TECHNICAL SCIENCE GRADE 10

basic education

Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

sasol
reaching new frontiers

TECHNICAL SCIENCE GRADE 10

ISBN 978-1-4315-2284-2
9 781431 522842

TECHNICAL SCIENCE GRADE 10

sasol inzalo foundation

UKUQONDA institute

Developed and funded as an ongoing project by the Sasol Inzalo Foundation in partnership with the Ukuqonda Institute

Published by The Ukuqonda Institute: http://www.ukuqonda.org.za

9 Neale Street, Rietondale 0084; Title 21 company, reg. no. 2006/026363/08;

Public Benefit Organisation, PBO Nr. 930035134

ISBN: 978-1-4315-2284-2

This book was developed with the participation of the Department of Basic Education of South Africa (DBE) with funding from the Sasol Inzalo Foundation (SaIF).

Authors: Andre Goosen, Peter Moodie

Text editors: Carol MacDonald, Lynne Owen-Smith

Project managers: Andrew Hofmeyr, Rod Sherwood

Contributors from the Ukuqonda Institute:
Chris Human, Carol MacDonald, Karen van Niekerk, Leonora van Staden

Independent reviewers:
Prof. John Bradley, Prof. Diane Grayson, Ms Maria Lycoudi

Contributors from the Department of Basic Education:
Sivuyile Kutu, Desiree Letswiti, Veena Maharaj, Morongwa Masemola, Willie Monoreng, Thandi Oane, Modiba Phosa

The sequencing of topics and the nature of activities was determined by the requirement to comply with the CAPS for Technical Science.

Illustrations and computer graphics: Lisa Steyn Illustration, Mark de Lange, Melany Pietersen (Happy Artworks Studio), Tina Nel, Rod Sherwood, Leonora van Staden, Paddy Bouma

Photographers: Kim Stevens, Rebekah Swanepoel, Leonora van Staden, Maria van Koersveld (Vivid Milieu), Martin van Niekerk Photography

Cover photograph: Kim Stevens

Text design: Mike Schramm

Layout and typesetting: Ink Design

Printed by: [printer name and address]

Acknowledgements:

Thanks to John Orr Technical High School, Johannesburg, for participating in piloting some of the learning material in this book in the classroom, while the book was being written.

Thanks to the Concrete Materials and Structural Integrity Research Unit (CoMSIRU), Department of Civil Engineering, University of Cape Town (http://www.comsiru.uct.ac.za) for free sharing of photos of structural testing and structural failure, specifically, Figure 3.21, Figure 5.25, Figure 5.31a and Figure 5.31b.

Thanks to Tomson Motors and Stellenbosch Auto Clinic, Stellenbosch who helped with photographing certain machinery.

Thanks also to the following photographers and organisations who made their images available for use in the book:

Figure 3.24c (steel framework) courtesy of freeimageslive/yoshihi; Creative Commons Attribution 3.0 Unported license

Figure 3.25 (cutting corrugated iron for roofing repairs) ©Shutterstock/kezza

Figure 5.9b (roller support for bridge) courtesy of Civil Engineering Photos/Karl Jansen

Figure 5.9c (sliding bearing) ©Freyssinet Limited

Figure 5.23 (2005 Landslide in Conchita, CA) credit: U.S. Geological Survey, Department of the Interior/USGS; U.S. Geological Survey/photo by Mark Reid

Figure 7.7b (asteroid impact on the moon) credit: NASA http://www.nasa.gov/multimedia/guidelines/index.html

Figure 7.9 (skateboarder) ©Shutterstock/taboga

Figure 7.15 (cross-country mountain biking) by Steve Bennett (2009); Multi-license with GFDL and Creative Commons CC-BY 2.5

Figure 7.18 (demolition crane) ©Shutterstock/Lisa Rivali

Figures 9.10b and 9.10c (sulfur) by Pseudopanax (2014); courtesy of Wikimedia Commons; Public Domain

Figure 9.14 (iodine crystals) by Dnn87 (2008); courtesy of Wikimedia Commons; Creative Commons Attribution 3.0 Unported

Figure 9.15 (silicon and germanium) by Jurii (2009); courtesy of Wikimedia Commons; Creative Commons Attribution 3.0 Unported

Figure 11.20 (glass insulators) by Adrian Pingstone (2004); courtesy of Wikimedia; Public Domain

Figure 11.21 (silicon) by Jurii (2009); courtesy of Wikimedia Commons; Creative Commons Attribution 3.0 Unported

Figure 12.19 (van de Graaff generator) by Jon 'ShakataGaNai' Davis (2008); courtesy of Wikimedia Commons; Creative Commons Attribution 3.0 Unported

Figure 12.30 (Cuneus) courtesy of Wikimedia Commons https://commons.wikimedia.org/wiki/File:Cuneus_discovering_the_Leyden_jar.png; the drawing seems to be signed 'Laplante' in the lower right corner - Downloaded August 12, 2013 from Augustin Privat Deschanel (1876) Elementary Treatise on Natural Philosophy, Part 3: Electricity and Magnetism, D. Appleton and Co., New York, translated and edited by J. D. Everett, p. 570, fig. 382 on Google Books

Table 13.1 bicycle dynamo by http://www.flickr.com/photos/23672158@N04/ (2009); courtesy of Wikimedia Commons; Creative Commons Attribution 2.0 Generic

Table 13.1 carbon resistor by Inductiveload (2007); courtesy of Wikimedia Commons; Public Domain

Table 13.1 heater ©Shutterstock/ Natalia Barsukova

Figure 16.2 (replica of Robert Stephenson's steam locomotive) by Barry Lewis (1991); courtesy of Wikimedia Commons; Creative Commons Attribution 2.0 Generic

Figure 16.11b (thermocouple): permission for reuse obtained from spares4appliances.co.uk

Figure 16.21 (stove plate) by freefoodphotos; Creative Commons Attribution 3.0 Unported License

Figure 16.24a (fire wood) ©Shutterstock/schankz

Resource pages: lightning rod ©Shutterstock/MimaCZ

Resource pages: photograph of Brunel courtesy of Wikipedia https://en.wikipedia.org/wiki/Isambard_Kingdom_Brunel#/media/File:IKBrunelChains.jpg; Public Domain

Resource pages: Clifton suspension bridge uploaded by InverseHypercube; courtesy of Wikipedia; Public Domain

CONTENTS

CHAPTER 1 Maths skills for Science

This chapter covers the Maths skills you will use throughout your Technical Science course – and probably, throughout your life!

Unit 1.1 Units and measurements

The **metric system*** is a system of measurement that was first used over 300 years ago. It is based on multiples of ten, e.g. $\frac{1}{10}$, 1 unit, 10, 100, etc., so it is a **decimal*** system.

The International System of Measurement (SI system)

The International System of Measurement, known as the SI system, developed out of the metric system. It is the official system of most countries in the world including South Africa. We rely on this system to apply formulae and do calculations in Science and Technology.

The seven fundamental units of measurement

All measurements in the SI system are based on the seven **fundamental units*** of measurement listed in Table 1.1. Many people prefer to call these the base units.

There is a standard symbol for every SI unit of measurement. We use symbols instead of writing whole words out because it saves time and space.

Most symbols are written in lowercase letters, like "m" for metre. But there are exceptions. Some symbols are written in capital letters, such as "A" for Ampere and "K" for kelvin – these units are often named after the person who first used the unit.

* the **metric system** is an internationally agreed decimal system of measurement
* **decimal** – based on the number ten
* **fundamental units** are the basic units, from which we can get other units

Table 1.1: Physical quantities, units and symbols of the seven fundamental units of measurement in the SI system

Physical quantity	Abbreviation	Name of unit	Symbol for unit
length	l	metre	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	ampere	A
temperature	T	kelvin	K
luminous intensity	I_v	candela	cd
amount of a substance	n	mole	mol

Activity 1 Use symbols in the SI system

Use the correct units from the table.

1. What units would you use to answer these questions?

- **a)** How high is the ceiling of your workshop?
- **b)** What is the mass of a general purpose hammer?
- **c)** How many seconds are there in an hour?

2. What is the rating (the maximum number of amperes) of a 3-prong plug, such as on an electric heater or a kettle? (Have a look at one of these.)

Derived units

Many units have been developed from the basic SI units. These are called **derived*** units, because they can be written in terms of the fundamental units.

For example, the derived unit for **area*** is the square metre (m^2).

Table 1.2 gives some more derived units that you will use.

> ✻ **derived** means it comes from something else. Derived units come from basic units.
>
> ✻ **area** is the amount of flat space that an object takes up

Table 1.2: Physical quantities, units and symbols of some derived units

Physical quantity	Name of derived unit	Symbol for derived unit	SI fundamental unit equivalents
force, weight	newton	N	$kg{\cdot}m{\cdot}s^{-2}$
energy, work, heat	joule	J	$kg{\cdot}m^2{\cdot}s^{-2}$
moment	newton metre	N·m	N·m
electric charge	coulomb	C	s·A
electrical capacitance	farad	F	$kg^{-1}{\cdot}m^{-2}{\cdot}s^4{\cdot}A^2$
electrical resistance	ohm	Ω	$kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-2}$
voltage, electrical potential difference, electromotive force	volt	V	$kg{\cdot}m^2{\cdot}s^{-3}{\cdot}A^{-1}$
magnetic flux	weber	Wb	$kg{\cdot}m^2{\cdot}s^{-2}{\cdot}A^{-1}$
magnetic field strength, magnetic flux density	tesla	T	$kg{\cdot}s^{-2}{\cdot}A^{-1}$
frequency	hertz	Hz	s^{-1}
pressure, stress	pascal	Pa	$kg{\cdot}m^{-1}{\cdot}s^{-2}$
power	watt	W	$kg{\cdot}m^2{\cdot}s^{-3}$

NOTE: These units will be used throughout this course.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 2 2016/01/05 3:15 PM

Prefixes

The SI system is based on multiples of ten, so it is called a decimal system. It has a set of prefixes which describe the size of the numbers relative to one unit of the quantity being measured. For example:

- The prefix kilo- in kilometre indicates that a kilometre is one thousand times bigger than one metre.
- Milli- in millimetre indicates that a millimetre is one thousand times smaller than one metre.

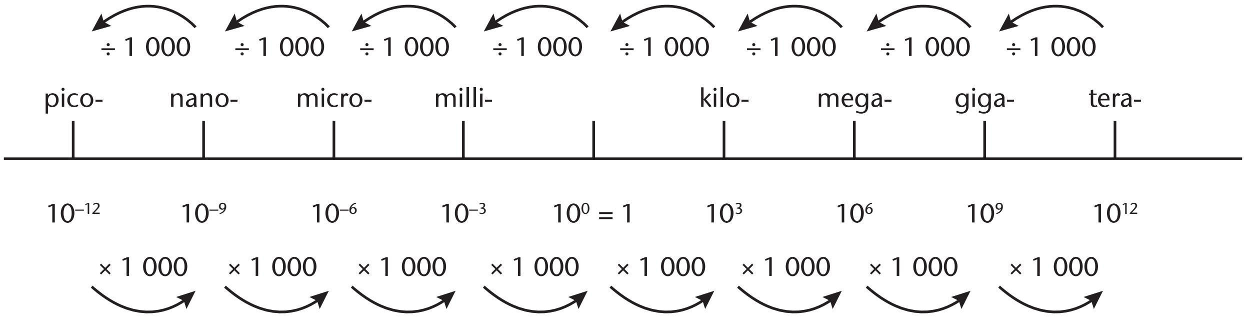


Table 1.3: Some metric prefixes that are used in Technical Sciences and the Technology subjects			
Prefix	**Symbol for prefix**	**Multiplication factor**	**Exponential form**
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
unit quantity	no prefix	1	10^{0}
deci	d	0,1	10^{-1}
centi	c	0,01	10^{-2}
milli	m	0,00 1	10^{-3}
micro	µ	0,000 001	10^{-6}
nano	n	0,000 000 001	10^{-9}
pico	p	0,000 000 000 001	10^{-12}

NOTE: Use Table 1.3 as a reference. You need to understand how it is constructed and you should know the order of all the prefixes and their symbols.

The centimetre-gram-second system

The centimetre-gram-second system (CGS) comes from the metric system. The CGS system is based on the centimetre as the unit of length, the gram as the unit of mass, and the second as the unit of time.

Conversions between units

Artisans, technicians and engineers need to be able to convert a quantity measured in one unit to a quantity measured in another unit.

Table 1.4: Table of conversion factors using standard prefixes

Factors to use in conversion			Examples using measurements of length
from	to	factor	
milli	centi	$\frac{1}{10}$	$300\text{ mm} = \frac{300}{10} = 30\text{ cm}$
milli	unit amount (1)	$\frac{1}{1\,000}$	$300\text{ mm} = \frac{300}{1\,000} = 0{,}3\text{ m}$
milli	kilo	$\frac{1}{1\,000\,000}$	$300\text{ mm} = \frac{300}{1\,000\,000} = 0{,}000\,3\text{ km}$
centi	milli	10	$30\text{ cm} = 30 \times 10 = 300\text{ mm}$
centi	unit amount (1)	$\frac{1}{100}$	$30\text{ cm} = \frac{30}{100} = 0{,}3\text{ m}$
centi	kilo	$\frac{1}{100\,000}$	$30\text{ cm} = \frac{30}{100\,000} = 0{,}000\,3\text{ km}$
unit amount (1)	milli	1 000	$0{,}3\text{ m} = 0{,}3 \times 1\,000 = 300\text{ mm}$
unit amount (1)	centi	100	$0{,}3\text{ m} = 0{,}3 \times 100 = 30\text{ cm}$
unit amount (1)	kilo	$\frac{1}{1\,000}$	$0{,}3\text{ m} = \frac{0{,}3}{1\,000} = 0{,}000\,3\text{ km}$
kilo	milli	1 000 000	$0{,}000\,3\text{ km} = 0{,}000\,3 \times 1\,000\,000 = 300\text{ mm}$
kilo	centi	100 000	$0{,}000\,3\text{ km} = 0{,}003 \times 100\,000 = 30\text{ cm}$
kilo	unit amount (1)	1 000	$0{,}000\,3\text{ km} = 0{,}003 \times 1\,000 = 0{,}3\text{ m}$

NOTE: You must understand how this table works.

Worked examples: Convert quantities

1. Convert 5 601 milligrams to grams.

Solution

$5\,601\text{ mg} = 5\,601 \times \frac{1}{1000} = 5{,}601\text{ g}$

2. Convert 0,535 kilolitres to millilitres.

Solution

$0{,}535\text{ kl} = 0{,}535 \times 1\,000\,000 = 535\,000\text{ ml}$

Activity 2 Convert quantities

1. Show your working and do not use a calculator for these conversions.
   - **a)** 4 kilograms to grams
   - **b)** 4 200 milligrams to grams
   - **c)** 765 centimetres to metres
   - **d)** 8,765 kilometres to metres
   - **e)** 0,321 kilometres to millimetres
   - **f)** 471,2 g to kg
   - **g)** 102,5 m to mm

Conversion factors for measurements of time

Time is the only fundamental quantity in the SI system that is not based on the decimal system. You may need to convert between hours and seconds, for example, if you need to convert a speed in km/h to a speed in m/s.

Table 1.5: Table of conversion factors for measurements of time

Factors to use in conversion			Examples
from	to	factor	
seconds	minutes	$\frac{1}{60}$	300 s = 300 ÷ 60 = 5 min
seconds	hours	$\frac{1}{3\ 600}$	300 s = 300 ÷ 3 600 = $\frac{1}{12}$ h
minutes	seconds	60	5 min = 5 × 60 = 300 s
minutes	hours	$\frac{1}{60}$	5 min = 5 ÷ 60 = $\frac{1}{12}$ h
hours	seconds	3 600	12 h = 12 × 3 600 = 43 200 s
hours	minutes	60	12 h = 12 × 60 = 720 min

Worked examples: Convert periods of time

1. Convert 240 minutes to hours.

   Solution

   $$240 \text{ min} = 240 \times \frac{1}{60} = 4 \text{ h}$$

2. Convert 5 400 seconds to hours.

   Solution

   $$5\ 400 \text{ s} = 5\ 400 \times \frac{1}{3600} = 1{,}5 \text{ h}$$

3. Convert 2 h 10 min 30 s to seconds.

   Solution

   $$2 \text{ h } 10 \text{ min } 30 \text{ s} = 2 \times 3\ 600 + 10 \times 60 + 30 = 7\ 830 \text{ s}$$

Activity 3 Convert periods of time

1. Show your working. You may use a calculator. Convert:

a) 3 660 seconds to hours

b) 2,5 hours to seconds

c) 72 minutes to seconds

d) 2,5 days to hours

e) 36 525 days to years

f) 5 400 milliseconds to seconds

Other systems of measurement

The imperial system of measurement is based on the foot as the unit of length and the pound as the unit of mass. It is still used in the United States of America (USA).

Another odd unit of measurement still used in the USA is degrees Fahrenheit (°F) which is used to measure temperature. Some thermometers are still marked in degrees Fahrenheit.

To convert from °F to °C:

$C = (5 \div 9) \times (F - 32)$

To convert from °C to °F:

$F = (9 \div 5) \times C + 32$

where:

- C is the temperature in degrees Celsius (°C)
- F is the temperature in degrees Fahrenheit (°F)

Activity 4 Convert temperatures

Convert the temperatures in the second column of the table.

Number	Given temperature	Formula	Substitution	Answer
1	37 °C	$F = (9 \div 5) \times C + 32$	$= (9 \div 5) \times 37 + 32$	98,6 °F
2	212 °F	$C = (5 \div 9) \times (F - 32)$	$= (5 \div 9) \times (212 - 32)$	100 °C
3	32 °F			
4	3 000 °C			
5	0 °C			

Unit 1.1 Summary activity

1. Complete the table by filling in the missing physical quantity, unit or symbol.

Physical quantity	Unit name	Symbol for unit
length		
		kg
	second	
electric current		
		K

2. Explain the meaning of the term "derived unit" using the newton as an example.

3. Complete the table by filling in the missing prefix, symbol for prefix or multiplication factor.

Prefix	Symbol for prefix	Multiplication factor
Mega-	M	1 000 000
kilo-		
no prefix	no prefix	1
		0,01
	m	
micro		

4. Convert the periods of time below. Show your working. You may use a calculator.

a) 7 200 seconds to hours

b) 0,5 hours to seconds

c) 100 minutes to seconds

d) 0,041 7 days to hours

5. An engineer from America feels ill and takes a thermometer out of her first-aid kit. Her temperature is 101,5 °F. You phone your clinic for advice but the nurse does not understand degrees Fahrenheit. Convert it to degrees Celsius for the nurse.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 7 2016/01/05 3:15 PM

Unit 1.2 Scientific notation

Scientists often have to deal with very large numbers. For example, in **standard notation** the mass of the Earth is about 6 000 000 000 000 000 000 000 000 kg.

Scientific notation is a way of writing very large numbers easily. In scientific notation the mass of the Earth is $5{,}97 \times 10^{24}$ kg which is much easier to write.

first digit other digits exponent

$$5{,}97 \times 10^{24} \text{ kg}$$

decimal comma

The number 24 written as an **exponent*** represents the number of zeros in the number.

> * **exponent** – the exponent of a number says how many times to use the number in a multiplication

An example of a very small number is the diameter of a proton. The proton is a tiny particle inside the nucleus of an atom.

In **standard notation**, the diameter of a proton is 0,000 000 000 000 004 m. In **scientific notation** it becomes $4{,}0 \times 10^{-15}$ m.

How to write a number in scientific notation

The format for scientific notation is simple.

- The first digit of the number is followed by the decimal comma.
- This is followed by zero or the rest of the non-zero digits.
- This is followed by a multiplication sign and 10 to an appropriate power.

Worked examples: Convert numbers to scientific notation

1. Convert a simple number in standard notation to scientific notation. 124 is not a very large number or very small number, but it can be written in scientific notation.

Solution

First write 1,24 (the decimal comma is written after the first digit)

We know that $124 = 1{,}24 \times 100$

And we know that $100 = 10^2$

$\therefore\ 124 = 1{,}24 \times 10^2$

2. Convert a small number in standard notation to scientific notation. We will use the thickness of electroplating on a component. The layer is 150 µm thick. That is 0,000 15 m thick in standard notation.

Solution

First write 1,5 (the decimal comma is written after the first digit)

We know that $0{,}000\,15 = 1{,}5 \times 0{,}000\,1$

$$\text{And we know that } 0{,}000\,1 = \frac{1}{10\,000} = \frac{1}{10^4} = 10^{-4}$$

$\therefore\ 0{,}000\,15 \text{ m} = 1{,}5 \times 10^{-4}$ m

3. Convert a large number in standard notation to scientific notation. In standard notation, the mass of the moon is 74 000 000 000 000 000 000 000 kg.

Solution
- Identify the position of the decimal comma:
  74 000 000 000 000 000 000 000,0
- Shift the decimal point so that there is just one digit to the left of the point: 7,4 000 000 000 000 000 000 000
- Count the number of places the decimal point has moved to get to the new place: 7,4 000 000 000 000 000 000 000
- .... that is 22 places to the left.
  ∴ 74 000 000 000 000 000 000 000 kg = $7{,}4 \times 10^{22}$ kg

Figure 1.1 *The moon*

Quick Activity:

1. What can you say about the exponent of a number that is very small?
2. What can you say about the exponent of a number that is very big?

Activity 5 Convert numbers from standard notation to scientific notation

Convert to scientific notation, using the correct units.

1. When you study light or electromagnetic radiation, you need to work with the speed of light, which is 300 000 000 $m \cdot s^{-1}$.
2. When you design a solar water heater panel, you predict the output of the panel based on the amount of solar radiation the panel receives from the Sun. In the Free State, the annual radiation is 2 400 kilowatt hours per square metre.
3. The diameter of an atom is about (of the order) 0,000 000 000 1 metres.
4. In electrostatics you will study charges. The charge of a single electron is 0,000 000 000 000 000 000 160 2 coulombs.

Convert numbers from scientific notation to standard notation

Worked examples: Convert numbers from scientific notation to standard notation

1. **Convert a very small number in scientific notation to standard notation**
   We use the mass of an electron in this example. In scientific notation, the mass of an electron is $9{,}109 \times 10^{-31}$ kg.

   Solution
   What is the exponent of the base 10? It is –31.
   So the decimal comma must shift 31 places to the left of the first number:
   00,000,000,000,000,000,000,000,000,000,009,109
   ∴ $9{,}109 \times 10^{-31}$ kg = 0,000 000 000 000 000 000 000 000 000 000 910 9 kg

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 9 2016/01/05 3:15 PM

2. **Convert a large number in scientific notation to standard notation**
   We use the mass of the Sun in this example. In scientific notation, the approximate mass of the Sun is $1{,}988 \times 10^{30}$ kg.

   Solution

   What is the exponent of the base 10? It is 30.

   So the decimal comma must shift 30 places to the right:

   1,988 000 000 000 000 000 000 000 000 000 000

   Identify the position of the decimal point:

   1 988 000 000 000 000 000 000 000 000 000 000,0

   $\therefore$ $1{,}988 \times 10^{30}$ = 1 988 000 000 000 000 000 000 000 000 000 000,0 kg

Activity 6 Convert numbers from scientific notation to standard notation

1. It takes $7{,}1 \times 10^{7}$ joules of heat energy to raise an ingot of steel from room temperature to melting point.
2. A heavy current conductor is rated at $7{,}5 \times 10^{5}$ volt-amps.
3. The thickness of a film of oil between the roller and the race in a particular roller bearing is $5{,}5 \times 10^{-6}$ m. Convert this figure to standard notation in both metres and micrometres.
4. The thickness of the chrome plating on a machine cover is $6{,}6 \times 10^{-7}$. Convert this figure to standard notation in both metres and micrometres.

Calculations using scientific notation

Multiply large numbers

Worked examples: Multiply large numbers

Problem: Multiply 8 000 000 by 4 000.

Solution

We can do this using standard notation:

8 000 000 × 4 000	(write out the multiplication problem)
= 8 × 1 000 000 × 4 × 1 000	(factorise)
= 8 × 4 × 1 000 000 × 1 000	(gather similar numbers)
= 32 × 1 000 000 000	(multiply similar numbers)
= 32 000 000 000	(multiply)

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 10 2016/01/05 3:15 PM

We can also do this multiplication using scientific notation:

$8\,000\,000 \rightarrow 8{,}0 \times 10^6$	(convert numbers to scientific notation)
$4\,000 \rightarrow 4{,}0 \times 10^3$	
$8 \times 10^6 \times 4 \times 10^3$	(write out the whole calculation)
$= 8 \times 4 \times 10^6 \times 10^3$	(gather similar numbers)
$= 32 \times 10^9$	(multiply similar numbers)

But 32×10^9 is not yet in scientific notation. What makes it "not yet in scientific notation"?

$= 3{,}2 \times 10^1 \times 10^9$	(convert 32 to scientific notation)
$= 3{,}2 \times 10^{10}$	(multiply the base 10 numbers)

Divide large numbers

Worked examples: Divide large numbers

Problem: Divide 8 000 000 by 4 000.

Solution

We can do this in standard notation:

$\frac{8\,000\,000}{4\,000}$	(write out the division problem)
$= \frac{8\,000}{4}$	(divide numerator and denominator by 1 000)
$= 2\,000$	(divide)

We can also do it in scientific notation:

$8\,000\,000 \rightarrow 8{,}0 \times 10^6$	(convert numbers to scientific notation)
$4\,000 \rightarrow 4{,}0 \times 10^3$	
$= \frac{8 \times 10^6}{4 \times 10^3}$	(write out the division problem)
$= \frac{8}{4} \times \frac{10^6}{10^3}$	(break up and gather similar numbers)
$= 2 \times 10^3$	(divide similar numbers)

Activity 7 Multiply and divide large numbers in scientific notation

Do not use your calculator in this activity. Show all your working.

