred between objects of different temperature.*

NUCLEAR PHYSICS FACTS (CHP 5)

1. *The **nucleus** contains protons and neutrons. Protons have a **positive** charge.*
2. ***Isotopes** of an element have the same number of protons but different numbers of neutrons.*
3. *The number of protons is called the **atomic number**.*
4. *The number of protons plus neutrons is called the **mass number**.*
5. *The nucleus, $_{23}V^{51}$ has **23** protons and 28 neutrons.*
6. *The three types of radiation are **alpha**, **beta** and **gamma**.*
7. ***Alpha** are helium nuclei.*
8. ***Beta** are high speed nuclear electrons.*
9. ***Gamma** are electromagnetic radiation.*
10. *In beta emission, a **neutron** turns into a **proton** and emits a **beta**.*
11. ***Ionisation** is the removal of electrons by radiation. **Alpha** cause this to happen most readily.*
12. *Gamma radiation is highly penetrating in matter because they have no **mass** or **charge**.*
13. *Identify X in this nuclear reaction:* $_{92}U^{238} \rightarrow {}_{90}Th^{234} + X$ ***(alpha)***
14. ***Activity** is the number of nuclei that decay each second. Its unit is the **Becquerel (Bq)**.*
15. *The time during which half the atoms in a radioactive sample decay is called the **half-life**.*
16. ***Fission** is the splitting of a heavy nuclei into approximately equal parts.*
17. ***Fusion** is the joining of two light nuclei together. Both this reaction and the previous reaction produce huge amounts of **energy**.*
18. *In a nuclear reaction fission occurs continuously due to a **chain reaction** occurring.*
19. *The half-life of a radioactive sample which has its activity change from 1000 Bq to 125 Bq in 12 minutes is **4 minutes**.*
20. *Identify X in this nuclear reaction:* $_{1}H^{2} + {}_{11}Na^{23} \rightarrow {}_{12}Mg^{24} + X$ ***(neutron)***
21. ***Fusion** reactions occur in the sun.*
22. *The type of radiation absorbed by a few cm of air is **alpha**.*

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