1. $125 \times 2\,000$
2. $4\,000 \times 750\,000$
3. $\frac{90\,000\,000}{1\,500}$
4. $\frac{1\,800}{900\,000}$
5. $1\,200 \times 1\,400$
6. $2\,100 \times 6\,000$
7. $1\,860\,000 \div 6\,000$
8. $136\,000 \div 34\,000\,000$

Multiply small numbers

Worked examples: Multiply small numbers

Problem: Multiply 0,08 by 0,000 04.

Solution

We can do this using standard notation:

$0{,}08 \times 0{,}000\,04$	(write out the multiplication problem)
Count the decimal places in 0,08	(there are 2) and in 0,000 04 (there are 5).
$= 8 \times 0{,}01 \times 4 \times 0{,}000\,01$	(factorise)
$= 8 \times 4 \times 0{,}01 \times 0{,}000\,01$	(gather similar numbers)
$= 32 \times 0{,}000\,000\,1$	(multiply the similar numbers)

Count the decimal places in 0,000 000 1 (there are 7).

$= 0{,}000\,003\,2$	(multiply the two numbers – move the decimal comma 7 places to the left)

We can also do this calculation using scientific notation:

$0{,}08 \rightarrow 8{,}0 \times 10^{-2}$	(convert numbers to scientific notation)
$0{,}000\,04 \rightarrow 4{,}0 \times 10^{-5}$	
$8 \times 10^{-2} \times 4 \times 10^{-5}$	(write out the multiplication sum)
$= 8 \times 4 \times 10^{-2} \times 10^{-5}$	(gather similar numbers)
$= 32 \times 10^{-7}$	(multiply similar numbers)
$= 3{,}2 \times 10^{-6}$	(convert to scientific notation)

Divide small numbers

Worked examples: Divide small numbers

Problem: Divide 0,08 by 0,000 04

Solution

We can do this in standard notation:

$\dfrac{0{,}08}{0{,}000\,04}$	(write out the division problem)
$= \dfrac{8 \times 0{,}01}{4 \times 0{,}000\,01}$	(factorise top and bottom)
$= \dfrac{8}{4} \times \dfrac{0{,}01}{0{,}000\,01}$	(gather similar numbers)

Multiply numerator and denominator by 100 000 and simplify:

$$= \frac{8}{4} \times \frac{0{,}01}{0{,}000\,01} \times \frac{100\,000}{100\,000}$$

$= 2 \times 1\,000$

$= 2\,000$

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 12 2016/01/05 3:15 PM

We can also do this calculation using scientific notation:

$0{,}08 \rightarrow 8{,}0 \times 10^{-2}$	(convert numbers to scientific notation)
$0{,}000\,04 \rightarrow 4{,}0 \times 10^{-5}$	
$\frac{8 \times 10^{-2}}{4 \times 10^{-5}}$	(write out the division problem)
$= \frac{8}{4} \times \frac{10^{-2}}{10^{-5}}$	(gather similar numbers)
$= 2 \times 10^{3}$	(divide)

Activity 8 Multiply and divide small numbers in scientific notation

Calculate the following without using a calculator. Show all your working.

1. $0{,}003 \times 0{,}000\,02$
2. $0{,}15 \times 0{,}000\,004$
3. $0{,}09 \div 0{,}000\,03$
4. $0{,}000\,08 \div 0{,}000\,002$
5. $0{,}36 \times 0{,}000\,000\,2$
6. $0{,}001\,5 \times 0{,}000\,04$
7. $0{,}006\,66 \div 0{,}000\,022\,2$
8. $0{,}000\,000\,9 \div 0{,}000\,3$

Unit 1.2 Summary activity

1. Convert numbers from standard notation to scientific notation:
   - **a)** 555 000 m/s
   - **b)** 0,000 234 kg
2. Convert numbers from scientific notation to standard notation:
   - **a)** $6{,}2 \times 10^{6}$ J
   - **b)** $5{,}5 \times 10^{-6}$ mm
3. Multiply:
   - **a)** $2{,}5 \times 10^{3}$ by $3{,}25 \times 10^{4}$
   - **b)** $2{,}7 \times 10^{-3}$ by $2{,}5 \times 10^{-4}$
4. Divide:
   - **a)** $2{,}5 \times 10^{3}$ by $3{,}25 \times 10^{4}$
   - **b)** $2{,}7 \times 10^{-3}$ by $2{,}5 \times 10^{-4}$

Unit 1.3 Working with formulae

In the Senior Phase you learnt that speed = distance ÷ time. The words "speed = distance ÷ time" describe a relationship between the quantities speed, distance and time. The words are called a "word formula".

If you use the word **speed*** along with d for distance and t for time, the word formula becomes a symbolic formula, which we write as: speed = $\frac{d}{t}$.

The plural of **formula** can be either **formulae** or **formulas**.

* The letter *s* is not acceptable as a symbol for **speed**.

Definition: A formula is an equation that shows the relationship between variables.

In Grades 7 to 9, some formulae that you used in Maths were:

- perimeter of a rectangle: $P_{\text{rectangle}} = 2l + 2w$
- area of a triangle: $A_{\text{triangle}} = \frac{1}{2}bh$
- volume of a cylinder: $V_{\text{cylinder}} = \pi r^2 h$
- length of the hypotenuse of a right-angled triangle: $L_{\text{hypotenuse}} = \sqrt{a^2 + b^2}$
- speed: speed = distance ÷ time or speed = $\frac{d}{t}$

In Senior Phase Technology you used:

- current: $I = \frac{V}{R}$
- mechanical advantage = output effort ÷ input effort

In this subject and in Mechanical Technology, you will come across formulae such as:

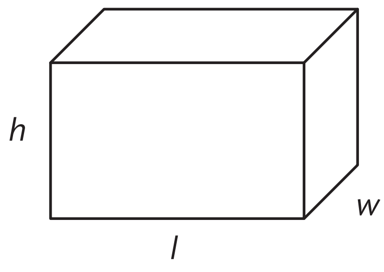
- acceleration = change in velocity ÷ time or $a = \frac{v_f - v_i}{t}$
- pressure = force ÷ area or $P = \frac{F}{A}$
- momentum = mass × velocity or $p = mv$

Why we use formulae

A formula tells you exactly what to do to solve a particular problem. If you don't use a formula, you have to work from basic principles to solve the problem.

For example, if you want to find the volume of a box, you could either use the formula $V = l \times w \times h$, or you could make a lot of little cubes and spend time working out how many cubes it takes to fill the box. You can either use a formula, or do things the long way.

Figure 1.2



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 14 2016/01/05 3:15 PM

How to choose a formula

How do you know which formula to use?

1. First read the question.
2. Identify the variables involved in the equation.
3. Identify those that are given and those that are not given.
4. Look for a formula that connects the given variables and the variables you are not given.

How to use a formula

Seven steps to follow when you use a formula to solve a problem:

Step 1 Write what you know – the known variables.

Step 2 Write what is unknown – the unknown variable, or what you are required to find (RTF) or required to calculate (RTC).

Step 3 Write the appropriate formula.

Step 4 If necessary, change the subject of the formula.

Step 5 Substitute known values into the formula. Take care to use the correct units.

Step 6 Do the calculations showing all the steps.

Step 7 Write the answer with the correct units.

Worked examples: Choose and use a formula

1. The Civil Technology class is practising how to set out the foundations of a building on the school field. To protect their work from destruction by soccer players, they want to put a fence around their work area. The area has a rectangular shape: 21 m long and 17 m wide.
   a) What formula do you use to calculate the length of fencing?
   b) How much fencing do they need?

   Solutions

   a) You need a formula that gives the perimeter of a rectangle. It is the formula $P = 2 \times l + 2 \times w$, where P stands for perimeter, l for length and w for width.

   b)

Step 1	Given	the area is rectangular; $l = 21$ m; $w = 17$ m	
Step 2	Unknown	length of fencing	
Step 3	Formula	$P = 2l + 2w$	
Step 4		(does not apply)	
Step 5		$= (2 \times 21) + (2 \times 17)$	(substitute)
Step 6		$= 42 + 34$	(calculate)
Step 7		$= 76$ m	

2. You have a simple circuit with a resistor and battery. Calculate the current across the resistor if the voltage is 3 V and the resistance is 10 Ω.

Solution

Given $V = 3$ V and $R = 10\ \Omega$

Unknown I

Formula $I = \dfrac{V}{R}$

$= \dfrac{3}{10}$ (substitute)

$= 0{,}3$ A

Activity 9 Choose and use a formula

To answer these questions you will need some of the formulae at the beginning of this unit. Show all the formulae and use the given method. You may use a calculator.

1. Calculate the area of a triangle where the height is 28 cm and the base is 10 cm.
2. A gantry crane in a workshop can move from one end of the factory to the other end in 36 seconds. The workshop is 18 m long. What is the crane's average speed as it moves from one end of the workshop to the other?
3. A cylindrical water tank has inside dimensions of radius = 30 cm; length = 1,8 m. What is the volume of the tank in cubic metres?
4. What is the mechanical advantage of a first class lever if an effort (input force) of 100 N is able to move a load (output force) of 700 N?
5. You have a simple circuit with a lamp, a 6 V battery, a switch and an ammeter. The lamp is glowing and the ammeter shows a current of 0,3 A. Calculate the resistance of the lamp.
6. The two short sides of a right-angled triangle are 120 mm and 160 mm. Calculate the length of the side opposite the right angle.
7. Calculate the mechanical advantage of a lever if the input arm is 600 mm and the output arm is 150 mm.
8. A swimming pool has a rectangular shape. It is 25 m long and 10 m wide. The bottom of the pool slopes down from the shallow end to the deep end. At the shallow end it is 1,2 m deep. At the deep end it is 2,4 m deep.
   - **a)** Calculate the volume of water, in cubic metres, that is needed to fill the pool.
   - **b)** The vertical sides and end of the pool are going to be re-tiled. Calculate the area, in square metres, of the tiles that will be needed to re-tile the pool up to the water-line.

How to change the subject of a formula

Under the heading "How to use a formula" on Page 15 is "Step 4 – If necessary, change the subject of the formula".

In Grade 9 Technology you used Ohm's Law:

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

or

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

where:

- R is resistance in ohms (Ω)
- V is voltage in volts (V)
- I is current in amps (A)

Change the subject in Ohm's Law

Ohm's Law is very useful for analysing simple circuits. In the form $R = \frac{V}{I}$ the formula enables you to find the resistance in a circuit. You can also use it to find V and I.

How do we use the formula it to find V or I? We change the subject of the formula.

A. How to make *V* the subject of the formula

Start with the formula:

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

We want to find V, so we turn the equation around to get V to the left hand side:

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

We want V to be the subject of the formula – we don't want I on the left-hand side – so multiply both sides by $\frac{I}{1}$:

$$\frac{V}{I} \times \frac{I}{1} = R \times \frac{I}{1}$$

$$\frac{V}{\cancel{I}} \times \frac{\cancel{I}}{1} = I \times R$$

$$V = IR$$

B. How to make *I* the subject of the formula

Start with the formula:

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

We want I on the left-hand side, so multiply both sides by I:

$$RI = \frac{VI}{I}$$

$$RI = V$$

We don't want R on the left-hand side, so multiply both sides by $\frac{1}{R}$:

$$RI \times \frac{1}{R} = V \times \frac{1}{R}$$

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

Worked examples: Change the subject of the formula

1. What is the voltage if the current is 0,3 A and the resistance is 10 Ω?

   Solution

   Given $I = 0{,}3$ A and $R = 10\ \Omega$

   Unknown V

   Formula $R = \frac{V}{I}$

   $V = IR$ (change the subject)

   $V = 0{,}3 \times 10$ (substitute)

   $= 3$ V

2. What is the resistance if the current is 0,3 A and the voltage is 3 V?

   Solution

   Given $I = 0{,}3$ A and $V = 3$ V

   Unknown R

   Formula $R = \frac{V}{I}$

   $= \frac{3}{0{,}3}$

   $= 10\ \Omega$

Activity 10 Change the subject of the formula

These activities are based on Activity 9, but now you need to change the subject of the formula.

1. Calculate the height of a triangle that has an area of 60 cm^2 and a base that is 15 cm.
2. A gantry crane in a workshop can move from one end of the factory to the other end in 32 seconds. The crane's average speed as it moves from one end of the workshop to the other is 1,5 m/s. How long is the workshop?
3. A cylindrical water tank has an inside radius of 20 cm; the volume of the tank is 0,2 cubic metres. How long is the cylinder in metres?
4. What effort is needed to use a first class lever to move a load of 700 N if the mechanical advantage is 5?
5. You have a simple circuit with a lamp, a battery, a switch and an ammeter. The lamp is glowing and the ammeter shows a current of 0,3 A. The resistance of the lamp is 36 Ω. Calculate the voltage of the battery.
6. The hypotenuse of a right-angled triangle is 24 cm long. One of the short sides is 16 cm long. Calculate the length of the other short side.
7. The mechanical advantage of a lever with an input arm of 600 mm is 5. Calculate the length of the output arm.

Quick Activity:

Look at the formulae in the Resource Pages at the end of the book and discuss:

- What does the symbol P stand for? What does p stand for?
- What does the symbol A stand for? Is there another A?
- What does V stand for? And what about v?

Warning: Incorrect use of symbols can endanger correct answers!

A symbol might stand for many different quantities or units. Take care to choose the right one.

Unit 1.3 Summary Activity

1. The area of a triangle is 75 cm^2 and the height is 15 cm. Calculate the length of the base of the triangle.
2. A router arm in a workshop can move from one end of the router bed to the other end in 7 seconds. The arm's average speed is 0,5 m/s. How long is the router bed?
3. A rectangular water tank has base measurements of 40 cm × 100 cm. The volume of the tank is 0,75 cubic metres. How high is the tank in centimetres?
4. The security fence of a rectangular yard is 220 m long altogether. One side is 40 m long. Calculate the length of the other side.

Unit 1.4 Rate

In Natural Sciences in previous grades you did an activity which involved taking someone's pulse before and after exercise. You will have counted the number of heart beats per minute before and after exercise and compared the two numbers. You were actually comparing heart rates.

In Mathematics, in the Senior Phase, you studied ratio and rate. You would have learnt that:

- When you compare two quantities of the same kind, you make a **ratio**. For example: In Grade 10 there are 20 girls and 15 boys. The ratio of boys to girls is $\frac{15}{20} = \frac{3}{4}$, or three to four.
- When the ratio compares two quantities of different kinds, you describe a **rate**. For example: on average, the learners do 45 minutes of homework each day. That is a rate of 45 minutes of homework per day.

Definition: A rate is a change in a physical quantity per unit of time.

So the concept of rate is not new to you. And it is important to understand the concept because it affects you directly every day:

- The cost of airtime is a rate. If the rate is high you don't get much airtime for your money. We measure the cost of airtime in Rand per minute.
- If you walk too slowly, you get to school late. Speed is a rate. We measure speed in metres per second.

- There are exactly 44 jelly babies in a pack. A generous friend shares a pack of jelly babies equally with you. You eat yours in 22 minutes. That is a rate of one jelly baby per minute.

Over the three years of this Technical Sciences course we will deal with many formulae that involve rate. They all describe a change in some physical quantity per unit of time: per hour, or per minute, or per second.

Rates are used every day in industry:
- A civil engineer designs an urban road to carry a peak load of 500 cars per hour.
- A mechanical technician has to design a boom that allows four vehicles per minute to pass.
- An electrician is required to set an alarm warning light that flashes three times per second.

Activity 11 Calibrate a candle: make a candle clock

The candle clock was used years ago to indicate the passing of time. Special candles were marked with lines spaced so that, as the candle burned down, one line would disappear each hour.

The process of marking the lines is called **calibration***. In this activity you will calibrate a candle to make a candle clock.

Apparatus
- ❑ a draught-free room and a fire-resistant workbench
- ❑ two identical straight candles
- ❑ two stable candle holders
- ❑ matches
- ❑ a permanent marker pen
- ❑ a stop watch

* **calibrate** means to set or correct a measuring instrument to measurements that we already know

A. Plan the activity a few days ahead as it might take most of the day to complete. AND ... plan a strategy to convince the principal to use your candle to run the school for a day.

B. Decide what marks you will make on the candle. You might choose, for example to make marks for 15 minute periods of time. Thin candles burn faster than thick candles.

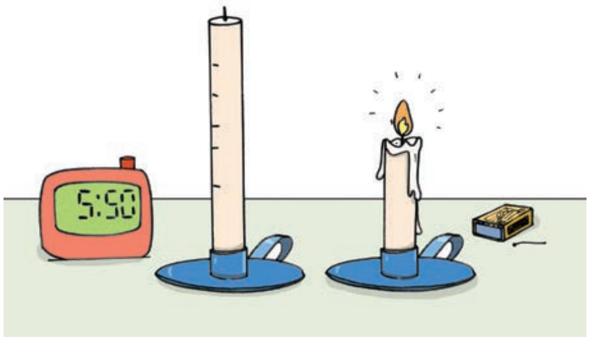
C. Place the candles firmly in the holders.

D. Put the candle holders close together and check that the candles are the same height.

E. Light one candle. After the chosen period of time make a mark on the second candle opposite the top of the burning candle. Carry on marking the second candle until about one third of the candle has burned.

F. Find the average (mean) distance between the marks you have made and continue marking the second candle at that spacing.

Figure 1.3 *Calibrating a candle clock*



Questions

1. Which two units of measurements are involved?

2. What is the rate involved?

3. What are the units of the rate?

Rates in Technical Sciences

In Technical Science all the rates we use compare some physical quantity with time. The rates we use are always in terms of some physical quantity per hour, per minute, or per second.

When we describe a rate, the word "per" is always used to separate the units of the two measurements. In previous examples we saw "metres per second", "Rands per hour" and "jelly babies per minute".

The word "per" sounds mysterious, but it isn't:

- Instead of writing "per" we use the slash "/". You could say that we pronounce "/" as "per".
- Instead of saying "per hour" you could say "for every hour" or "for every one hour".

For example, on the N1, most cars travel at 120 km/h. That means they travel 120 km for every hour that they are on the road.

If they travel for 2 hours they go twice as far: $2 \times 120 = 240$ km.

If they travel for just half an hour, they do half the distance: $\frac{1}{2} \times 120 = 60$ km.

Table 1.6: Some rate formulae used in Technical Sciences

Context	Word formula	Formula	Units
Motion	speed = distance ÷ time	$speed = \frac{d}{t}$	m/s
Motion	velocity = displacement ÷ time	$v = \frac{d}{t}$	m/s
Motion	acceleration = velocity ÷ time	$a = \frac{v}{t}$	m/s^2
Electric circuits	rate of charge = charge ÷ time	$I = \frac{Q}{t}$	C/s

When a rate describes the number of times something happens per second, that rate is called the frequency of that happening. The unit for "happenings per second" is Hertz (Hz). The following are examples of the use of frequency:

- Electricity is generated by Eskom at 50 Hz.
- The frequency of visible light is about 1 015 Hz.
- The frequency of sound the human ear can hear varies from 20 Hz to 20 000 Hz.

Worked examples: Rates

1. South African athlete Caster Semenya won gold in the women's 800 metres at the 2009 World Championships in a time of 1 minute 55,45 seconds. What was her average speed during the race? Speed is the rate at which a distance is covered.

Solution

Given: distance = 800 m

time = 1 min 55,45 s = 60 + 55,45 = 115,45 s

Unknown: speed

Formula: speed = $\frac{d}{t}$

$= \frac{800}{115,45}$ (substitute)

$= 6,93$ m/s

2. In a section of an electronic circuit, it is calculated that the flow of charge is 180 coulombs per hour. What is the rate of charge in that section of the circuit in coulombs per second?

Solution

Given: flow of charge = 180 coulombs per hour

time = 1 hour = 3600 seconds

Unknown: rate of charge

Formula: rate of charge = $\frac{Q}{t}$ (see Table 1.6)

$= \frac{180}{3600}$ (substitute)

$= 0,05$ C/s

Activity 12 Calculate rates

1. South African athlete Josia Thugwane won an Olympic gold medal in Atlanta in 1996. He won the 42,2 km marathon in 2 h 12 min 36 s. What was his average speed during the race?
2. Samuel was trying to lose mass. His mass decreased from 99 kg to 91 kg over 60 days. At what rate did he lose mass?
3. In the science laboratory, a trolley rolls down a 2 m long ramp. Its progress is measured by an electronic gadget at a displacement of 0,5 m from the start and again at 1,4 m. The time taken between the two points is 1,2 seconds. What is the trolley's average velocity between the two points?
4. An electric circuit is capable of delivering a charge to a capacitor at a rate of 0,9 coulombs per second. The capacitor will be fully charged with approximately 3 000 coulombs. How long, to the nearest hour, will it take to charge the capacitor? The formula to use is charge = rate of charge × time.

Unit 1.4 Summary activity

1. Rewrite the sentence below leaving out the incorrect words.
   When you compare two quantities of **the same kind/different kinds** you describe a rate.
2. Rewrite the sentence below by replacing any incorrect word with a correct word.
   In describing a rate, the word "per" is always used to separate the units of the two measurements.
3. In Technical Science all the rates we use are in terms of some physical quantity per hour, or per minute, or per second. Find three different formulae, one for each of these three time periods. Write them down together with their correct units.

Unit 1.5 Scalar and vector quantities

The practical activities we do involve the measurement and calculation of many different physical quantities, including distance, speed, time and force.

All physical quantities are divided into two broad groups: scalars and vectors.

Definition: **Physical quantities that have magnitude only are called scalars.**

Definition: **Physical quantities that have magnitude and direction are called vectors.**

Scalars

Scalars are physical quantities that have magnitude only (not direction). For example, a workshop manager might describe a block and tackle using scalar quantities like these:

- the mass it can lift (kilograms)
- the length of the chain (metres)
- mechanical advantage (a ratio that does not have a unit)
- guarantee period (years)

Quick Activity:

A beaker contains 250 ml of water. Does this measurement have direction? Which other quantities can you think of that do not have direction?

Vectors

Physical quantities that have magnitude and direction are called vectors. For example, a goalie has the ball in his hand, about to kick it up-field. He is not thinking about vectors, but he is thinking about how far and in what direction he plans to kick the ball.

Quick Activity:

A rescue vehicle lifted a 20 kN car out of the water.

Which words in the sentence above describe direction and which words describe magnitude?

Figure 1.4 *The vector describes the magnitude and the direction of the displacement of the ball.*

Activity 13 Recognise the difference between scalars and vectors

Copy the table below into your notebook. Then write either "scalar" or "vector" in the third column.

Example	Physical quantity	Scalar or vector
A typical bakkie has a 2 000 cm^3 engine.	2 000 cm^3	
The lion roamed 20 km in a north westerly direction before it was spotted.	20 km in a north westerly direction	
A diesel bakkie can travel 600 km on one tank of fuel.	600 km	
The hook of the truck-mounted crane can reach a height of 5,4 m above road level.	5,4 m above road level	

The graphical representation of vectors

All scalars and vectors represent physical quantities:

- A scalar is just a number and its unit. For example, an athlete ran a 30 km race.
- A vector is a number with its unit and a direction. For example, the race ended 1 km west of where it started.

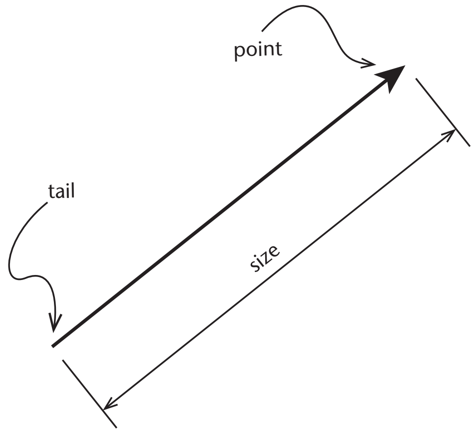
Vectors are useful because:

- You can describe them in words (as we did above).
- You can draw them (as we will on the next page).

We always draw vectors as arrows:

- The arrow **head** (the point) shows the **direction** of the vector.
- The **length** of the arrow represents the **size** or magnitude of the vector.
- The back end of the vector is called the **tail**.

Figure 1.5 *The length of the vector (tail to point) represents the size of the vector; the arrow head (the point) shows its direction.*



Measure and draw vectors

Vector diagrams are useful because:

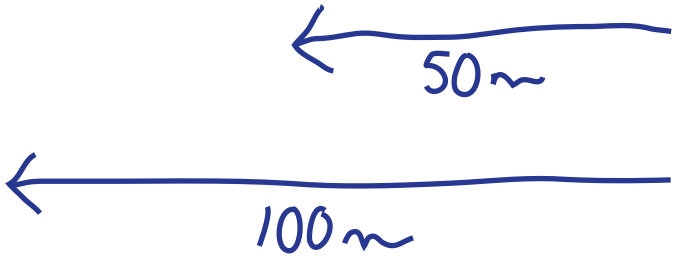
- You can learn about the magnitude and the direction of the vector just by looking at a drawing of the vector.
- You can draw a vector diagram to represent any vector quantity; e.g. displacement, velocity, force, etc.

Sketching and scale drawing

Sometimes we draw rough sketches of vectors; at other times we draw accurate diagrams.

When we sketch vectors, we do not need to use a scale – we draw an arrow of an appropriate size and describe its size in writing on the diagram. A sketch of a larger vector should be shorter than a sketch of a smaller vector.

Figure 1.6 *The sketch represents displacement vectors: 50 m to the left and 100 m to the left.*



Activity 14 Sketch vectors

Sketch the following vectors:

1. 5 m to the right
2. 2 m to the left and 6 m to the left
3. 50 m to the right and 70 m to the left
4. 1 500 m to the left and 1 700 m to the left

For an accurate vector diagram we draw the vector to scale.

Worked example: Draw accurate diagrams of vectors

1. Draw a vector to represent a man's displacement 80 m to the right.

Solution

We cannot draw 80 metres in your exercise book. We need to represent the 80 metres using a scale.

Based on our experience, we choose the scale 1 : 1 000. This means that 1 m on the ground is represented by:

$$\frac{1}{1\,000} = 0{,}001 \text{ m}$$

$$= 1 \text{ mm on the page}$$

So 80 m on the ground will be represented by:

$80 \times 1 \text{ mm} = 80 \text{ mm on the page}$

We could also have expressed the scale as 1 mm = 1 m. So 80 m on the ground is represented by:

$$\frac{80}{1} \times 1 \text{ mm} = 80 \text{ mm on the page}$$

Figure 1.7 *Drawing of a displacement vector 80 m to the right*

Scale 1 : 1 000

Activity 15 Draw accurate diagrams of displacement vectors

Draw the following displacement vectors using an appropriate scale:

1. 70 m to the right
2. 7 m to the right
3. 700 m to the left
4. 2 000 m to the left

Worked example: Sketch and draw displacement and force vectors

1. A tall man lifts a box from the floor to a shelf 2,5 m above the ground.

- **a)** Sketch and draw the displacement vector.
- **b)** The box weighs 50 N. Sketch and draw the force vector to represent the weight of the box.

Solutions

- **a)** The vector diagram in Figure 1.8 represents the height to which the box is lifted. The arrow points upwards to show the direction of the displacement. The scale is 1 cm = 1 m, so the arrow is 2,5 cm long.
- **b)** The vector in Figure 1.9 represents the weight of the box:
  - The arrow points downwards to show the direction of the force.
  - The scale is 1 cm = 10 N so the arrow is 5 cm long.

Figure 1.8 *Vector diagram of the 2,5 m upward displacement*

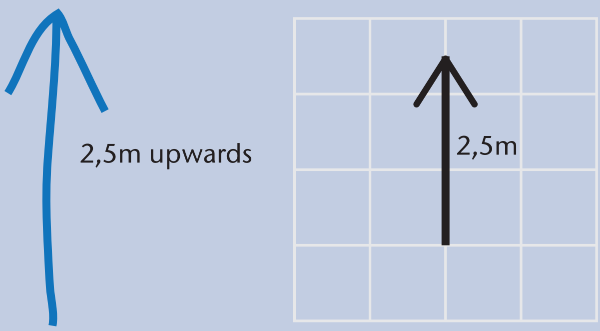
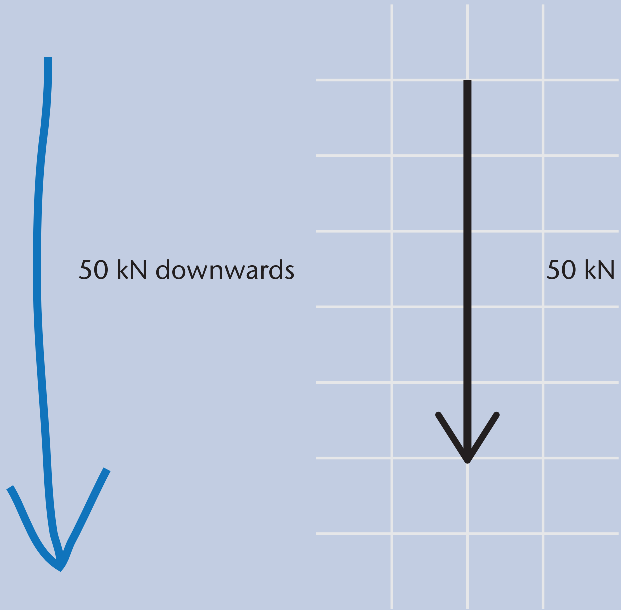


Figure 1.9 *Force vector for the weight of the box*



Activity 16 Displacement and force vectors

1. A lift in a building descends from the 10th floor to the ground floor. Each floor is 3,5 m high. The fully loaded lift exerts a force of 37 000 kN on the cable when it is stationary.

- **a)** Sketch and draw the displacement vector.
- **b)** Sketch and draw the force vector for the cable.

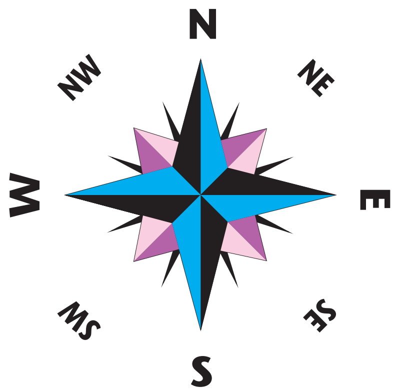
Direction of vectors

There are many ways to show the direction of vectors. In previous examples we described the direction as left, right, up or down. Other common ways of describing direction are forwards or backwards, in a positive direction, or in a negative direction.

We also use the following two methods:

- compass directions
- bearing

Figure 1.10 *Cardinal and inter-cardinal points of the compass*



Compass directions

This method uses the points of the compass to indicate direction.

North, south, east and west are called the cardinal points of the compass. North-east, south-east, south-west and north-west are the inter-cardinal points of the compass.

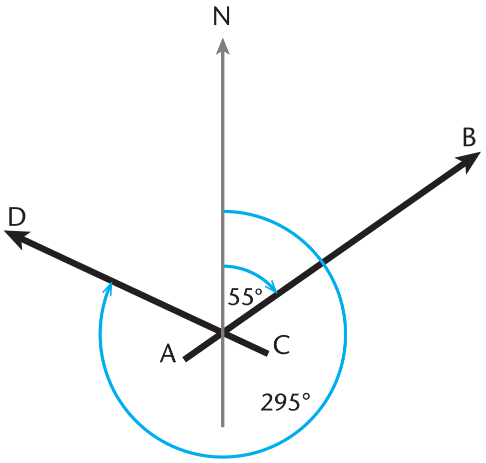
Bearing

Another way of indicating the direction of a vector is the angle of the line of the vector from the North line. This is called bearing.

In our work, the bearing of a vector is the angle in degrees measured in a clockwise direction between a line drawn straight up the page and the line of the vector.

For example, the bearing of vector AB in Figure 1.11 is 55° and the bearing of vector CD is 295°.

Figure 1.11



Activity 17 Measure and describe the magnitude and direction of vectors

1. Draw a table with three columns and nine rows in your notebook, at the top of a clean page. Give the columns headings as in the table below.

Name of vector	Magnitude of vector (mm)	Compass direction of vector	Bearing of vector (degrees)
1	45	North	0
2			

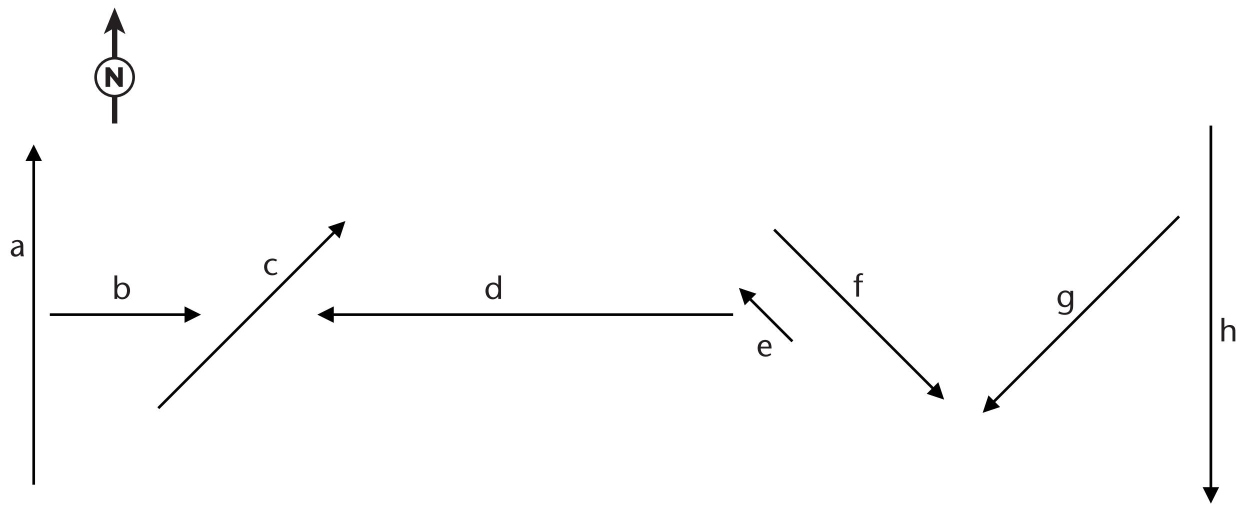
2. Measure the magnitude and direction of each of the vectors in Figure 1.12. Record the magnitude of the vector in millimetres and give the direction in terms of the eight points of the compass and bearing. The first one has been done for you as an example in the table.

3. Swap notebooks with a partner. Check your partner's answers and return the book.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 28 2016/01/05 3:15 PM

4. Discuss any problems and be ready, together, to describe your vectors to the class.

Figure 1.12 *What is the magnitude, compass and bearing direction of each of these vectors?*



Activity 18 Design your own vectors

1. Draw a table the same as the one in the last activity in your notebook.
2. In the table, design your own set of 8 vectors:
   - Make them different to the vectors in the last activity.
   - Use lengths which are multiples of 5 mm.
   - Use the cardinal and inter-cardinal points of the compass and bearing to describe direction.
3. In the space below the table, draw a large circle and mark the cardinal and inter-cardinal points.
4. Swap notebooks with a partner. In your partner's book, draw the vectors your partner has described in the table. Please work accurately.
5. Get your book back and check the vectors that have been drawn in your book. If you disagree, check and re-draw. You must agree that all the vectors are drawn correctly.

Activity 19 Draw vectors

Draw the following vectors accurately. Write down the scale that you use.

1. A ship sails 2 000 km on a bearing of 190°.
2. An explorer walks 10 km on a bearing of 235°.
3. A force of 155 N is acts on a bearing of 35°.
4. A force of 60 N acts in a north-easterly direction.

Activity 20 Read a diagram with vectors (Extension)

Figure 1.13 shows:

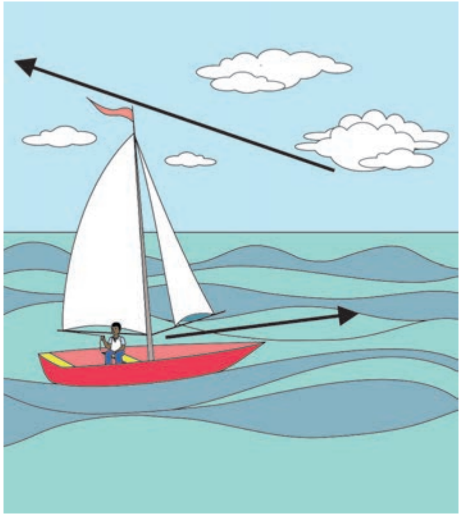
- a velocity vector for the wind
- a velocity vector for the yacht

1. Which of the pairs of vector quantities in the table below is reasonable and which is not reasonable for this situation?

2. Explain why you think the quantities are reasonable or not reasonable.

Pair of vectors	a	b	c
Wind	2 m/s east	20 m/s south	5 m/s north
Boat	0,5 m/s north	10 m/s west	1 m/s west

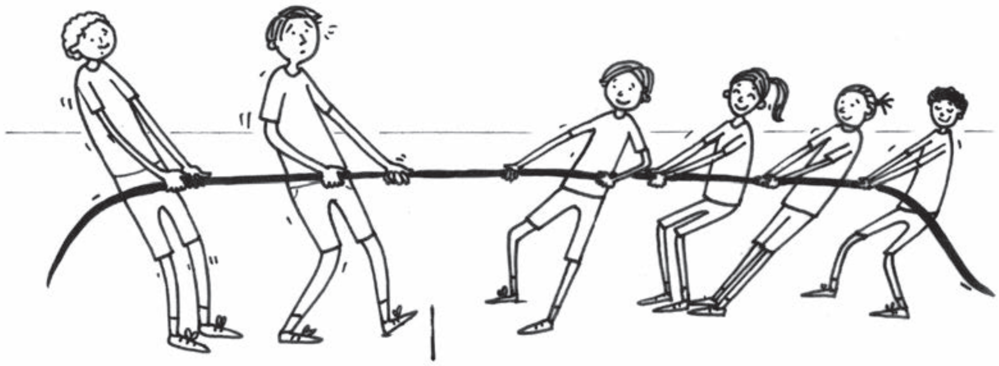
Figure 1.13 *Vector diagrams are useful for sailors. The boat's velocity vector is influenced by the wind's velocity vector.*



The resultant vector

The two biggest learners in the school hold one end of a long, thick rope and challenge other learners to a tug-of-war. Can the smaller learners win the game?

Figure 1.14 *Tug-of-war between smaller and bigger learners*



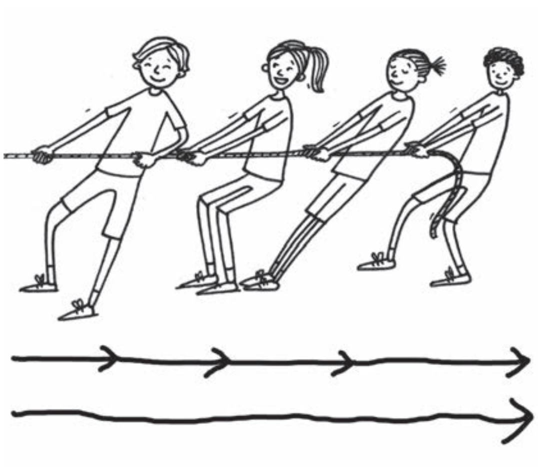
It might take as many as four smaller learners, but if they tug in the same direction, their individual efforts will add up to a combined effort large enough to win.

We can represent the efforts of the learners in the tug-of war using a vector diagram.

The small vectors in Figure 1.15 represent the individual efforts of four learners who have taken up the challenge. Their combined effort (the sum of their efforts) is represented by the one big vector. We find the length of the big vector by adding the smaller vectors together – the big vector is the **resultant** vector of the other vectors added together.

Definition: The resultant of two or more vectors is a single vector which can produce the same effect as the component vectors.

Figure 1.15 *The big vector is the resultant of the other vectors added together*



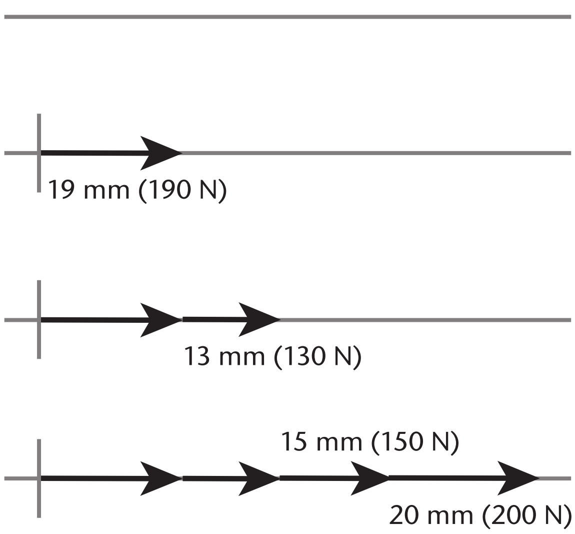
Methods of adding vectors

The efforts of the four learners in Figure 1.15 are 190 N, 130 N, 150 N and 200 N.

We can determine the length of the resultant vector in two different ways: by **calculation** and by the **graphical method**.

1. **By calculation**: Add the values of the vectors together.
   190 + 130 + 150 + 200 = 670 N
2. **By the graphical method**: Draw vectors tail-to-head.
   - **a)** Decide on a scale for the diagram: 1 mm = 10 N.
   - **b)** Draw a horizontal line across the page and make a mark *near* the left end of the line.
   - **c)** The first vector is 190 N. The scale is 1 mm = 10 N so it must be drawn 19 mm long, starting at the mark and pointing to the right.
   - **d)** Start the second vector exactly where the first vector ends: the tail of the second vector starts at the head of the arrow of the first vector. We say that the vectors are drawn tail-to-head.
   - **e)** Draw the remaining vectors in the same way.
   - **f)** Measure the length of the line of vectors. The scale of the drawing is 1 mm = 10 N, so to find the value of the vector multiply the total length by the scale factor of 10.

Figure 1.16



What is your answer? The length of the line of vectors you drew in (2) should have the same value as the sum of the vectors you found in (1).

Ask yourself: Does this result confirm that the resultant of two or more component vectors is a single vector which produces the same effect as the component vectors?

Quick Activity:

Write this question and its answer in your notebook:

What is the relationship between the component vectors and the resultant vector?

Activity 21 Addition by calculation and by the graphical method

1. Use calculation to find the resultants of the following groups of vectors:
  - **a)** 32 mm up the page; 47 mm up the page; 101 mm up the page
  - **b)** 7,6 m up; 13,7 m down; 3,6 m up; 1,7 m down
  - **c)** 4 cm to the right; 2 cm to the right; 30 mm to the right; 0,02 m to the right
  - **d)** +1 200 mm; –2,3 m; +76 cm; +0,5 m

2. Use the graphical method to draw the resultants of the following groups of vectors. State the scale of each drawing.
  - **a)** +6 cm; +2 cm; +2,5 cm; +4,5 cm
  - **b)** 101 mm left; 2,7 cm left; 0,027 m left
  - **c)** +1,3 m; +2,2 m; +0,7 m
  - **d)** +1 700 mm; –900 mm; +300 mm

More about vector addition

1. The effect of the order of the vectors

Activity 22 The effect of the order of vectors

Question: Does the order of the component vectors affect the size of the resultant vector?

1. Draw the four small vectors (190 N; 130 N; 150 N; 200 N) again, all pointing in the same direction and all along the same straight line, but put them in a different order. Take care to draw them to scale (19 mm; 13 mm; 15 mm; 20 mm).

2. Find the resultant of the four vectors graphically.

Answer: The order of the component vectors does not affect the size of the resultant vector.

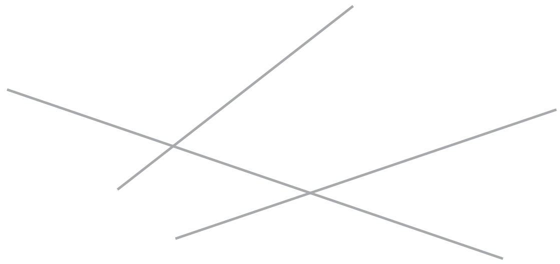
2. The effect of the direction of vectors

Activity 23 The effect of the direction of vectors

Question: Does the direction of the component vectors affect the direction of the resultant vector?

1. Draw three light lines right across the page, all at different angles, as in Figure 1.17.
2. On each of the lines, draw the same four vectors tail-to-head in the same direction.
3. Draw the resultant vector for each of the three sets of four vectors. Each resultant vector must be drawn parallel and close to the vectors it represents.

Figure 1.17

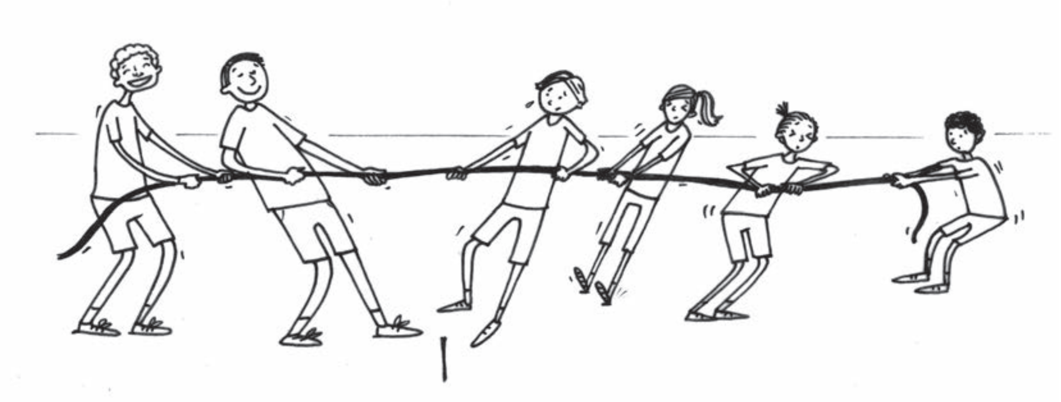


Answer: The direction of a resultant vector depends on the direction of the component vectors.

3a. Addition of vectors with opposite directions

Question: What happens when vectors along the same line act in opposite directions?

Figure 1.18



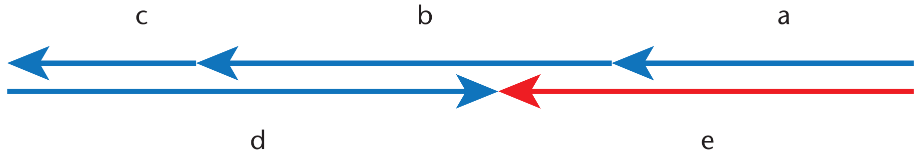
The cartoon shows us that vectors acting in opposite directions tend to cancel each other out.

The table on the next page describes a similar situation – a group of four vectors which all act along the same horizontal line but not all in the same direction. The vectors have been drawn below the table.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 33 2016/01/05 3:15 PM

Vector name	Vector length (mm)	Vector direction
a	40	Left
b	55	Left
c	25	Left
d	65	Right

Figure 1.19 *This is the graphical method of adding vectors with opposite directions.*



We can determine the resultant by calculation or by measurement.

- Calculation:
  40 Left + 55 Left + 25 Left + 65 Right = 55 Left
- Measurement:
  Vector e is 55 Left

Answer: Vectors that act in opposite directions tend to cancel each other out.

3b Addition of vectors with opposite signs

Question: What happens when vectors acting along the same straight line have different signs?

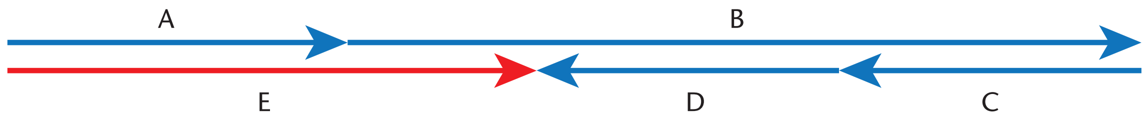
The table below describes another group of four vectors which all act along the same horizontal line. Some of the vectors have a positive sign and some have a negative sign.

Vector name	Vector length in mm	Vector direction
A	45	+
B	105	+
C	40	–
D	40	–

Graphical method of adding vectors with opposite signs

1. The positive direction is usually to the right and the negative direction is to the left.
2. Draw a horizontal line across the page.
3. Draw vector A on the line pointing in the positive direction (to the right).
4. Draw the component vectors tail-to-head, with B pointing in the positive direction and C and D in the negative direction.
5. Draw the resultant below – it starts at A's tail and ends at D's head.

Figure 1.20 *The graphical method of adding vectors with opposite signs (Scale 1 mm = 1 mm)*



We can determine the resultant by calculation or by drawing and measuring.

- Calculate:
  +45 + (+105) + (–40) + (–40) = 45 + 105 – 40 – 40
  = 70
- Draw and measure:
  Vector E is +70

Answer: Vectors with opposite signs tend to cancel each other out.

Activity 24 Addition of vectors

1. Use calculation to find the resultants of the following vectors:
   a) 4,5 cm North East (NE); 5,5 cm NE; 3,5 cm NE; 2,5 cm NE
   b) +9 cm; –5 cm; +7 cm; –2 cm
2. Use the graphical method to draw the resultants of the following vectors. Use an appropriate scale.
   a) 35 mm NW; 75 mm NW; 20 mm SE; 35 mm SE
   b) –0,11 m; –0,06 m; +0,03 m; +0,04 m

Unit 1.5 Summary activity

Complete the summary in your notebook.

1. Complete the sentences:

a) Physical quantities that have ______________ ______________ only are called scalars.

b) Physical quantities that have ______________ and ______________ are called vectors.

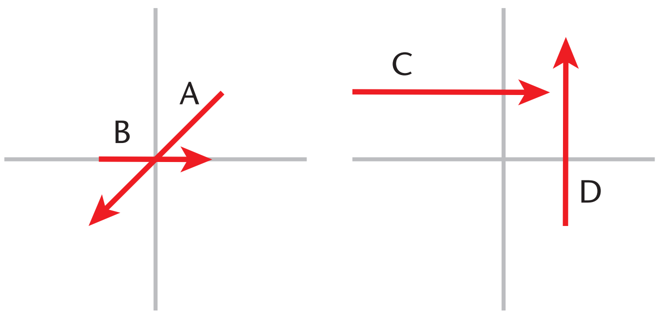
c) The resultant of two or more vectors is a single vector which ______________

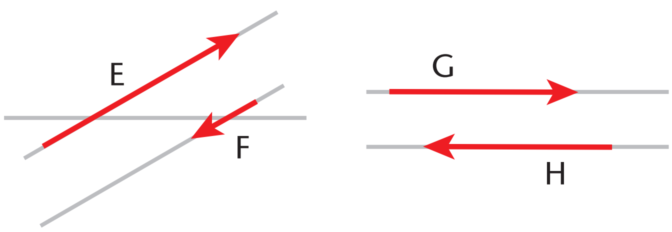
2. Categorise each of the following as either a scalar or a vector quantity by ticking a block.

	Description	Scalar	Vector
1	The hammer fell 5 m before crashing through the glass floor.		
2	The hammer had a 3 kg head.		
3	Three square metres of glass needed to be replaced.		
4	The new floor level is 16 mm higher than the old floor because the new glass is thicker.		

3. Describe the vectors below. Use compass directions.

Figure 1.21





Vector label	Magnitude in mm	Direction
A		
B		
C		
D		
E		
F		
G		
H		

4. Draw the following vectors:

a) if the positive direction is to the right: 88 mm; –99 mm

b) if the positive direction is up the page: –66 mm; 77 mm

5. Add the following vectors graphically using the tail-to-head method:

a) 33 mm + 2,2 cm + 0,04 m + 15 mm

b) 35 mm – 31 mm + 76 mm – 14 mm

6. Add the following vectors by calculation:

a) 2 mm + 2 cm + 2 m + 2 km (give the answer in metres)

b) 35 mm – 31 mm + 76 mm – 14 mm

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 37 2016/01/05 3:15 PM

Chapter summary

- The International System of Measurement (SI system) is a decimal system of measurement.
- Units used in the SI system are either fundamental units or derived units.
- A set of prefixes describes the size of the numbers relative to one unit of the quantity being measured. Conversion factors enable us to convert between different units with different prefixes.
- Time is the only fundamental quantity in the SI system that is not based on the decimal system.
- Other systems of measurement include the centimetre-gram-second system and the imperial system.
- Scientific notation is a way of writing very large numbers easily. In standard notation, the diameter of a proton is 0,000 000 000 000 004 m. In scientific notation, this becomes $4,0 \times 10^{-15}$ m.
- Rate is the change in a physical quantity in unit time. The rates we use are in terms of some physical quantity per hour, per minute, or per second.
- When a rate describes the number of times something happens per second, that rate is called the frequency. The unit for frequency is Hertz (Hz).
- All physical quantities are divided into two broad groups, scalars and vectors:
  - Physical quantities that have magnitude only are called scalars.
  - Physical quantities that have magnitude and direction are called vectors.
- We can use vector diagrams to represent any vector quantity.
- We represent vectors quantities graphically as arrows:
  - The back end of the vector is called the tail.
  - The length of the arrow represents the size of the vector.
  - The arrow head (the point) shows its direction.
- Arrows are drawn tail-to-head to represent any combination of vectors.
- The resultant of two or more vectors is a single vector which can produce the same effect as the component vectors.
- A resultant can be determined graphically or by calculation.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 38 2016/01/05 3:15 PM

Challenges and projects

1. Rate of flow

In the building regulations it states that, when a hot-water tap is turned on, it must not take more than 8 seconds for the hot water to flow from the geyser to the tap. At a new fast food shop, the pipes are designed so that the water flows through them at no more than 0,8 m per second, and the tap is 9 m from the geyser. Will the hot water get to the tap in 8 seconds? Hint: This is a simple speed problem.

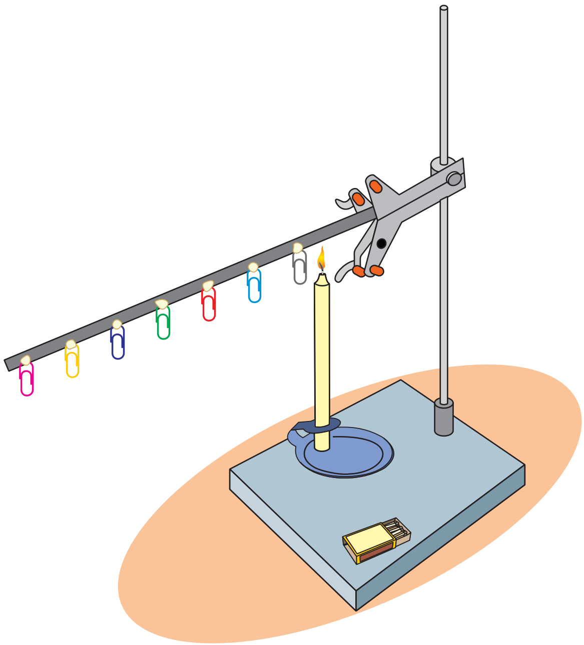
2. Here is a rate problem not included in the Technical Sciences curriculum but which you would be expected to do in Maths

A 65 kg man who wanted a better body started weight training and eating healthy food. After 200 days he looked better and weighed 77 kg. At what rate did he gain mass over the period? Give the answer in kg per day.

3. Investigate the rate of heat energy transfer along a metal rod

Question: How does the rate at which heat energy is transferred change with distance from the source of heat energy?

Figure 1.22



Apparatus

- ❑ retort stand, boss, clamp with insulated jaws
- ❑ metal rod
- ❑ candle holder and candle (or meths burner)
- ❑ matches
- ❑ paper clips
- ❑ ruler
- ❑ stopwatch (cell phone)

This could be done in different ways. One possible process is described below:

A. Set up the apparatus as in Figure 1.22.

B. Clamp a metal rod horizontally in a clamp on a retort stand.

C. Position the candle about 5 cm from the clamp.

D. Adjust the height of the boss so that the rod is 5 cm above the top of the candle.

E. Attach seven paper clips to the rod using melted candle wax, with the first paper clip 5 cm from the candle and the last paper clip at the end of the rod.

F. Copy the table below into your notebook:

Observations of the investigation							
Paper clip number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Distance from candle in centimetres	5	10	15	20	25	30	35
Time for clip to fall in seconds							

G. Write the heading "Hypothesis" in your work book and, with reference to the Question, describe what you expect to see when the candle heats the rod.

H. On a clean sheet in your notebook draw a set of axes with time along the horizontal axis and distance up the vertical axis.

I. Light the candle, start the stopwatch, observe what happens, and record the results.

Analyse results

1. Complete the table in your book.

2. On the axes you prepared, draw a line graph based on the figures in your table. See "How to draw a graph" in the Resource Pages.

3. Describe the shape of the line you have drawn: Is it steeper at the beginning or near the end?

4. If the graph is steep, what does that say about the rate at which heat energy is being transferred at that point on the rod?

5. If the graph is flat, what does that say about the rate at which heat energy is being transferred at that point on the rod?

Conclusion

6. Compare your analysis to your hypothesis. If your hypothesis was correct, rewrite it as the conclusion. If your hypothesis was not correct, say so, and write down what you have learned from the investigation.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 40 2016/01/05 3:15 PM

CHAPTER 2 Motion in one dimension

This whole chapter is about **motion.** Motion is another word for movement. Anything that is moving is in motion.

We limit our study of motion to movement that goes backwards or forwards along a straight line. We call this **motion in one dimension.**

Definition: **One dimensional motion is motion along a straight line, either forward or backward.**

Unit 2.1 Origin, position, distance and displacement

If you are asked to draw a dot, you would have to ask, “Where must I draw the dot?” If the reply is, “In the middle of the circle in Figure 2.1,” you will know exactly where to place the dot.

If the principal asks you to paint a Welcome sign, your first question might be “Where must I paint the sign?”

If the reply is “On the street-side of the wall to the right of the main gate,” you will know the required **position**.

Figure 2.1

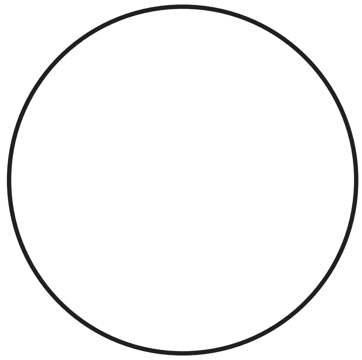
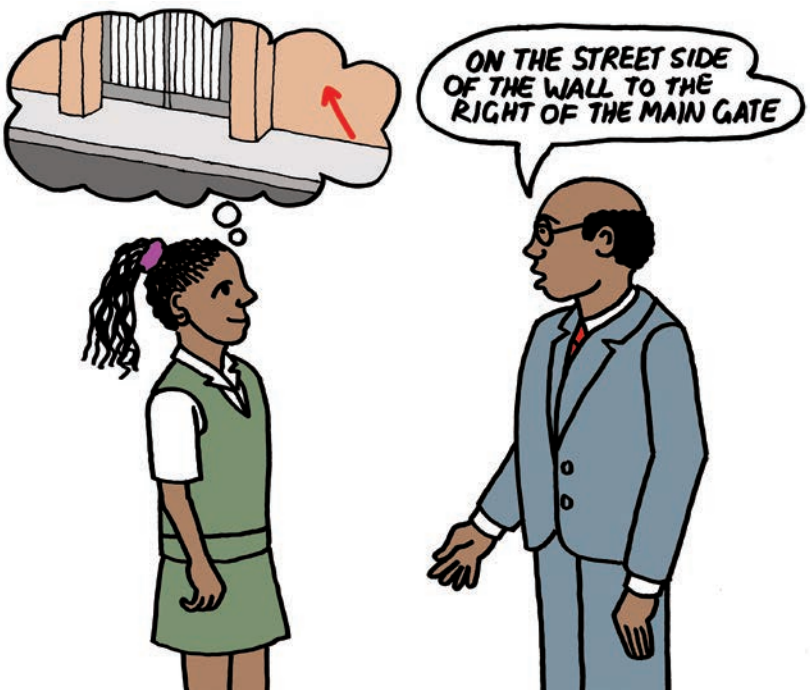


Figure 2.2



Definition: The position of an object is its location in relation to a reference point.

In the previous two scenarios, you were able to **locate*** the correct positions because you started from known points (the circle and the main gate). Known points are called **reference points***.

> * **locate** – to find the position of something
>
> * **reference point** – a point to which you compare the position of other points

For example:

- The reference point of a ruler is the zero mark.
- The reference point when you do the high jump is the ground.

Activity 1 Position and reference points

1. Look at Figure 2.3. Use the middle of the doorway (X) as your reference point. Describe the positions of:

a) the table saw

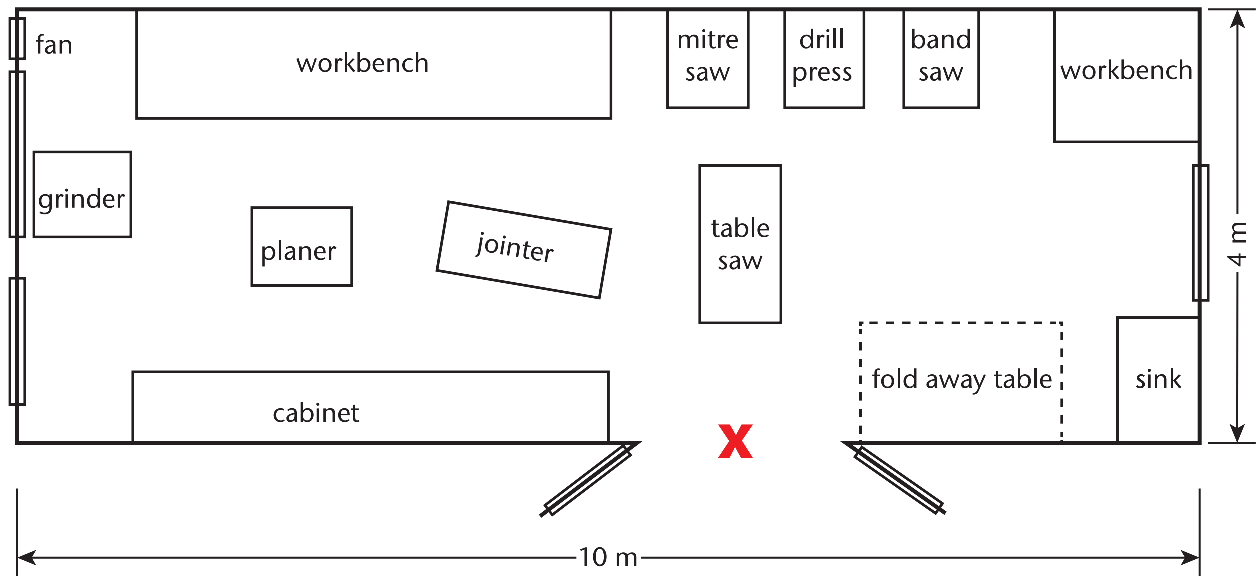
b) the cabinet

c) the workbench

d) the fan

e) the drill press

Figure 2.3 *The plan of a work room*



Origin and position

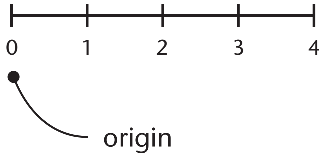
When we draw graphs, our reference point is usually the **origin***. The origin is the place from which we measure to find the position of an object.

> * **origin** – where something started from

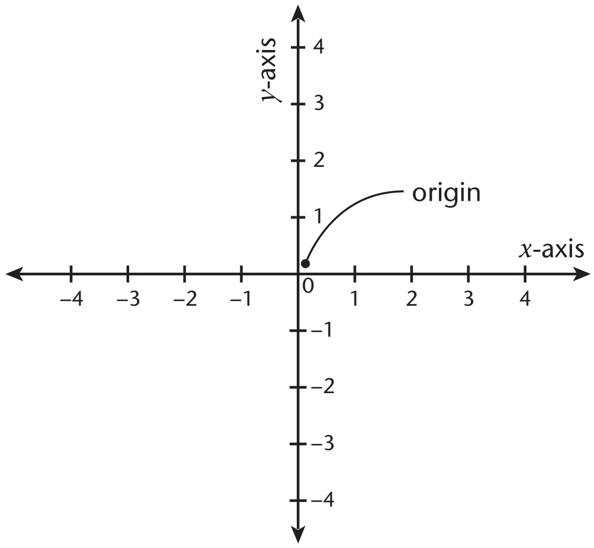
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 42 2016/01/05 3:15 PM

Figure 2.4

a)



b)



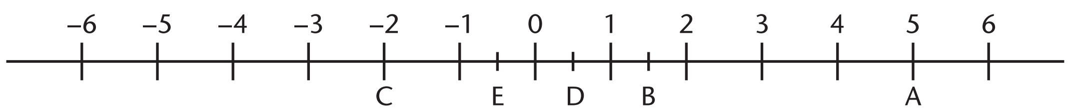
Activity 2 Origin and position: Positive and negative

Horizontal lines:

Vertical lines:

1. Draw a horizontal line right across the page. In the middle of the horizontal line, draw a short vertical line about 10 mm long. Label the vertical line ORIGIN.
2. Mark the positions of the following points on the horizontal line:
   - **a)** Point A is 55 mm to the right of the origin.
   - **b)** Point B is 33 mm to the left of the origin.
3. Discuss: Could you mark the positions of A and B if you didn't know where the origin was?
4. Look at Figure 2.5. The origin has the value zero (0).
   We describe positions to the right of the origin as positive (+).
   Positions to the left are negative (–). For example, the position of A is +5 cm. Write down the positions of A, B, C, D and E, relative to the origin, in centimetres.

   Figure 2.5

5. Re-draw the line in Figure 2.5 at full scale in your workbook. Mark and label the following points: G (+3 cm); H (+5,5 cm); J (–1 cm); K(–3,5 cm)
6. Draw the same line going up and down the page. Mark and label the following points: L (+3,5 cm); M (–2,5 cm); N (–5,0 cm); P (+0,5 cm)

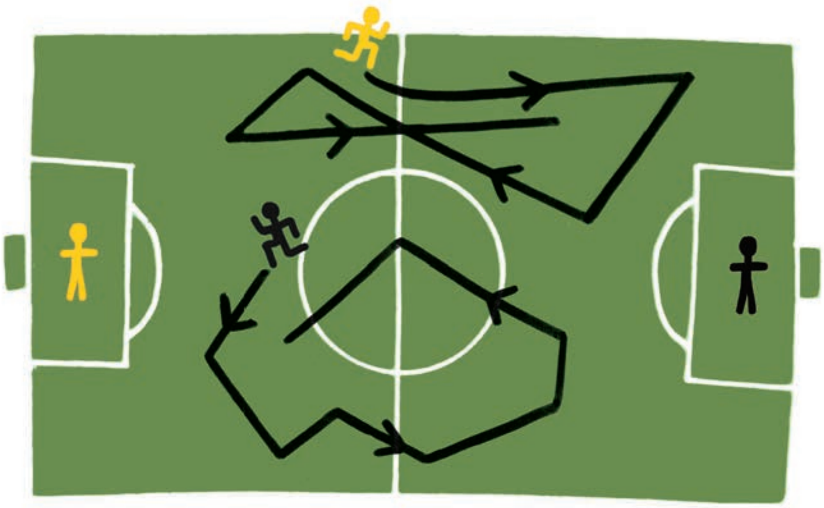
Distance

If you have run a 400 metre race in athletics, you will know that it is a longer, tougher race than the 100 m race. It covers a greater **distance**.

Activity 3 Measure a distance

Figure 2.6 shows the movements of two Buccaneers players in a period of play during a game of soccer against Chiefs. A coach uses this diagram to analyse the movements of the players.

Figure 2.6 **Track*** *of the movements of two soccer players*



> ✻ **track** (noun) – a line or path showing how something moves, or a path that you move along, like an athletics track
>
> ✻ **track** (verb) – to follow the course of movement of someone or something

1. Use a piece of string to measure the length of both the players' movements. Write them down. Use the scale 1 : 1 000 (1 cm on the diagram represents 1 000 cm or 10 m on the ground).
2. Which player covered the greater distance?

Definition: Distance is the length of the path between two points.

- The conventional symbol for distance is *d*.
- The SI unit for distance is the metre (m).

In Chapter 1, we learned that the word **distance** has a special meaning: it is the **total length of the actual path** between two points. It is a **scalar** quantity: it has magnitude but not direction. It does not matter what direction it takes. We are interested only in the length of the actual path from the start to the end.

Displacement

In Chapter 1 you learnt that distance and displacement are related, but they are different quantities in science.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 44 2016/01/05 3:15 PM

Definition: Displacement is the length of the shortest line between two points, in a particular direction.

- The conventional symbol for displacement is d.
- The SI unit for displacement is the metre (m).

Displacement is a physical quantity that has both a measurement of length and a direction (a magnitude and a direction). So it is a vector quantity.

Direction of a displacement

Because displacement is a vector quantity, we need to give the direction when we state the measurement. We can describe the direction in terms of:

- positive (+) or negative (–)
- up or down
- north or south; east or west
- a compass direction
- a bearing (degrees from the north line)

Worked example: The difference between distance and displacement

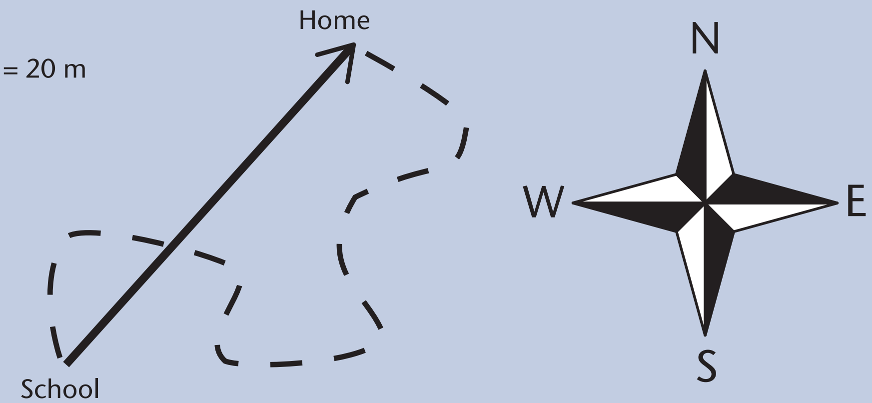
Thabo walks home from school along the winding road shown by the dashed line in Figure 2.7 below.

a) What distance does Thabo walk?

b) What is Thabo's displacement?

Figure 2.7

Scale: 1 mm = 20 m



Solutions

a) The length of the winding road is 2 km, so Thabo's home is 2 km from the school along the road. We say that the distance Thabo walks is 2 km. As he walks, his direction changes many times. But as we are talking about distance, we are not interested in direction. Distance is a measurement of length only.

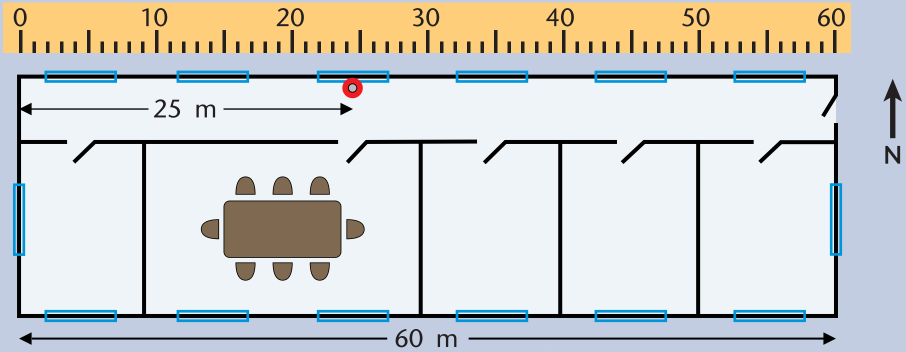
b) The length of the straight line from the school to Thabo's home is 1 km in the direction north-east. We say that the displacement of Thabo's home from the school is 1 km in a north-easterly direction. A displacement involves both a measurement of length and a direction.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 45 2016/01/05 3:15 PM

Worked example: Displacement

You are a business manager. You have built new offices and are fitting a radio-buzzer system into the offices. You will use it to call people in other offices to your office. The offices are side-by-side along a 60 m passage that runs east/west as in Figure 2.8. The transmitter is 25 m from the west end, opposite the door to your office.

Figure 2.8 *The layout of your new business premises*



Your assistant goes into the passage to test the system. He walks 15 m to the east and you test the buzzer – it works. Now he walks another 18 m along the passage and you test the buzzer – it does not work. He turns around and walks 5 m back along the passage and you test the buzzer – it works.

What is the range of the transmitter in the east end of the passage?

Solution

The transmitter range to the east = 15 m + 18 m – 5 m = 28 m. This is a displacement: it is a measurement of length and a direction.

Your assistant then walks along the west passage to test the buzzer. He walks right to the end of the passage – the buzzer does not work. He walks back 5 m, and the buzzer works. Transmitter range to the west is 25 m – 5 m = 20 m. This is also a displacement: it is a measurement of length and a direction.

Activity 4 Measure distance and displacement

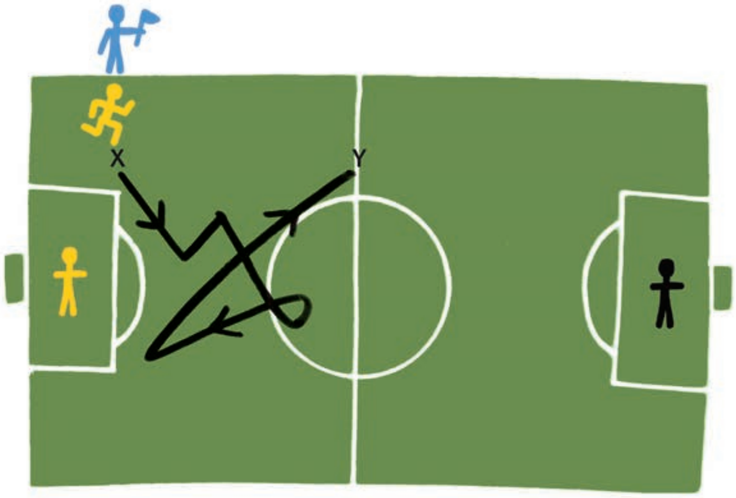
Figure 2.9 on the next page shows the track of the movement of a Chiefs defender. The player starts at point X and ends at point Y.

> * the **period of play** is the interval of time during which they were playing

1. Determine the **displacement** of the player over the **period of play***. Use the scale 1 : 1 000 (1 cm on the diagram represents 1 000 cm or 10 m on the ground).
   - In Question 1 you do not add up each distance to get the total distance. You are interested in where he ended up compared to where he started off.
   - How do you describe the direction of the displacement? Is it "parallel to the goal-line", or "across the field" or "parallel to the side-line and towards the gold goal", or "straight up the field away from the black goal", or is it something else?

2. During the period of play in (1), the linesman ran up and down the touchline opposite the player to check for off-side play.
   a) What distance did the linesman cover?
   b) Calculate the linesman's displacement over this period.

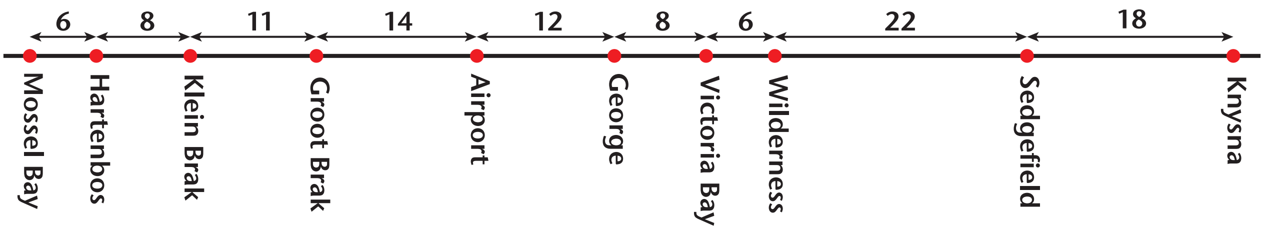
Figure 2.9 *The track of a player over a short period of play*



Activity 5 Calculate displacement

N2enChicken sells chicken-'n-chips to businesses along the N2 highway on the Garden Route. The food is cooked in George. A small bakkie delivers batches of hot chicken-'n-chips direct from the kitchen to wherever it is needed.

Figure 2.10 *The N2 from Mossel Bay to Knysna*



1. If a call for more chicken-'n-chips comes from Sedgefield, how far will the van have to travel from George and in what direction?
2. While it is at Sedgefield, the bakkie is called directly to the airport. What is the distance to the airport and what is the direction?
3. What is the length of the bakkie's journey from the airport back to the kitchen and in what direction must it travel?

Unit 2.2 Speed and velocity

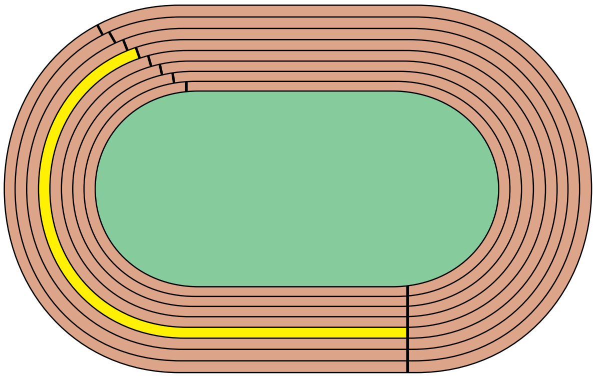
Speed

We know about **speed**. We describe things as fast or slow; for example:

- Usain Bolt is called the fastest man in the world because he ran a 200 m race in a world record time of 19,19 seconds.
- A taxi looking for passengers on a busy street drives slowly.

What else is fast and what else is slow?

Figure 2.11 *The 200 m track*



Definition: Speed is the rate of change of distance.

The formula for speed

speed = distance covered ÷ time taken to cover the distance

When we use symbols instead of words, the formula is:

$$\text{speed} = \frac{d}{t}$$

where:

- speed is measured in metres per second (m/s)
- d is the symbol for displacement measured in metres (m)
- t is the symbol for time measured in seconds (s)

Worked example

Calculate Usain Bolt's speed when he ran the 200 m in 19,19 seconds.

Solution

Given $d = 200$ m; $t = 19{,}19$ s

Unknown speed

Formula $\text{speed} = \frac{d}{t}$

$= \frac{200}{19{,}19}$ (substitute)

$= 10{,}42$ m/s

Average speed

If you watch Usain Bolt run the 200 m, you can see that he does not run at the same speed throughout the race. When the gun goes his speed is zero, his speed increases over the first 80 m, and he seems to run the last 120 m at a constant speed.

So the formula for speed, speed = $\frac{d}{t}$ is better described as the formula for **average speed.**

In most questions relating to speed, although we talk about speed, we actually mean average speed.

Figure 2.12 *Usain Bolt on his way to winning the men's 200 m final at the London 2012 Olympic Games*

Activity 6 Calculate speed

1. A 400 m runner's time is 48 seconds. Calculate his average speed in metres per second.

2. A courier delivery van took 2 hours to get from Pretoria to Soweto in peak hour traffic. The total distance was 80 km. Calculate the courier's average speed in kilometres per hour.

3. The Trans-Karoo Express took 24 hours and 23 minutes to cover the 1 642 km of the railway line on a journey from Joburg to Cape Town. It stopped for a total of 59 minutes at stations along the route. Calculate the average speed in kilometres per hour while it was in motion.

Velocity

To most people, speed is the same as velocity. Speed and velocity are related but they are not the same. In Science, speed and velocity are different physical quantities. Speed is based on distance; velocity is based on displacement.

Definition: Velocity is the rate of change of displacement.

The formula for velocity

The word formula for velocity is:

velocity = displacement ÷ time

When we use symbols instead of words, the formula is:

$$v = \frac{d}{t}$$

where:

- v is the symbol for velocity measured in metres per second (m/s)
- d is the symbol for displacement measured in metres (m)
- t is the symbol for time measured in seconds (s)

Speed is a scalar quantity; velocity is a vector quantity

Because speed is based on distance, which is a scalar quantity, speed is a scalar quantity – it has magnitude but no direction.

Because velocity is based on displacement, which is a vector quantity, velocity is a vector quantity – it has magnitude and direction.

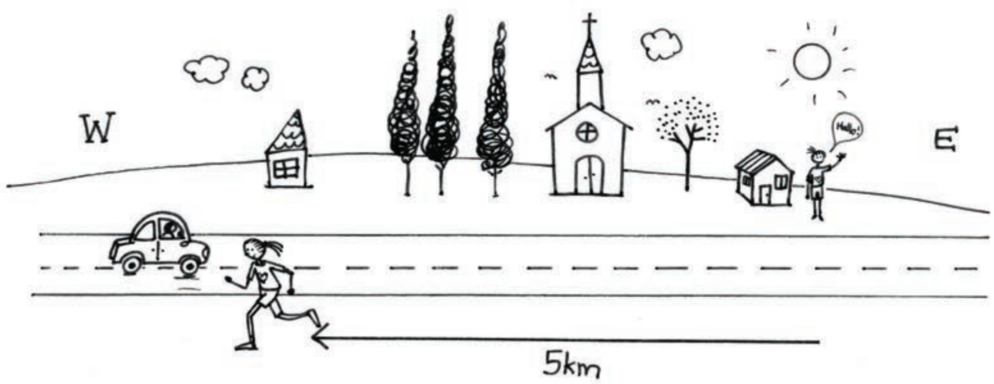
Velocity is useful

Karabo wants to get fit. She jogs along Church Street and she covers 5 km in 30 minutes.

So her speed is $\frac{5}{30}$ km/min which is 10 km/h.

Karabo's brother has to fetch her after her jog. But he doesn't know which direction she went in. Did she go east along Church Street or did she go west? He wants to be on time to fetch her, so he is interested in her speed and direction – her velocity.

Figure 2.13



Worked examples: Calculate velocity

1. A box is displaced (moved) 100 m to the right in 20 seconds. Calculate the velocity of the box.

Solution

Given $d = 100$ m; $t = 20$ s; direction is to the right

Unknown velocity

Formula $v = \frac{d}{t}$

$= \frac{100}{20}$ (substitute)

$= 5$ m/s to the right

2. An object is moving in a straight line. It moves 4 m to the right in 8 seconds. Calculate its velocity.

Solution

Given $d = 4$ m; $t = 8$ s; direction is to the right

Unknown velocity

Formula $v = \frac{d}{t}$

$= \frac{4}{8}$ (substitute)

$= 0{,}5$ m/s to the right

3. An object is moving in a straight line. Its displacement is 10 m to the left at a velocity of 2 m/s. How long does it take?

Solution

Given $d = 10$ m; $v = 2$ m/s; direction is to the left

Unknown time

Formula $v = \frac{d}{t}$

$t = \frac{d}{v}$ (change subject)

$= \frac{10}{2}$ (substitute)

$= 5$ s

4. An object is moving in a straight line. It travels forwards at a velocity of 0,1 m/s for 0,8 s. Calculate its displacement.

Solution

Given $t = 0{,}8$ s; $v = 0{,}1$ m/s; direction is forward

Unknown displacement

Formula $v = \frac{d}{t}$

$d = v\,t$ (change subject)

$= 0{,}1 \times 0{,}8$ (substitute)

$= 0{,}08$ m forward

Activity 7 Calculate velocity, time and displacement

1. Calculate an object's velocity if it moves forwards by 1,5 m in 5 seconds.
2. An object moves to the left at 4,2 m/s. Calculate how far it will move in 5 seconds.
3. An object is moving in a straight line. It moves 24 m to the right in 16 seconds. Calculate its velocity.
4. An object moves 76 m to the left at a velocity of 19 m/s. Calculate the time it took.
5. An object moves to the left at 0,75 m/s for 20 seconds. Calculate its displacement.

Vector diagrams in displacement and velocity problems

If an object moves in a straight line with two or more different movements, we can use a vector diagram to determine its displacement.

Worked examples: Use vector diagrams

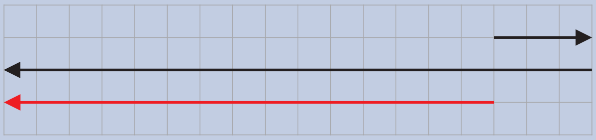
Abel is organising his workshop. He moves a box 3 m to the right in 6 seconds. He unpacks the box, which takes 12 seconds and then he moves it 18 m to the left, taking 12 seconds to move it.

1. Use a vector diagram to determine the displacement of the box at the end.

Solution

Given: The box moves 3 m to the right, then 18 m to the left

Figure 2.14 *1 grid space = 1 m*



- Draw component vectors.
- Measure the resultant vector: 15 m.
- In what direction is the resultant vector? It is to the left.

∴ The displacement of the box is 15 m to the left.

2. Calculate the velocity of the box over the whole time period.

Solution

Given d = 15 m to the left; $t = 6 + 12 + 12 = 30$ s

Unknown velocity

Formula $v = \frac{d}{t}$

$= \frac{15}{30}$ (substitute)

$= 0{,}5$ m/s to the left

Activity 8 Use vector diagrams

1. An object moves 20 m to the left in 5 seconds. It then moves 13 m to the right in 9 seconds. Use a vector diagram to determine the object's total displacement and calculate the object's velocity over the period of time.
2. A car caught in peak hour traffic moves 60 m in 20 s; stops for 16 s; moves 20 m in 12 s; stops for 18 s; moves 90 m in 22 s and then stops. Use a vector diagram to determine the car's total displacement and calculate the car's velocity over the period of time.
3. A runner doing interval training is running north along a street with electricity poles every 50 meters. He runs one pole, then walks one pole, runs two poles, walks one pole, runs three poles, etc.
   - **a)** Use a vector diagram to find his displacement after his fifth run.
   - **b)** If he runs at 5 m/s and walks at 2,5 m/s, calculate how long it will take him to the end of his fifth run.
4. Engineers expect that a particular machine's output will decrease by about 10% each month. Use a vector diagram to illustrate how many months it will take to reach an output of 65%.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 53 2016/01/05 3:15 PM

Unit 2.3 Acceleration

Karabo is trying to improve her running speed by including sprints (fast runs) in her training. She runs back and forth between kilometre markers on the road. She jogs, speeds up, sprints, slows down and jogs again.

This change of velocity is called acceleration.

Definition: Acceleration is the rate of change of velocity.

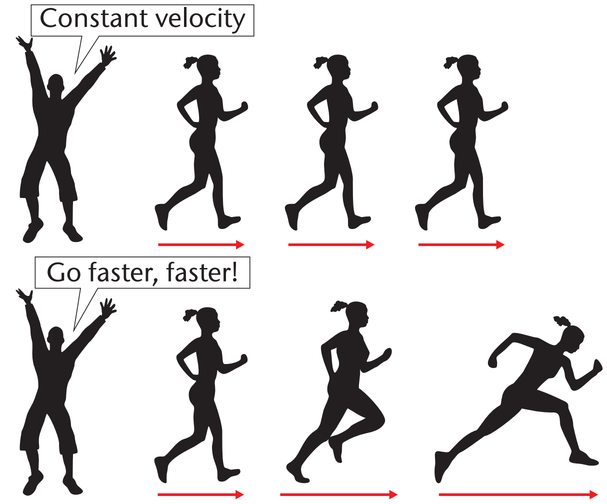
An object's acceleration is the measure of the change of its velocity over a period of time:

- If there is a change in velocity, there is acceleration.
- If velocity is constant, there is no acceleration (even if an object is moving very fast).

Look at the velocity vectors in Figure 2.15 to see the difference between constant velocity and acceleration:

- For constant velocity, the vectors are all the same length. There is no acceleration.
- For acceleration, the velocity vectors are increasing in length.

Figure 2.15 *Constant velocity and changing velocity*



Activity 9 Find the similarities and differences between some physical quantities

Work in groups of two:

- Look at the table below. Start by looking at the headings in the top two rows, the physical quantities in the left-hand column and the data in the body of the table.
- Discuss the answers to Questions 1, 2 and 3 on the next page, and then write the full sentences out in your notebook.

✻ **magnitude** – the size of a quantity

Physical quantity	Description of physical quantities		
	Units of the physical quantity	Does the physical quantity have **magnitude***?	Does the physical quantity have direction?
distance	metres	yes	no
displacement	metres	yes	yes
speed	metres per second	yes	no
velocity	metres per second	yes	yes
time	seconds	yes	no
acceleration	metres per second per second	yes	yes

1. Study Columns 3 and 4 in the table and discuss the following sentence:
   All the physical quantities have ______________ but they don't all have ______________
2. Study columns 2, 3 and 4 and complete the following sentences:
   a) Distance and displacement are similar because they are measured in _____________ and they both have ______________
   b) Distance and displacement are different because _______________ does not have direction while _______________ does have direction
   c) Speed and velocity are similar because they are measured in ______________ and they both have _______________
   d) Speed and velocity are different because _______________ does not have direction while _______________ does have direction.
   e) Displacement, velocity and acceleration are similar because they all have _______________ and _______________

The formula for acceleration

The word formula for acceleration is:

acceleration = change in velocity ÷ time

= (final velocity – initial velocity) ÷ time

When we use symbols instead of words, the formula is:

$$a = \frac{v_f - v_i}{t}$$

where:

- a is the symbol for acceleration measured in metres per second per second (m/s^2 or $m.s^{-2}$)
- v_f is the symbol for the final velocity measured in metres per second (m/s or $m.s^{-1}$)
- v_i is the symbol for the initial velocity measured in metres per second (m/s or $m.s^{-1}$)
- t is the symbol for the period of time measured in seconds (s)

The unit for acceleration

This is the first time that you have met the unit "metres per second per second". You need to understand how it is derived.

$$\text{Acceleration} = \frac{\text{change in velocity (metres per second)}}{\text{time (seconds)}}$$

Look at the units on the right-hand side of the formula:

- the units are metres per second/second
- this can be written as m/s/s
- and this can be simplified to m/s^2 or $m.s^{-2}$

The unit of the left-hand side of the formula must be the same as the unit of the right-hand side, so the unit for acceleration is m/s^2 or $m.s^{-2}$.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 55 2016/01/05 3:15 PM

Worked examples: Calculate acceleration

1. An object is moving to the right. Over a period of 5 seconds its velocity changes from 2 m/s to 12 m/s. Calculate its acceleration.

   Solution

   Given $v_i = 2$ m/s; $v_f = 12$ m/s; $t = 5$ s

   Unknown acceleration

   Formula $a = \dfrac{v_f - v_i}{t}$

   $= \dfrac{12 - 2}{5}$ (substitute)

   $= 2$ m/s^2

2. Two powerful dragsters are on the start-line of a straight 400 m track. The green light flashes and the dragsters roar down the track. Just 8 seconds later the winner crosses the line at a velocity of 100 m/s. Calculate the winner's acceleration in m/s^2.

   Figure 2.16 *A dragster*

   Solution

   Given $v_i = 0$ m/s; $v_f = 100$ m/s; $t = 8$ s

   Unknown acceleration

   Formula $a = \dfrac{v_f - v_i}{t}$

   $= \dfrac{100 - 0}{8}$ (substitute)

   $= 12{,}5$ m/s^2

Activity 10 Calculate acceleration

1. An object is accelerating. Its velocity changes from 24 m/s to 72 m/s in 12 seconds. Calculate its acceleration.
2. Calculate the acceleration of an object that goes from 7 m/s to 9 m/s in 2 minutes.

3. A young sprinter reaches a speed of 9 m/s in 1,5 seconds in the 100 m race. Calculate her acceleration.
4. A heavy truck and trailer is 28 m long. It pulls away from a stop sign at full power. It takes 5,6 seconds for the back of the trailer to reach the stop sign. Calculate the truck's acceleration.
5. A super-bike's velocity changes from 120 km/h to 210 km/h in 3,2 seconds. Calculate its acceleration.
6. A bullet leaves the barrel of a rifle 0,001 2 s after it is fired, moving at a velocity of 1 000 m/s. Calculate the bullet's acceleration in the barrel.

Worked example: Calculate time for acceleration

An object is accelerating. Its acceleration is 3 m/s². How long does it take to go from an initial velocity of 15 m/s to a final velocity of 24 m/s?

Solution

Given $v_i = 15$ m/s; $v_f = 24$ m/s; $a = 3$ m/s²

Unknown time

Formula $a = \frac{v_f - v_i}{t}$

$t = \frac{v_f - v_i}{a}$ (change the subject)

$= \frac{24 - 15}{3}$ (substitute)

$= 3$ s

Remember how to change the subject of a formula – look back at Chapter 1.

Activity 11 Calculate time from the acceleration

1. An object is accelerating. Its acceleration is 2 m/s². How long does it take to go from an initial velocity of 4 m/s to a final velocity of 14 m/s?
2. Calculate the period of time that an object takes to go from 27,5 m/s to 42,5 m/s if its rate of acceleration is 0,5 m/s².
3. A cheetah can accelerate at a rate of 10 m/s². Calculate how long it takes to reach a speed of 100 km/h.
4. Under full power a space shuttle accelerated at 30 m/s². Calculate how long it took to reach a speed of 10 000 km/h.
5. A Formula 1 racing car accelerated at 35 m/s². Calculate the time it took to accelerate from 140 km/h to 280 km/h.
6. A longbow is being used to shoot an arrow. The arrow is in contact with the string for 0,01 seconds and leaves the bow at a speed of 60 m/s. Calculate the arrow's acceleration as it is being shot.

Worked examples: Calculate velocity from acceleration

1. An object is accelerating. Its initial velocity is 12 m/s. Its acceleration is 3 m/s². What will the velocity be 9 seconds later?

Solution

Given $a = 3$ m/s²; $t = 9$ s; $v_i = 12$ m/s

Unknown final velocity

Formula $a = \frac{v_f - v_i}{t}$

Remember that $(a \times t)$ can also be written as at or sometimes $a \cdot t$.

$v_f = v_i + (a \times t)$ (change the subject)

$= 12 + (3 \times 9)$ (substitute)

$= 39$ m/s

2. An object accelerates at 0,25 m/s² for 55 seconds. Its final velocity is 40 m/s. Calculate its initial velocity.

Solution

Given $a = 0{,}25$ m/s²; $t = 55$ s; $v_f = 40$ m/s

Unknown initial velocity

Formula $a = \frac{v_f - v_i}{t}$

$v_i = v_f - a \cdot t$ (change the subject)

$= 40 - (0{,}25 \times 55)$ (substitute)

$= 26{,}3$ m/s

Activity 12 Calculate velocity from the acceleration

1. An object is accelerating. At the start of a period of time its velocity is 17 m/s. Calculate the velocity 8,5 seconds later if its acceleration is 0,75 m/s².
2. An object is accelerating. At the end of a 2,5 second period of time its velocity is 2,75 m/s. Calculate its velocity at the beginning of the period if the acceleration is 0,25 m/s².
3. A horse can accelerate at a rate of 5 m/s². It reaches its maximum velocity after 3,5 seconds from a standing start. Calculate the maximum velocity.
4. Under full power, a 125 cc motor scooter accelerates at 3 m/s². Calculate its velocity after 10 seconds.
5. A hot Corsa bakkie can accelerate at 5,5 m/s². Calculate its speed after accelerating for 10 seconds.
6. A catapult is being used to shoot a stone. The stone is in contact with the leather sling of the catapult for 0,2 seconds during which time the acceleration is 200 m/s². Calculate the stone's velocity as it leaves the sling.

Worked examples: Calculate acceleration with conversion from km/h to m/s

1. A motor-cycle is travelling along the road. The biker looks at the speedometer and sees that the velocity is 30 km/h. Ten seconds later the velocity is 90 km/h. Calculate the bike's acceleration over that period.

a) Convert the velocity from km/h to m/s.

b) Find the bike's acceleration.

Solutions

a)
- metres in a kilometer = 1 000
- minutes in an hour = 60
- seconds in a minute = 60
- seconds in an hour = 60 × 60 = 3 600 seconds

So to convert km/h to m/s:

- we multiply the kilometres in the numerator by 1 000
- we multiply the hours in the denominator by 3 600

$$30 \text{ km/h} = 30 \times \frac{1\,000}{3\,600} = 8{,}33 \text{ m/s}$$

$$90 \text{ km/h} = 90 \times \frac{1\,000}{3\,600} = 25{,}00 \text{ m/s}$$

b) Given $v_i = 8{,}33$ m/s; $v_f = 25$ m/s; $t = 10$ s

Unknown acceleration

Formula $a = \frac{v_f - v_i}{t}$

$= \frac{25{,}00 - 8{,}33}{10}$ (substitute)

$= 1{,}67 \text{ m/s}^2$

Activity 13 Calculation with conversion

1. Convert these numbers:

a) 879 mm to metres

b) 1 001 001 m to kilometres

c) 2 345 cm to metres

d) 9 009 009 cm to kilometres

e) 1 009 kilometres to metres

f) 0,019 kilometres to metres

g) 6,5 hours to minutes

h) 6 h 20 min to seconds

i) 87 minutes to hours and minutes

j) 197 minutes to decimal hours

2. Convert these velocities from km/h to m/s:

a) 10 km/h **b)** 141 km/h **c)** 50,25 km/h

3. Convert these velocities from m/s to km/h:

   a) 13 m/s **b)** 149 m/s **c)** 15,15 m/s

4. A Boeing 747 aeroplane is taking off from Oliver Tambo airport. The pilot looks at the ground-speed meter and sees that the velocity is 30 km/h. Ten seconds later the velocity is 330 km/h. Calculate the acceleration of the aeroplane over that period in metres per second.
5. An object is accelerating. At the end of a 5 second period of time its velocity is 10 km/h. Calculate its velocity at the beginning of the time period if the acceleration is 0,3 m/s^2.
6. A very long conveyor belt on a coal mine can accelerate at a rate of 0,2 m/s^2. It reaches its operating velocity after 42 seconds. Calculate its operating velocity in kilometres per hour.
7. Under full power an 89 000 kg mine truck accelerates at 0,5 m/s^2. Calculate its velocity in kilometres per hour after 30 seconds from an initial velocity of zero.
8. A hot Optimum taxi, fully loaded, can accelerate at 2,5 m/s^2. Calculate its velocity in kilometres per hour after accelerating for 12 seconds from standing still.

Choose your words carefully in Science

When you have driving lessons, as you approach an intersection, the instructor will tell you to apply the brakes, or he will say “decelerate”.

As you leave the intersection, he will tell you to accelerate or push down on the accelerator. The words, “acceleration” and “deceleration” are understood in everyday language.

In Science we do not use the word “deceleration” to describe slowing down.

Acceleration can be positive or negative

We know that velocity is a vector quantity with direction and magnitude. The motion that we study is motion along a straight line, so the direction is generally defined as either positive (+) or negative (–). Positive is usually to the right; negative to the left.

Acceleration is also a vector quantity with direction and magnitude. And, like velocity, it can have positive or negative values:

- If the sign (+ or –) of the acceleration is the same as the sign of the velocity, the object will speed up.
- If the signs are opposite, the object will slow down.

Another way of saying this is:

- If the object is speeding up, its acceleration has the same direction as its motion.
- If an object is slowing down, then its acceleration has the opposite direction to its motion.

Worked example: Acceleration can be positive or negative

1. An object is moving in a positive direction. Over a period of 5 seconds its velocity changes from 12 m/s to 2 m/s. Calculate its acceleration.

Solution

Given $v_i = 12$ m/s; $v_f = 2$ m/s; $t = 5$ s

Unknown acceleration

Formula $a = \frac{v_f - v_i}{t}$

$= \frac{2 - 12}{5}$ (substitute)

$= -2\ \text{m/s}^2$

2. An object is moving in a negative direction. Over a period of 5 seconds its velocity changes from –12 m/s to –2 m/s. Calculate its acceleration.

Solution

Given $v_i = -12$ m/s; $v_f = -2$ m/s; $t = 5$ s

Unknown acceleration

Formula $a = \frac{v_f - v_i}{t}$

$= \frac{-2 - (-12)}{5}$ (substitute)

$= +2\ \text{m/s}^2$

3. An object moving in a negative direction. Over a period of 5 seconds its velocity changes from –2 m/s to –12 m/s. Calculate its acceleration.

Solution

Given $v_i = -2$ m/s; $v_f = -12$ m/s; $t = 5$ s

Unknown acceleration

Formula $a = \frac{v_f - v_i}{t}$

$= \frac{-12 - (-2)}{5}$ (substitute)

$= -2\ \text{m/s}^2$

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 61 2016/01/05 3:16 PM

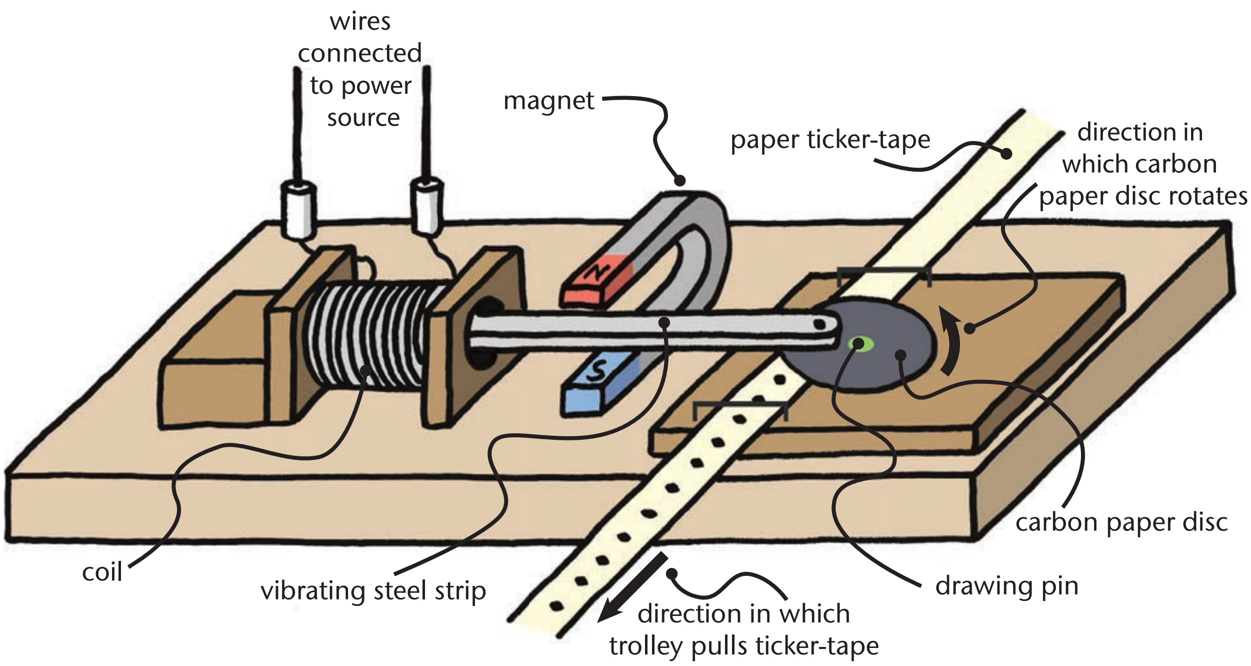
Activity 14 Acceleration can be positive or negative

1. An object is moving in a positive direction. Over a period of 17,5 seconds its velocity changes from 0,5 m/s to 2,1 m/s. Calculate its acceleration.
2. An object is moving in a positive direction. It is accelerating at $-2{,}5\ m/s^2$. How long does it take to slow down from 175 m/s to 12,5 m/s?
3. An object moving in a positive direction accelerates for 8 seconds at $-2{,}0\ m/s^2$. Its initial velocity is 16 m/s. Calculate its final velocity.
4. An object is moving in a negative direction. Over a period of 17 seconds its velocity changes from –0,5 m/s to –2 m/s. Calculate its acceleration.
5. An object is moving in a negative direction. It is accelerating at $-1{,}5\ m/s^2$. How long does it take to speed up from –3 m/s to –15 m/s?
6. An Optimum taxi is driving down Church Street. The driver spots a passenger ahead. Over a period of 5 seconds the velocity of the taxi changes from 15,5 m/s to 2,5 m/s. Calculate its acceleration.
7. The same taxi is driving up Church Street. The traffic lights (robots) change to red, and over a period of 2 seconds the taxi's velocity changes from 45 km/h to 0 km/h. Calculate its acceleration.
8. A rival taxi sitting on the tail of the taxi in Question 7 has bad brakes, and can slow down at only $6\ m/s^2$. Discuss whether there was an accident or not.

How to calculate velocity using a ticker-timer

We can use a ticker-timer instead of a stopwatch to measure velocity.

Figure 2.17 *A ticker-timer*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 62 2016/01/05 3:16 PM

A ticker-timer is a special device that makes dots on a long strip of paper at regular time intervals. It makes 50 dots per second. So if you pull a piece of tape through the ticker-timer, you will see how fast the tape has moved:

- If you pull it slowly, the dots are close together.
- If you pull it quickly, the dots are further apart.

Figure 2.18 *How the ticker-timer makes marks on the tape*

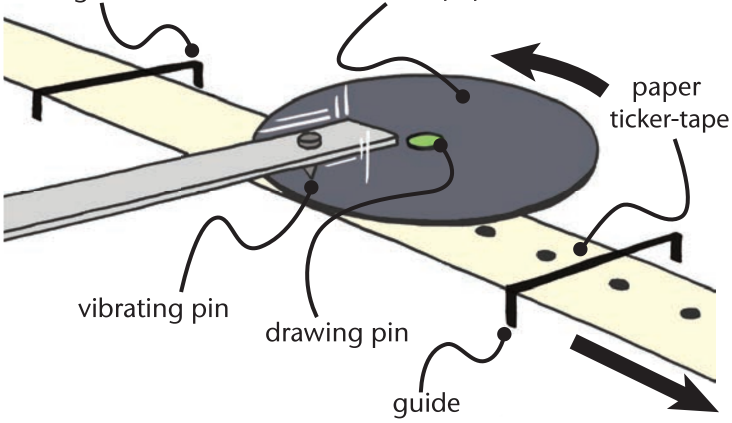
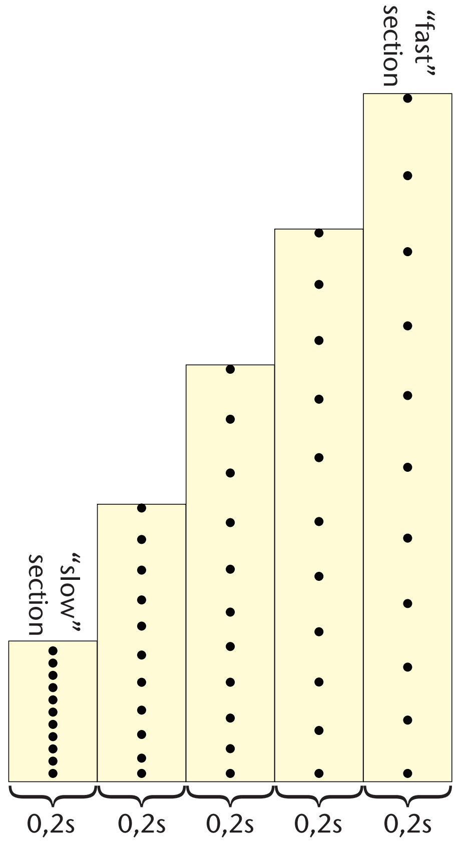


Figure 2.19 *Lengths of ticker-tape each representing 0,2 seconds*



Look at the pieces of paper in Figure 2.19.

You see dots and the spaces between dots:

- The strip that passed through the ticker-timer has been cut into 5 pieces.
- Each piece has been cut through the middle of a dot and has 10 spaces.
- The timer makes 50 dots per second.
- This means that each piece represents $\frac{1}{5}$ of the time it took to make 50 dots.
- Therefore each piece took $\frac{1}{5}$ of 1 second (0,2 s) to pass through the timer.

Study the 5 strips in Figure 2.19.

Look at the "fast" section in Figure 2.19.

- What does the fact that the dots are further apart tell us about the speed of the moving tape?
- What is the link between the distance between the dots and speed?
- Look at the "slow" section.
- What does the fact that the dots are closer together tell us about the speed of the moving tape?
- What is the link between the distance between the dots and speed?

Speed of a strip

To calculate the speed represented by a strip of paper, we use the following formula:

$$\text{speed} = \frac{\text{length of strip}}{\text{time}} = \frac{d}{t}$$

where:

- speed is in cm/s
- *d* is in cm
- *t* is in s

Worked examples: Velocity of a strip

- We will call this velocity because it has magnitude and direction.
- When we work with ticker-tape we will not convert cm/s to m/s.

1. A strip of tape has 10 spaces on it and is 10 cm long.

a) How many seconds does the strip represent?

b) What velocity (in cm/s) does the tape represent?

Solutions

a) The timer makes 50 dots per second, so 50 dots represent 1 s

The number of spaces = 10, so the strip represents $\frac{10}{50} = 0{,}2$ s

b) Given length = 10 cm; $t = 0{,}2$ s

Unknown velocity

Formula $v = \frac{d}{t}$

$= \frac{10}{0{,}2}$ (substitute)

$= 50$ cm/s

2. A piece of tape is 5 spaces long and 7 cm long.

a) How many seconds does it represent?

b) Calculate the velocity of the tape in cm/s.

Solutions

a) Given 50 spaces = 1 s; number of spaces = 5

50 spaces is 1 second, so 5 spaces will be $\frac{5}{50} = 0{,}1$ s

b) Given length = 7 cm; time = 0,1 s

Unknown velocity

Formula $v = \frac{d}{t}$

$= \frac{7}{0{,}1}$ (substitute)

$= 70$ cm/s

Activity 15 Work with ticker-tape

1. You have done a ticker-tape activity on an object moving 1 metre. You cut the length of tape into "ten-space strips".
   a) What length of time does each strip represent? Write this as a decimal fraction.
   b) If the strips are all the same length, what can you say about the speed that the object moved at?
   c) What does it mean if a piece of tape has dots that are close together and get further apart at the end of the tape?
   d) In another experiment, the dots are far apart and then get closer and closer together at the end of the tape. What does this tell you about the speed of the object?
2. In an experiment with a car on a ramp and a ticker-timer, the distances between the dots varied from close to far apart to close again. Write down at least two possible causes of this outcome.

Chapter summary

- One dimensional motion is motion along a straight line, either forward or backward.
- The **position** of an object is its location in relation to a **reference point**, which is called the **origin** in graphical work. Reference points are known points.
- Distance is the length of the path between two points. The conventional symbol for distance is *d*; the SI unit for distance is the metre (m); distance is a scalar.
- Displacement is the length of the shortest line between two points, in a particular direction. The conventional symbol for displacement is *d*; the SI unit for displacement is the metre (m); displacement is a vector.
- Speed is the rate of change of distance:
  $\text{speed} = \frac{d}{t}$
  where:
  - speed is measured in metres per second (m/s or $m.s^{-1}$)
  - *d* is the symbol for distance measured in metres (m)
  - *t* is the symbol for time measured in seconds (s)
- In most questions relating to speed we actually calculate average speed.
- Velocity is the rate of change of displacement:
  $v = \frac{d}{t}$
  where:
  - *v* is the symbol for velocity measured in metres per second (m/s or $m.s^{-1}$)
  - *d* is the symbol for displacement measured in metres (m)
  - *t* is the symbol for time measured in seconds (s)

- Speed is a scalar quantity; velocity is a vector quantity.
- Acceleration is the rate of change of velocity:

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

  where:
  - a is the symbol for acceleration measured in metres per second per second (m/s^2 or m.s^{-2})
  - v is the symbol for velocity measured in metres per second (m/s or m.s^{-1})
  - t is the symbol for time measured in seconds (s)
- Acceleration is a vector quantity with direction and magnitude – it can have positive or negative values.
  - If the sign (+ or –) of the acceleration is the same as the sign of the velocity, the object will speed up.
  - If the signs are opposite, the object will slow down.

Experiment 1: Determine the velocity of a trolley

This is the first of ten experiments that will be assessed informally by your teacher (the marks will not be recorded). Your work will be assessed according to the Record of Assessment of Experiment and the Assessment Rubric.

Apparatus
- ❑ ticker-timer, tape, power supply, trolley
- ❑ ruler
- ❑ a long ramp (at least 1,2 m) made of smooth material

Work in groups of four to fulfill the aim of the experiment:
- Base your work on what you have done in this chapter.
- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Record, in your notebook:
- what you do
- what you observe and your comments on your observations

Aim of the experiment

Study, using a ticker-timer, the motion of a small trolley as it moves down a ramp.

Plan the experiment

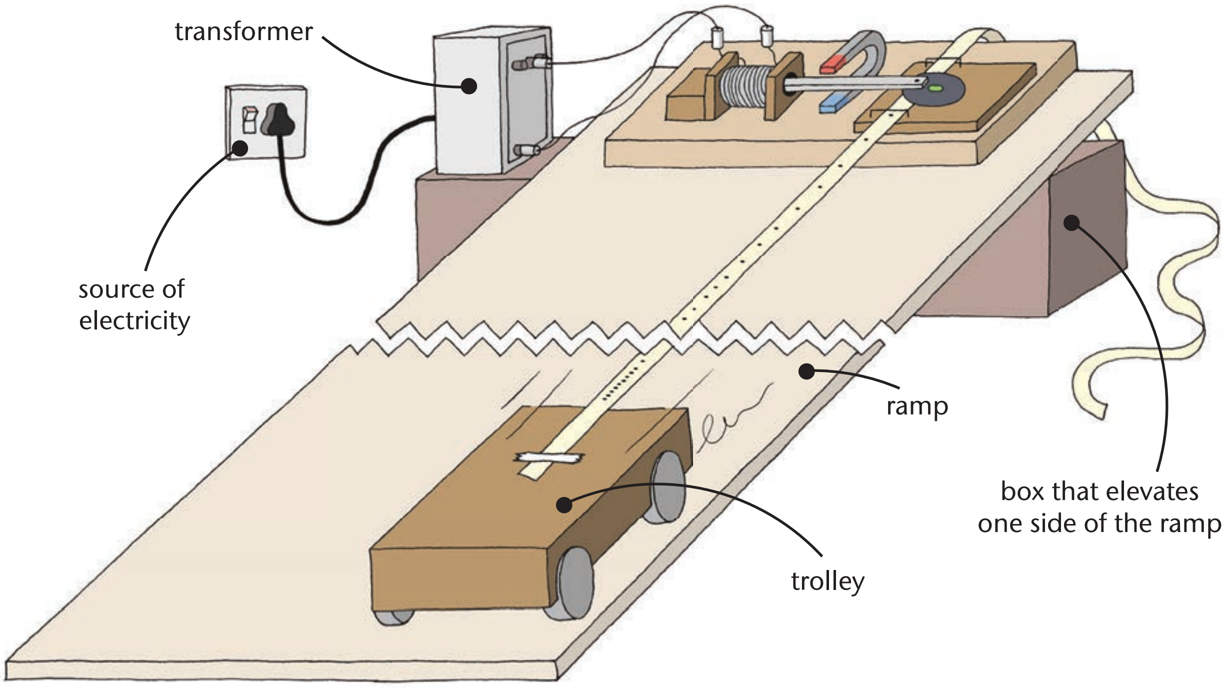
A. Set up the apparatus as in Figure 2.20.

B. Thread a 1 m length of ticker-tape through the ticker-timer. Make sure that the tape goes underneath the carbon paper disc.

C. Switch the ticker-timer on. It vibrates rapidly and hits the top of the carbon paper. Pull the piece of paper out “in one smooth move” and look at the pattern of the dots. Switch the ticker-timer off.

D. At one end of the strip all the dots are in the same place, then they start to spread out. What does that tell us?

Figure 2.20



E. Draw a copy of the table below in your workbook, with at least twenty rows.

a	b	c	d	e
Strip number	Time for each strip (s)	Time at the end of each strip (s)	Length of each strip (cm)	Average velocity of each strip (cm/s)
1	0,2	0,2		
2	0,2	0,4		
3	0,2	0,6		
4	0,2			

Do the experiment

F. Thread a 1,5 m length of ticker-tape through the ticker-timer. Attach the end of the tape to your trolley at the top of the ramp. Switch the ticker-timer on and let the trolley move down the ramp. Switch the ticker-timer off.

G. Remove the tape. Draw a line after each 10 spaces on your strip, through the 10th dot. Number each section of paper. Cut the tape along the lines into strips with 10 spaces on each strip. Cut exactly on the dots.

Capture the data to create information

Distance:

1. Measure each strip of paper in centimetres and enter its value into the table.
2. Prepare a piece of graph paper to draw a graph of the length of tape (distance) versus time. Time is on the horizontal axis – make 1 cm on the graph paper equal to 0,2 seconds.

Distance is on the vertical axis – make 1 cm on the paper equal to 2 cm of the ticker-tape. Label the axes with the physical quantities and the units.

3. For each strip, plot a point to represent the strip's length and the time from the beginning of the first strip. Join the first plotted point to the second point with a straight, ruled line; the second point to the third point; etc. When you have plotted all the points, draw a "best-fit" line.

4. What does the shape of your line tell you about the distances that the trolley covered per 0,2 s as it went down the slope?

Velocity:

5. Prepare another piece of graph paper to draw a graph of velocity versus time. Time is on the horizontal axis – make 1 cm on the paper equal to 0.2 seconds. Velocity is on the vertical axis – make 1 cm on the paper equal to 2 centimetres per second. Label the axes with the physical quantities and the units.

6. Now calculate the average velocity for each strip and enter these values in the table.

For example: Average velocity = $\frac{\text{length}}{\text{time}} = \frac{20\text{ cm}}{0{,}2\text{ s}} = 100\text{ cm/s}$

7. For each strip, plot a point to represent the strip's average velocity and time. Because these are average velocities, the time value for each strip must be plotted in the middle of the time period. Join the first plotted point to the second point with a light, straight, ruled line; the second point to the third point; etc. When you have plotted all the points, draw a "best-fit" line.

8. What does the shape of your line tell you about the trolley's velocity during each 0,2 s as it went down the slope?

Draw a conclusion

Write a conclusion that relates to the aim of the experiment.

Recommend improvements

Suggest how the experiment could be improved.

Challenges and projects

Challenge number 1

In a warehouse, the goods are moved back and forth in the aisles by robotic trolleys.

- To prevent damage to fragile goods as they are moved, the trolleys have three speeds: slow, medium and fast.
- A trolley starts slowly, then moves at medium speed, then at fast speed. As the trolley approaches its destination it slows to medium speed, then to slow speed and then it stops.
- It moves at slow speed for 4 seconds, at medium speed for 6 seconds and at fast speed for as long as necessary.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 68 2016/01/05 3:16 PM

- Slow is 0,05 m/s; medium is 0,2 m/s; fast is 0,4 m/s.
- When a box of glasses was moved from A to B, the total time was 30 seconds

Questions

1. For what period of time did the trolley travel at fast speed?
2. Calculate the displacement in the fast stage.
3. Calculate the displacement from A to B.
4. Calculate the velocity from A to B.

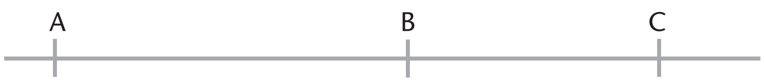
Challenge number 2

To shape a piece of wood, a carpenter makes a computer-controlled router move in a straight line from A to B, from B to C and then back to B:

- From A it moves to the right to B, at 80 mm per minute for 4 minutes.
- From B it moves further to the right to C, at 60 mm per minute for 2 minutes.
- It immediately returns to B at 100 mm per minute, and stops.

NOTE: In this activity the unit of time is minutes. It is not necessary to change it to seconds.

Figure 2.21



Questions

1. What are the displacements from A to B, from B to C and from A to C?
2. Calculate the velocity of the router as it moves from A to C.
3. Calculate the velocity of the cutter over the whole process.

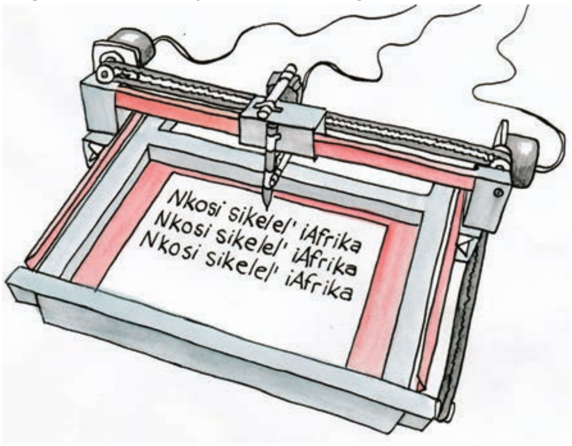
Challenge number 3

Plotters are computer-controlled machines that draw lines on paper.

Plotters were invented about 30 years ago when plotters were used for drawing plans for houses, ships, and so on. Plans are now produced by very large printers.

The movements of the pen of the home-made plotter in Figure 2.22a are controlled by stepper motors. The rotor of a stepper motor can be controlled to turn just a few degrees at a time – it can take many individual "steps" to complete one rotation. This makes very fine movements of the pen possible.

Figure 2.22a *A plotter drawing letters*



To draw a horizontal line, the pen starts at the origin (on the left) then moves (to the right) to the position at which the required line starts. There it is lowered onto the paper. The pen traces a line on the paper as it moves to the position where the line ends. The pen is then lifted up and it returns to the origin.

Figure 2.22b *A stepper motor*

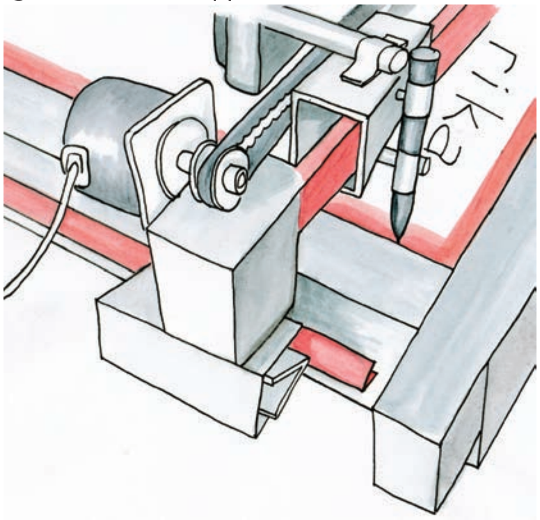
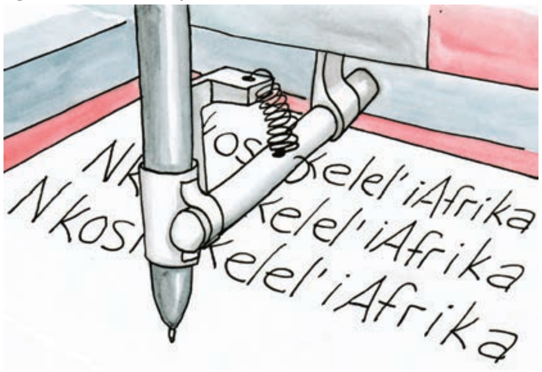


Figure 2.22c *A pen-holder*



Questions

1. There are five consecutive displacement vectors involved in drawing a line. Describe those vectors by choosing words from the list at the bottom of the page to complete the steps below:

- **a)** From origin to __________
- **b)** From __________ to pen down
- **c)** From start of line to __________
- **d)** From __________ to pen up
- **e)** From __________ to __________

<table>
<tr><td colspan="2">origin</td><td colspan="2">pen down</td><td colspan="2">pen up</td></tr>
<tr><td colspan="3">end of line</td><td colspan="3">start of line</td></tr>
</table>

2. The plotter drew the dark line in Figure 2.23 below.

Figure 2.23 *The dark line was drawn by the plotter.*

Measure the following distances in millimetres:

- **a)** from the origin to the start of the line
- **b)** from the start of the line to the end of the line
- **c)** from the end of the line to the origin

3. Describe the magnitude and direction of each of the five vectors. The pen starts 20 mm above the paper.

4. The stepper motor of our plotter takes 200 steps to complete one rotation. One rotation of the motor gives a 30 mm line on the paper. How many steps does the motor take to move the pen:

- **a)** from the origin to the start of the line?
- **b)** from the start of the line to the end of the line?
- **c)** from the end of the line to the origin?

CHAPTER 3 Forces

Everything you have learnt previously about forces applies to this subject:

- In Technology, our focus was the types of forces in structures and the size of forces that are needed to lift objects.
- In Natural Sciences, you studied different types of forces.

Unit 3.1 Introduction to forces

In Technology, you learned about forces in four different ways as shown by Figure 3.1:

- how forces are **transferred** using hydraulics, levers, gears, pulleys, cranks, etc.
- how forces can be **multiplied** using mechanical advantage in hydraulics, levers, gears and pulleys
- how loads on structures affect the **forces in structural members**; e.g. tension, compression, bending, shear and torsion
- how materials can be used to resist the **effects of forces in structures**; e.g. by triangulation, use of different sections and different materials, etc.

Figure 3.1 *This crane is an example of forces being transferred and multiplied, loads affecting the forces in members, and materials being used to resist the effects of forces.*

What is a force?

Definition: A force is a push or a pull.

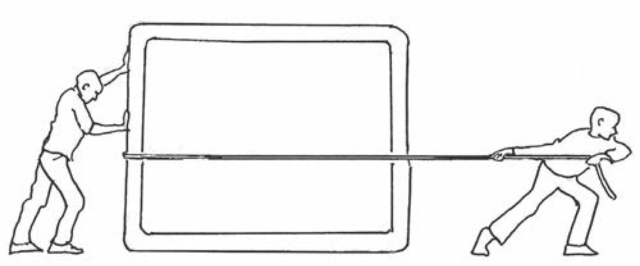
Definition: When two interacting bodies are in contact (when they touch), the force between them is a **contact force**.

Definition: When two interacting bodies are not in contact (not touching), the force between them is a **non-contact force**.

A force is a push or a pull

- **A force is a push or a pull on a body** when it interacts with another body. **Whenever there is an interaction between two bodies**, there is a force on each of the bodies. This interaction can be between bodies that are touching each other, or between bodies that are far apart.

Figure 3.2 *A force is a push or a pull.*



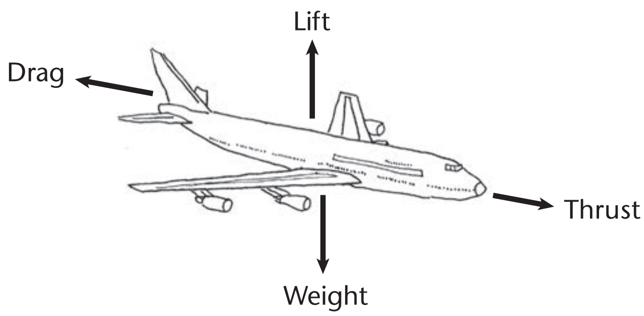
- **A force can change the motion of an object**, make it go faster, slower, start it, stop it, or hold it in one place. It can also change the direction of motion and the shape of an object.
- **A force has both magnitude and direction**, so it is a vector quantity. It is measured in the SI unit of newton (N) and represented by the symbol *F*. The magnitude of a force can be measured directly using a Newton Meter or a spring balance.
- **A force is not something you can see or touch, but you can see and feel what it does**. Forces are acting all around us – a builder is pushing a wheel barrow, steel columns are supporting roofs of factories, cranes are lifting loads.

Figure 3.3 *A force can change the motion of an object.*

When a force acts on an object, the object is either being **pushed or squashed**, or it is being **pulled or stretched**.

The types of forces we learnt about in Technology – **tension**, **compression**, **shear**, **bending and twisting** – develop only when something is pushed or pulled.

Figure 3.4 *A force is not something you can see or touch.*



Quick Activity:

- Look at the four photographs in Figure 3.5.
- Identify and describe the pushes and pulls in each of the four pictures. There might be more than two pushes or pulls in a picture.

Figure 3.5 *Examples of pushes and pulls*

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 72 2016/01/05 3:16 PM

Contact forces and non-contact forces

Most forces that you feel every day are contact forces.

You recognise them easily – you **push** a supermarket trolley, **lift** a spanner, **kick** a ball or **bite** an apple. These actions all require contact between two objects, like your teeth and the apple, or the spanner and your hand.

Non-contact forces, forces that act over a distance, are harder to recognise. We will study only the following three types of non-contact forces:

- the **gravitational force**; e.g. the attractive force that the Sun and the planets **exert*** on each other
- **magnetic forces**; e.g. the force of attraction or repulsion that two magnets in the same magnetic field exert on each other
- **electric forces**; e.g. the force of attraction or repulsion that two charges in the same electric field exert on each other

Figure 3.6 *Contact forces*

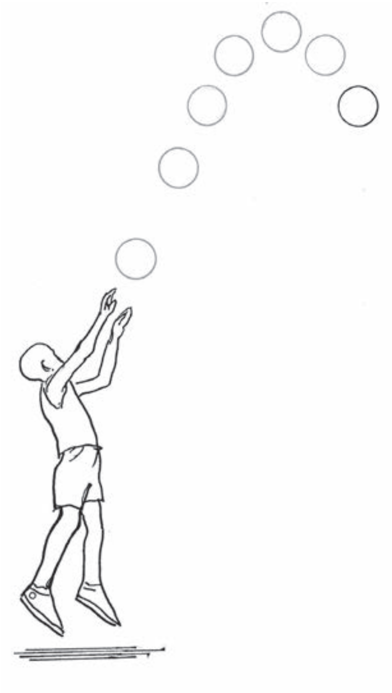
* If you **exert** a force on something, it means that you cause something to feel a force.

Gravitational force

The Earth's gravitational force is the force with which the Earth pulls everything that we can see or touch towards the centre of the Earth. Objects are pulled towards the Earth without any physical contact between the object and the Earth – gravitational force is a **non-contact force**.

Look at Figure 3.7. When you throw a ball up, it is the force of gravity that pulls it back without having any contact with the ball.

Figure 3.7



The Earth also exerts a force on you – it exerts an attractive force on you in proportion to your mass. This means that your weight depends on your mass. Your weight is the downward force that the Earth **exerts** on your mass.

Mass

The masses of some familiar objects are:

- The mass of a 100 mm nail is about 10 g.
- The mass of a litre of water is 1 kg.
- The mass of the wheel of a bakkie is about 30 kg.
- Your own mass is ....?
- The mass of a small 4-door car or a small elephant is about 1 000 kg.

Activity 1 Practise measuring masses using different scales

Take turns to do this in pairs.

Apparatus

- ❑ bathroom scale
- ❑ 100 N spring balance
- ❑ 20 N spring balance
- ❑ friend with a schoolbag of books
- ❑ a plastic litre bottle (with a handle and screw-on lid) containing 1 litre of water

A. Use the appropriate scale to determine the mass of the bottle of water, your friend's bag and your friend. Record the mass in kilograms and the scale or balance that you used each time.

B. Determine the mass of them all together and record the mass and which scale you used.

C. Check that the masses add up correctly.

Item	Tick the box to show the size of the scale used		Mass
	20 N	100 N	
Bottle			
Bag			
Friend			
Bottle + bag + friend			

The definition of mass

Definition: Mass is a measure of the amount of matter in an object.

Some people use the words "stuff" or "substance" in the above definition, instead of "matter".

Think about two balls of about same size: a polystyrene ball and a steel ball. The steel ball has much more matter in it, so its mass is greater than the mass of the polystyrene ball. This leads us to ask: what is matter?

Figure 3.8 *Iron and polystyrene balls*

Matter

Matter is the stuff that things are made of.

Definition: Matter is anything that occupies space and has mass.

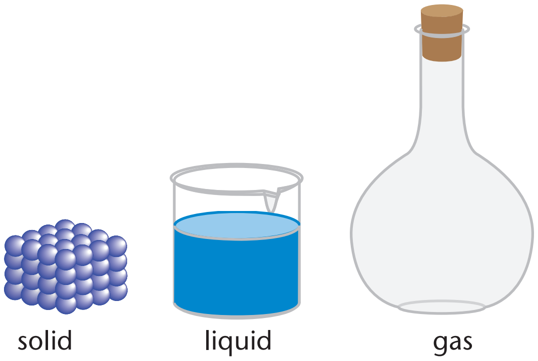


Figure 3.9 *Matter can be a solid, a liquid or a gas.*

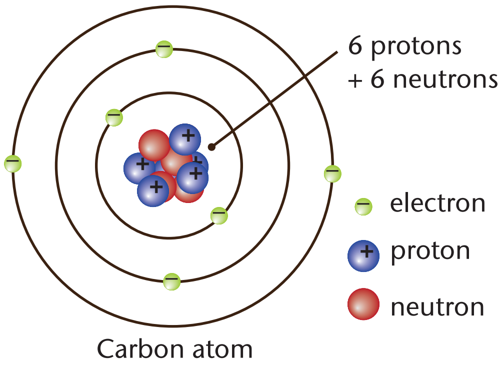


Figure 3.10 *Atoms are the building blocks of matter.*

Steel is made mostly of atoms of iron, carbon and other metals (it is an alloy). The atoms are joined together very closely, so a lot of them fit into a small space. So we can say that there is a lot of matter in a small space in steel. This means that steel is very dense.

Did you know?

The density of steel is about 8 000 kg/m^3 and the density of expanded polystyrene is about 20 kg/m^3. That means that the density of steel is 400 times the density of expanded polystyrene.

On the other hand, in polystyrene foam (expanded polystyrene), the atoms are spread out with pockets of air trapped in the polystyrene. So polystyrene has a lower density than steel and a polystyrene ball has less mass than a steel ball of the same size.

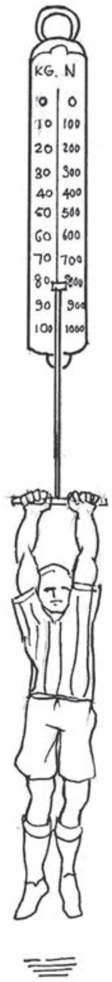
The relationship between mass and weight

If you ask a fit soccer player what he weighs, he might say 80 kg. Is he right? No, he is wrong. His mass might be 80 kg, but his weight is about 800 N.

The soccer player's mass is the amount of matter he is made of. His weight is the downward force exerted on him by the Earth's gravity – this depends on his mass and on the effect of gravity.

So your weight depends on your mass and the effect that the mass of the Earth has on your mass – we call this the acceleration of gravity (g) and it has a value of 9,8 m/s^2.

Figure 3.11 *How to calculate weight*



The mathematical relationship between mass and weight is:

weight = mass × acceleration of gravity

or

$F_g = m\,g$

Where:

- F_g is the symbol for the weight of an object (the force exerted on it by the Earth) in newtons (N)
- m is the symbol for the mass of the object in kilograms (kg)
- g = 9,8 m/s², which is called the acceleration of gravity

NOTE:

- The acceleration of gravity is measured using the unit m/s^2.
- Do you recognise m/s^2 as the unit we used for the measurement of acceleration in Chapter 2?

Worked examples: Calculate weight

1. What is **a)** the mass and **b)** the weight, of 1 litre of water?

Solution

a) 1 kilogram

b) Given: mass of 1 litre is 1 kilogram; $g = 9{,}8$ m/s²

Unknown: weight

Formula: weight = mass × gravity

$$F_g = m \times g$$
$$= 1 \times 9{,}8 \quad \text{(substitute)}$$
$$= 9{,}8 \text{ N}$$

2. If the mass of a brass door knob is 500 g, what is its weight?

Solution

Given: $m_{knob} = 500$ g $= 0{,}5$ kg; $g = 9{,}8$ m/s²

Unknown: weight

Formula: $F_g = m_{knob} \times g$

$$= 0{,}5 \times 9{,}8 \quad \text{(substitute)}$$
$$= 4{,}9 \text{ N}$$

Activity 2 Calculate weight

Calculate the weight of objects of the following masses on Earth in newtons. If the answer is more than 1 000 N, express it in kilonewtons (kN) as well.

1. a trailer with a mass of 1 000 kilograms

2. a first team rugby prop forward of mass 101,9 kilograms

3. 50 grams of sugar

4. 8 milligrams of sodium bicarbonate

5. a 4 525 kg drop forge

6. an 8 tonne truck (1 tonne = 1 000 kg)

7. 0,1 milligrams of arsenic

8. your own mass

Magnetic force

Magnetism is a property of some metals – called magnets – that exert a force on other magnets or magnetic substances.

The force is called a magnetic force. The force is felt everywhere in the space immediately around a magnet: it is strongest close to the magnet and decreases rapidly with distance.

All magnets have two ends, which are called poles. Each magnet has a north pole and a south pole.

The north pole of one magnet will attract the south pole of another magnet. But two north poles will repel each other and two south poles will do the same. We say that unlike poles attract and like poles repel.

So a magnetic force can be a force of attraction or a force of repulsion.

Figure 3.12 *The force is felt in the space around the magnet.*

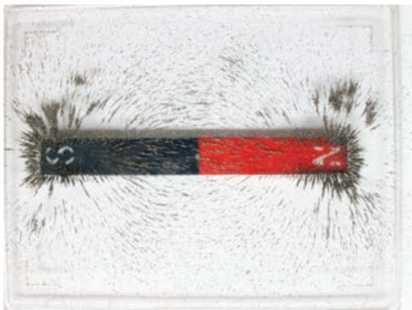
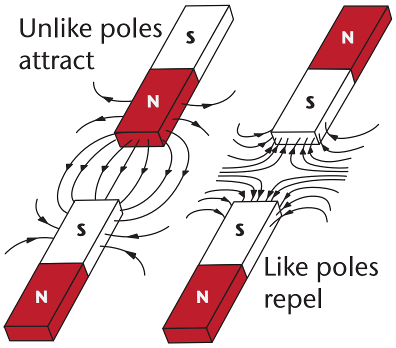


Figure 3.13 *The magnetic force is a force of attraction or repulsion.*



Electric force

When the air is dry and you pull your jersey off in the darkness of your room, you might see sparks and hear a crackle of electricity. This is static electricity. The sparks and crackles are made by little electric charges.

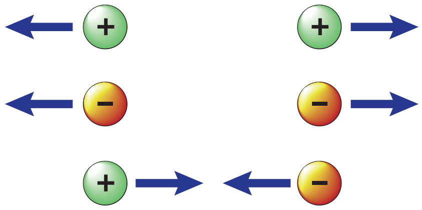
When certain materials are rubbed together or pulled apart, tiny electric charges gather on the surfaces because of the rubbing: we say the surfaces become electrostatically charged.

In Chapter 12 you will learn that:

- These little charges can be either negative (–) or positive (+).
- Unlike charges (+) and (–) attract each other, but like charges (+) and (+) or (–) and (–) repel each other.

The electric force and the magnetic force are similar in that both can be forces of attraction or of repulsion; but the gravitational force is a force of attraction only.

Figure 3.14 *The electric force is a force of attraction or repulsion between charges.*



Unit 3.2 Kinds of forces

Any **structural member*** subject to a pushing or pulling force is stretched or squashed by the force.

* A **structural member** is a part of something bigger – a system of beams, slabs and columns in the structure.

Tension or tensile force

Definition: **A tensile force is a pulling/stretching force. It causes the object on which it acts to tend to stretch.**

An object that is pulled or stretched is said to be in tension or is acted on by a tensile force.

Quick Activity:

Stand up, grab a friend's hand and lean back. Feel the tension.

Tension is the force that is transmitted through a body such as a piece of string, a cable, or a steel bar when it is pulled by forces acting on opposite ends.

Figure 3.15 *Tension acts directly along the rope and pulls equally on the objects at opposite ends.*

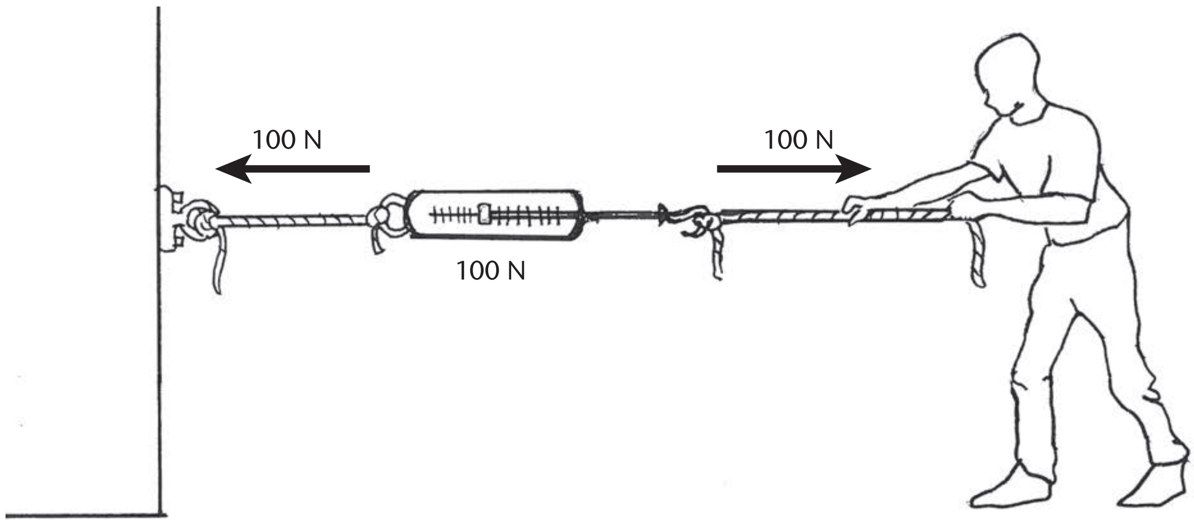
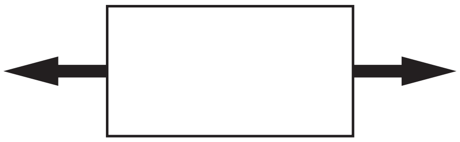


Figure 3.15 shows how tension in a rope, for example, acts directly along the length of the rope and pulls equally on the objects on the opposite ends of the rope.

We use the symbol in Figure 3.16 to represent an object subject to a tensile force.

Figure 3.16 *Symbol for a tensile force*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 78 2016/01/05 3:16 PM

Examples of objects in tension are:

- steel cables used to stabilise a cell phone tower or telephone pole
- the rope used in a block and tackle
- steel rods used in cross bracing of steel framed buildings
- the tie beam of a wooden roof truss
- a bolt holding parts of a structure or machine together

Figure 3.17a *Cable stabilising a tower*

Figure 3.17b *The rope in a block and tackle*

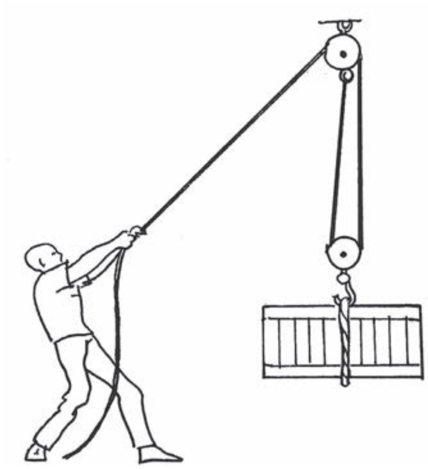


Figure 3.17c *Cross bracing of a steel framed building*

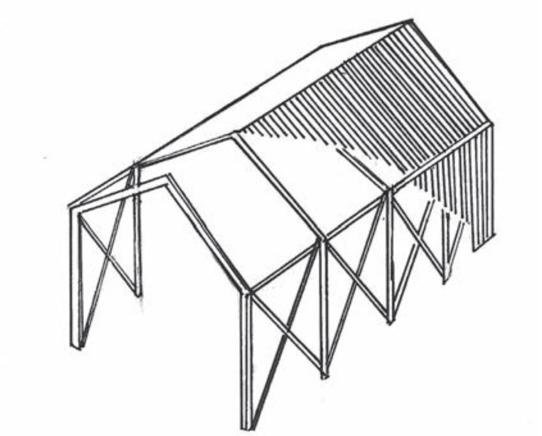
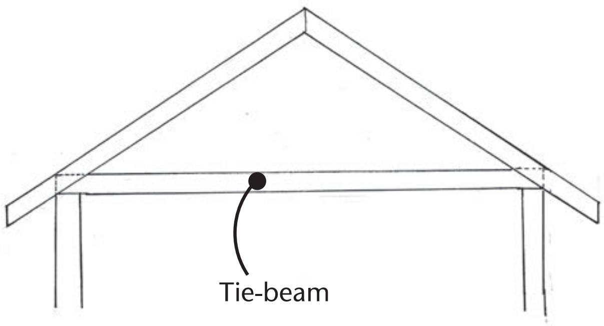


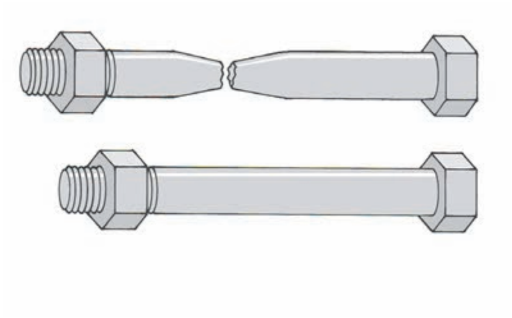
Figure 3.17d *The tie beam in a roof truss*



Stress

We have a word to describe the way a member "feels" a force – we say that the member is "stressed". If a force is too great and the member is stressed too much, it will fail by deforming (going out of shape), or by fracturing (breaking).

Figure 3.18 *This bolt has failed in tension. The picture shows the bolt before failure and after failure.*



Compressive force

Definition: A compressive force causes the object on which it acts to tend to compress (to be squashed or compacted).

A structural member that is being compressed is said to be in compression or to be **acted on by compressive forces**.

Quick Activity:

Stand up – put your hands on your desk and ask your partners to press down on your hands with their hands. Feel the compression.

We use the symbol in Figure 3.19 to represent an object that is subject to a compressive force.

Figure 3.19 *Symbol for a compressive force*

Objects subject to compression forces include:

- vertical steel members of a cell phone tower
- the columns (vertical members) in concrete framed buildings
- the girders and struts of a wooden truss
- gaskets, disc brakes and piston rods in cars

Figure 3.20a *The steel columns of this cell phone tower are heavier than all the other members*

Figure 3.20b *Columns of a concrete framed building*

Figure 3.20c *The top and end members, as well as the vertical struts of this truss bridge, are in compression.*

Compression

Tension

If the compressive force is too great, the member will fail by buckling or being crushed.

Figure 3.21 *Compression failure in a concrete column. The concrete has broken away and the reinforcing bars have buckled.*

Bending force

Definition: A bending force causes the object on which it acts to tend to bend.

A **beam** is a horizontal structural member designed to carry a vertical load and to resist bending and shear forces. The forces in a beam are caused by the weight of the beam itself (called the dead load), by loads placed on the beam (called the live load), and the reactions to these loads at the positions where the beam is supported.

These loads and reactions cause the beam to tend to bend. Figures 3.22 and 3.23 show typical beams. The bending is usually greatest in the middle of the beam.

Figure 3.22 *An overhead crane makes use of a beam. The four forces acting on the beam cause bending in the beam.*

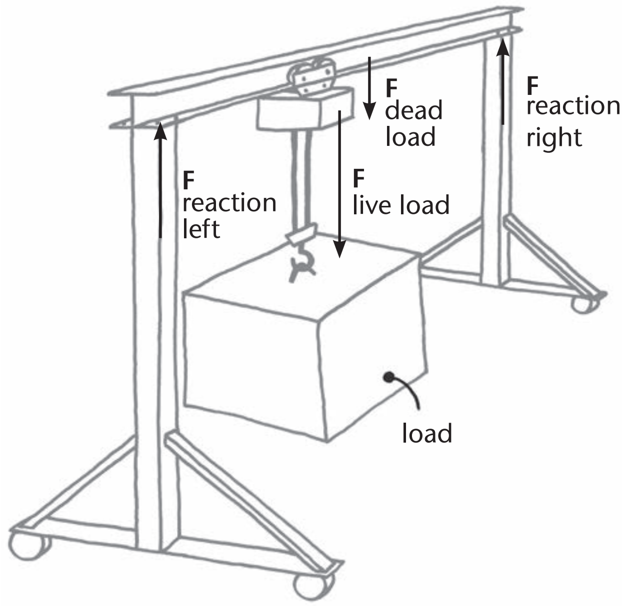
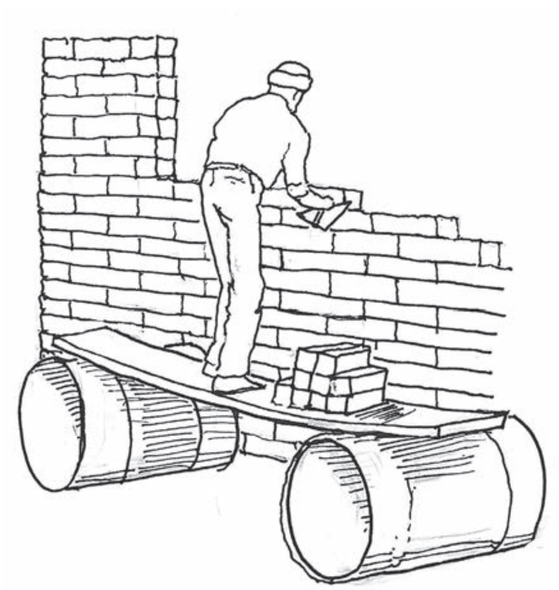


Figure 3.23 *The bending is usually greatest in the middle of the beam.*



Quick Activity:

Someone lies on his back on the floor. He tenses all his muscles. Four others take a shoulder or an ankle and lift him just 10 cm off the floor. Does he bend in the middle?

If a beam is overloaded it might fail by deforming (by bending too much) or by fracturing (by bending and breaking). It is the structural engineer's job to select the appropriate materials, size and shape to ensure that the beam does not fail.

Examples of beams are:

- the horizontal members in a steel, concrete or wood framed building
- the purlins that support the "corrugated iron" cladding on most roofs in South Africa
- the horizontal beams in a steel-framed building

Figure 3.24a *Wooden floor joists*

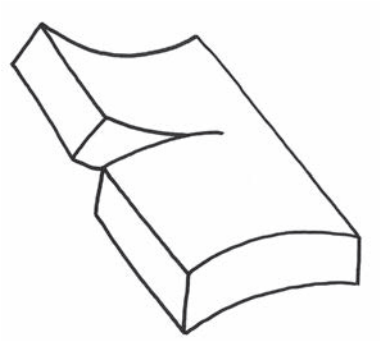
Figure 3.24b *Wood purlins that support a "corrugated iron" roof*

Figure 3.24c *Steel beams in a steel-framed building*

Shear force or shearing force

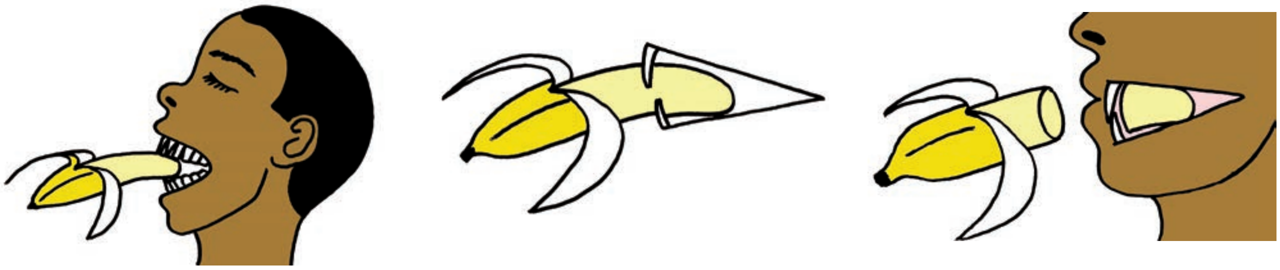
The pair of tinsnips in Figure 3.25 below cuts the sheet metal with a shearing action – the tinsnips cause the metal to shear.

Figure 3.25 *Tin snips cut the sheet metal with a shearing action.*



Definition: Shearing forces are unaligned forces that push one part of an object in one direction, and another part of the object in the opposite direction.

Figure 3.26 *The teeth in your lower jaw are not aligned with the teeth in your upper jaw. When you bite something, they work with a shearing action.*



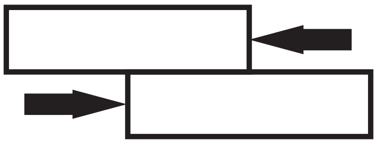
Can you visualise what happens to a banana when you bite it with your front teeth? The top teeth push the part of the banana (in your hand) down while the bottom teeth push the other part (in your mouth) up. The teeth slide past each other, creating a shearing action.

Quick Activity:

Hang from your fingers from a window sill at shoulder height – feel the shearing force where your fingers bend over the edge.

We use the symbol in Figure 3.27 to represent an object subject to shearing forces.

Figure 3.27 *Symbol for a shearing force*



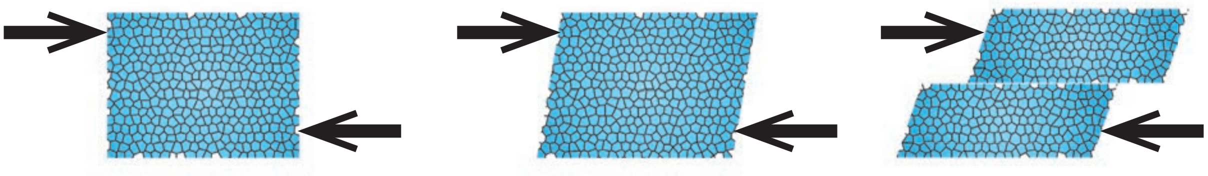
How does a material shear?

When forces on opposite sides of an object act in opposing directions as in Figure 3.28 a below, the object will tend to deform as in Figure 3.28 b, and might even fail as in Figure 3.28 c.

Figure 3.28 a *Forces on opposite sides of an object acting in opposing directions*

Figure 3.28 b *The object deforms.*

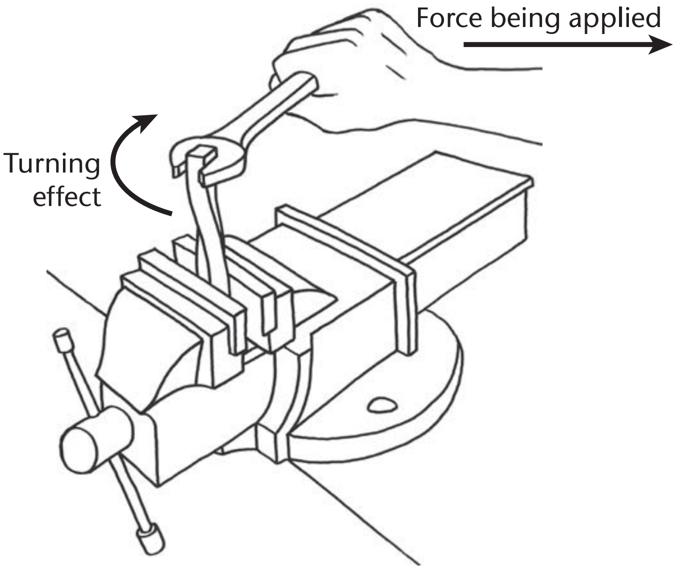
Figure 3.28 c *The object shears.*



Torsion

Torsion is not a force, it is the result of a turning action that has a twisting effect on an object. An object "feels" torsion when one end of the object is held firmly while the other end is turned or twisted. The stress caused by torsion is a shear stress.

Figure 3.29 *The hand applies a force which has a turning effect on the spanner. The square bar experiences a twisting effect: it "feels" the torsion.*



If you use a screwdriver to remove a screw from a piece of wood, the screw will experience torsion all along its length as you apply a turning force to the handle of the screwdriver.

Figure 3.30 *The two faces of a screw that has failed in torsion*

Quick Activity:

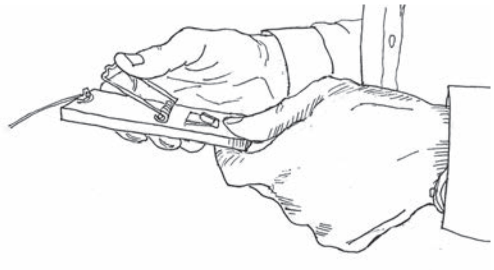
Take a piece of chalk and twist it – don't bend it – twist it until it breaks. You might see a classic torsion failure.

Objects subject to torsion include:

- screws and bolts
- the drive shafts of a car
- the bit of a drill
- the vertical column of a tower crane when the jib is side-on to the wind

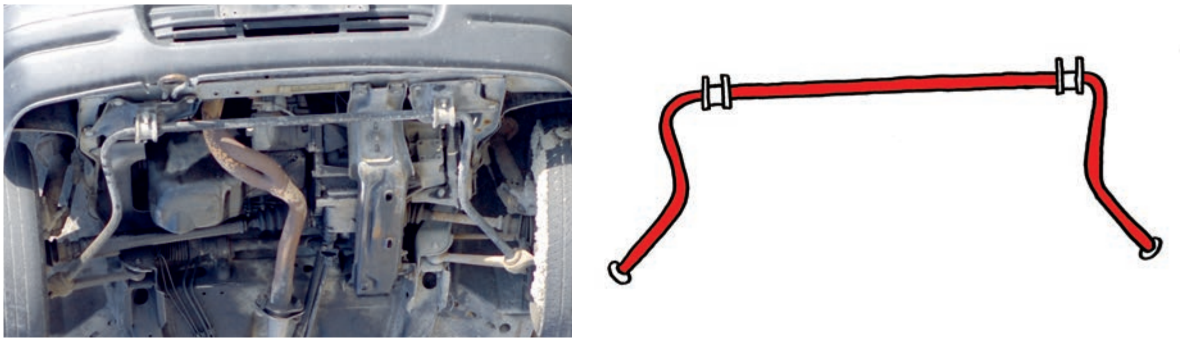
When you set a mouse-trap, the spring experiences torsion.

Figure 3.31 *Setting a mousetrap*



Torsion bars, like the one shown in Figure 3.32, are used in vehicle suspension systems to improve stability on the road.

Figure 3.32



Normal force

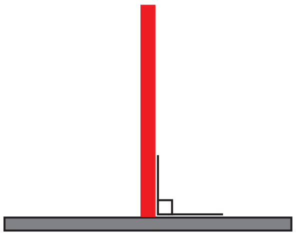
Definition: The normal force is the perpendicular force exerted by a surface on an object that touches the surface.

When two objects touch each other, a contact force is created as a result of their interaction. If one of the objects is a flat surface, the contact force that acts upwards from the surface, perpendicular to the surface, is called the normal force (F_N).

The diagrams in Figure 3.33 will help you to understand what a normal force is.

Figure 3.33 *A perpendicular line and a normal force*

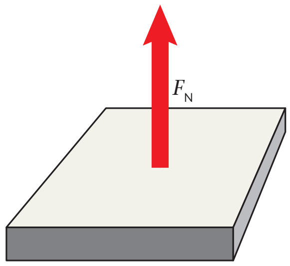
If two lines are at 90° (a right angle) to each other, we call them perpendicular.



If a surface and a line are perpendicular to each other, we say the line is normal to the surface.

A line that is perpendicular to a surface is called a normal line or just the normal.

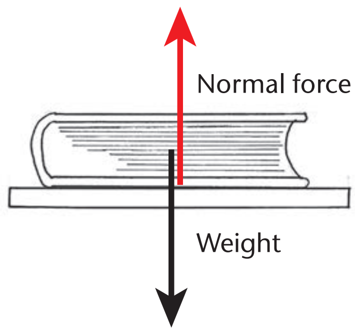
A force coming from the surface along a normal line is called a normal force, F_N.



When an object rests on a horizontal surface then the normal force is equal in size and opposite in direction to the weight of the object.

Think about the book resting on the table in Figure 3.34. The table exerts a normal force on the book, equal and opposite weight of the book.

Figure 3.34 *The normal force on an object on a level surface*



Frictional force

Friction is a force that is exerted whenever a surface of one object moves across a surface of another object. If two surfaces are touching and one of the objects starts to move, a frictional force develops between them.

Definition: The frictional force F_f is the force parallel to the surface that opposes the motion of an object and acts in the direction opposite to the motion of the object.

You experience friction in many ways every day:

- When you strike a match, the friction generates enough heat to start a chemical reaction – lighting the match.
- When you slide a bolt to lock a door or a gate, you need to overcome friction to slide it.
- Non-slip walking surfaces made of rubber or steel are used in dangerous areas to prevent you from slipping.

Figure 3.35 *We experience friction in many different ways.*

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 86 2016/01/05 3:16 PM

The frictional force opposes motion

Figure 3.36 shows a block being pushed across a flat surface. The motion of the block is to the right. The frictional force:

- opposes the motion of the object (it is opposite to the direction of the force causing the motion)
- acts parallel to the surface

The size of the frictional force depends on two things:

- the roughness of the surfaces – the rougher the surfaces, the greater the friction
- the normal force between the two surfaces – the greater the weight of the object, the greater the normal force and the greater the friction

Figure 3.36

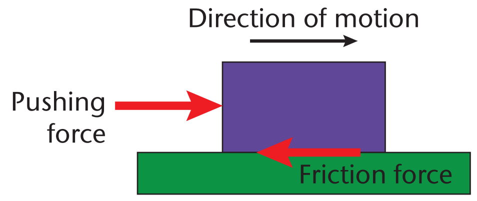


Figure 3.37a *The rougher the surface, the greater the friction.*

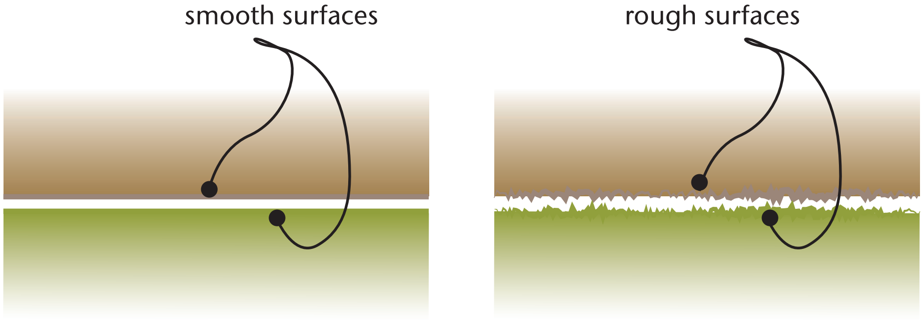
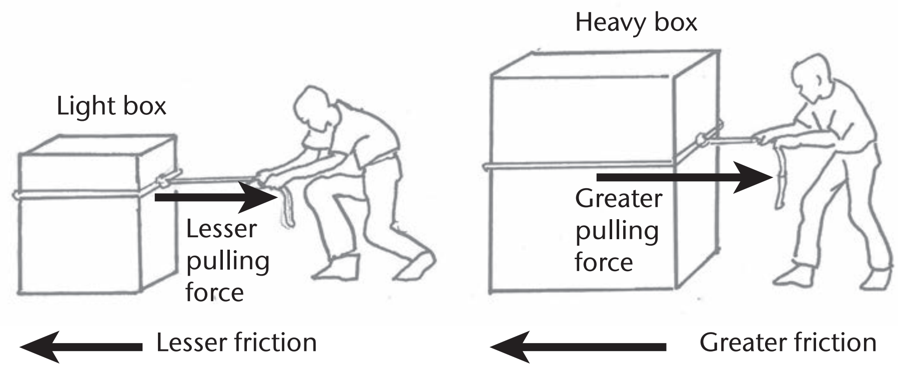


Figure 3.37b *The greater the weight, the greater the friction.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 87 2016/01/05 3:16 PM

The spring balance

Look at the spring balance in Figure 3.38. A spring balance is a device used to measure weight or force.

An object to be weighed is hung from a hook on the end of the spring. The spring is stretched by the weight of the object and an indicator points to the measurement of the weight in newtons on a scale.

In Grade 9 you used a spring balance to measure the weights of objects. We will use spring balances to measure the weight of objects as well as the magnitude of forces.

Figure 3.38 *A spring balance*

Apparatus

❑ spring balances

Activity 3 Review how to use a spring balance

A. Familiarise yourself with the features of the spring balances in your school. Your balances might look slightly different to the balance in Figure 3.38, but they will have the same features.

B. Check the rating of the scale. The rating is the maximum weight a balance can take without overstretching.

C. Hang the spring balance from a hook that has been screwed into a table or shelf, so that an object being weighed can hang freely underneath the spring balance.

D. Zero the scale: Use the scale adjuster to ensure that the indicator points to zero on the scale when the balance is hanging from a hook and nothing is hanging on the balance.

E. Hang an object to be weighed on the spring balance hook.

F. Read the scale marked in newtons (not grams or kilograms).

Experiment 2 Estimate and measure the weight of various objects

This is the second of ten experiments that will be assessed informally.

Work in groups of four to fulfill the aim of the experiment:

Base your work on what you have done in this chapter.

- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Apparatus

❑ spring balances with a rating lower than 100 N

Aim of the experiment: Estimate and measure the weights of various objects using a spring balance.

Plan the experiment

A. Collect ten objects to be weighed. They must range from light to heavy and each must have something that can hook onto the spring balance.

B. Draw a copy of the table below in you notebook. It must have at least ten rows for data.

Object	Estimated weight (N)	Actual weight (N)	Difference between estimated weight and actual weight (N)

Do the experiment

C. Pick up each object and feel how heavy it is. But do not use the scale yet.

D. Arrange the objects from lightest to heaviest. But do not use the scale yet.

E. Now weigh your heaviest object to ensure it does not exceed the rating of the scale. If it is too heavy, replace it with a lighter one.

F. Write the names of your group's objects in the table, in the order of what you estimate to be lightest to heaviest.

G. Each member of the group must estimate the weight of the lightest object and write it down.

H. Now weigh the lightest object and record its actual weight in the actual weight column.

I. Calculate the difference between estimated weight and actual weight.

J. Repeat steps G, H and I for all the objects in the table.

K. Add all your differences up. The person with the lowest number may have the title of *Estimator-in-chief*!

Draw a conclusion

Draw a conclusion related to your estimations.

Recommend improvements

- Discuss changes you could make to the procedure to ensure that you get smaller differences when you do this activity again.
- Write down your own recommendations to improve the experiment.

Activity 4 Compare the weight to the mass of various objects

Key question: How does the weight of an object relate to its mass?

A. Choose three objects with a range of different weights.

B. Draw up a table like the one below.

C. Record the weight of each object on the newton scale.

D. Now read the scale in kilograms and record the masses in the table on the following page.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 89 2016/01/05 3:16 PM

E. Divide weight by mass.

Number	Object	Weight (N)	Mass (kg)	Weight ÷ Mass

F. Look at your table. What is the relationship between weight and mass?

Unit 3.3 Force diagrams and free body diagrams

Force diagrams and free body diagrams show the forces acting on objects. They are used to analyse the forces in physical situations.

Definition: A force diagram is a picture of the object of interest with all the forces acting on it drawn as arrows, each acting through its point of application.

Definition: In a free body diagram, the object of interest is represented by a dot and all the forces acting on it are represented by arrows pointing away from the dot.

We usually start with a picture of the **physical situation.** In structural design this is called a **space diagram**. Figure 3.39a, below, is a picture of the physical situation. In this case there is a crane unloading a box off a truck.

Figure 3.39a

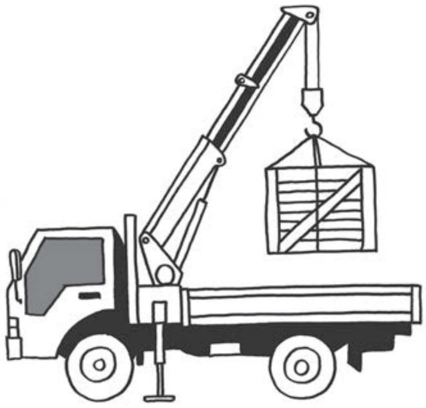


Figure 3.39b

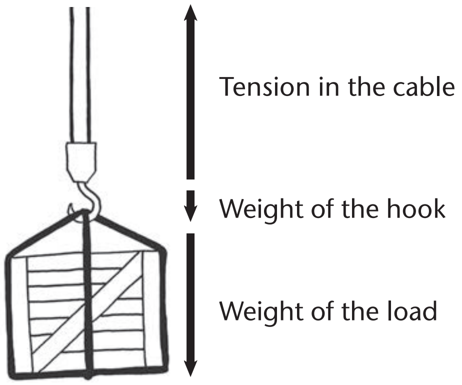
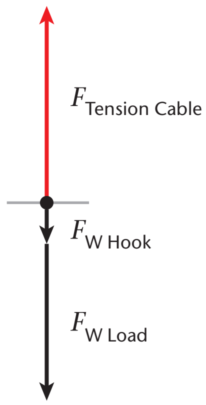


Figure 3.39c



The second image (Figure 3.39 b) is a **force diagram**. It shows:

- The **object of interest** and all objects that interact with the object of interest. In this case the object of interest is the hook. The object is shown isolated from the situation.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 90 2016/01/05 3:16 PM

- All the forces that act on the object of interest are represented by arrows which have the following features:
  - They show the line along which the force acts.
  - Their tails are at the point of application of the force.
  - They have descriptive names.

The third image (Figure 3.39 c) is a **free body diagram** – it is based on the force diagram. We use the free body diagram to **isolate** the object of interest from everything except for the forces that act on it.

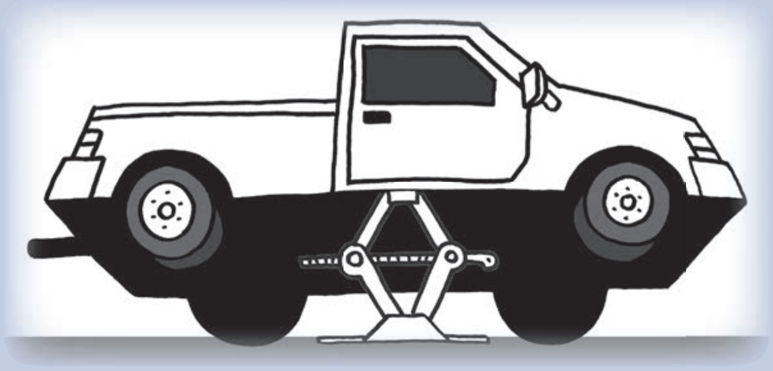
- The object is shown isolated from the situation and is now represented by a dot.
- All the forces acting on the dot are drawn as arrows pointing away from the dot.
- The forces are given symbolic names.

Remember that the arrows in free body diagrams represent forces. If we are analysing a situation using the **graphical method** we treat the arrows as vectors and draw them to a given scale:

- The length of the arrow reflects the magnitude of the force.
- The direction of the arrow shows the direction in which the force is acting.
- If more than one force acts in the same direction, the arrows are drawn tail-to-head.

Worked examples: Draw force diagrams and free body diagrams

Figure 3.40 *The physical situation: a car on a jack at the side of a road*



The physical situation in Figure 3.40 is a car on a jack at the side of a road.

1. The object of interest is the **jack**.

The picture in Figure 3.40 suggests that the forces acting on the jack represent:

- about half of the weight of the car (the other half is on the two wheels that are on the ground)
- the weight of the jack
- the normal force of the ground on the jack

Draw a force diagram and free body diagram to represent the physical situation.

Solution

Figure 3.41 *Force diagram: the object of interest is the jack*

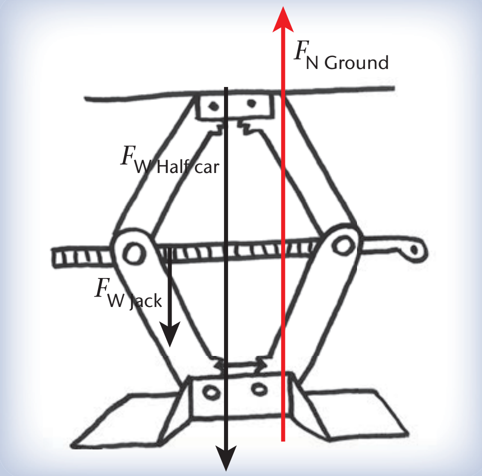
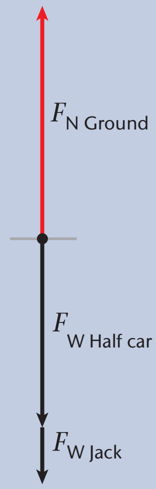


Figure 3.42 *Free body diagram for the jack*



2. The object of interest is the **car**.

The picture suggests that the forces acting on the car represent:

- the weight of the car acting on the jack
- the normal force of the jack on the car
- the normal force of the ground on the two wheels

Draw a force diagram and free body diagram to represent the physical situation.

Solution

Figure 3.43 *Force diagram: the car is the object of interest*

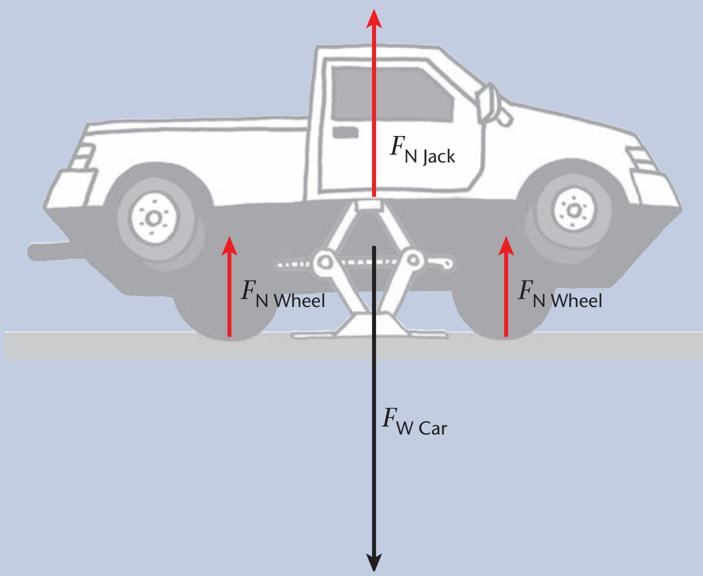
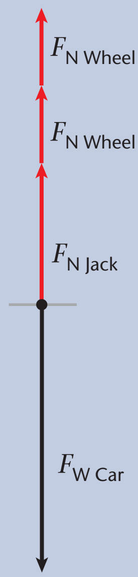


Figure 3.44 *Free body diagram for the car*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 92 2016/01/05 3:16 PM

Activity 5 Draw force diagrams and free body diagrams

Draw force diagrams and free body diagrams for each of the three physical situations that follow. All the forces have been described for you.

Situation 1:

A man is holding a bag of flour above the middle of a low table. The bag is the object of interest.

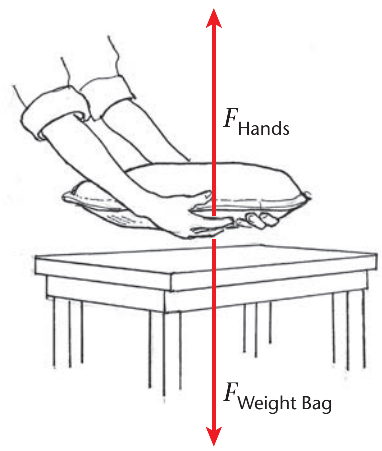
- F_{Hand} and F_{Weight} are equal in magnitude but opposite in direction.

Situation 2:

The bag is in the middle of the table. The bag is the object of interest.

- $F_{\text{Normal Table}}$ and $F_{\text{Weight Bag}}$ are equal in magnitude but opposite in direction.
- $F_{\text{Normal Table}}$ acts on a line through the centre the table
- $F_{\text{Weight Bag}}$ acts through the centre of the bag.

Figure 3.45 *The force diagram sets the scene.*



Situation 3:

The bag is on the table. The object of interest is the table.

- $F_{\text{Weight Bag}}$ acts downwards through the middle of the bag.
- $F_{\text{Weight table}}$ acts downwards through the middle of the table.
- $F_{\text{Weight Table}} + F_{\text{Weight Bag}} = 4 \times F_{\text{Contact Floor}}$
- $F_{\text{Contact Floor}}$ acts upwards through the bottom of each leg of the table.

Activity 6 Draw free body diagrams

Draw a free body diagram for each physical situation below.

1. A car battery is on a worktop. The battery is the object of interest.
2. A rotten hen's egg is floating in a pot of water. The egg is the object of interest.
3. A small box is stacked on a bigger box which itself is on a weighing scale.
   - **a)** The object of interest is the small box.
   - **b)** The object of interest is the big box.
   - **c)** The object of interest is the weighing scale.
4. A swing is hanging motionless from two chains in a play-park.
   - **a)** The object of interest is the seat of the swing.
   - **b)** An old man sits quietly on the swing with his feet off the ground. The object of interest is the seat.
5. A circus gymnast is hanging motionless from a bar suspended from ropes in the circus tent.
   - **a)** The object of interest is the gymnast. **b)** The object of interest is the bar.

Unit 3.4 Resultant, equilibrant and equilibrium

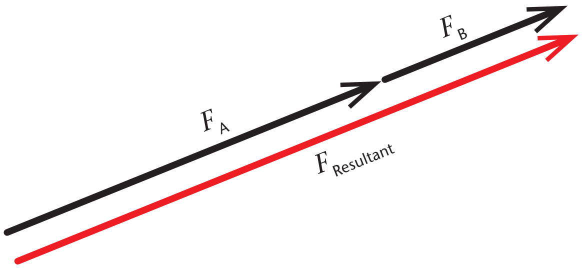
Resultant

In Unit 1.5 on scalar and vector quantities, we learnt that the **resultant** of any two (or more) vectors is the single vector which produces the same effect as the component vectors acting together.

Definition: **The resultant of two or more forces is the single force that can produce the same effect as the two or more forces.**

For example if we add two force vectors, such as F_A and F_B in Figure 3.46, then the resultant is force vector $F_{Resultant}$.

Figure 3.46 *Two force vectors and their resultant force vector*



Worked example: Determine resultant force

1. A rugby player's car is stuck in the mud. He can push with a force of 900 N but can't get the car out of the mud. Two passing netball players, each of whom can push with a force of 400 N, come to help. Together, they get the car onto firm ground. Determine the total force that was needed to move the car by:

a) the graphical method

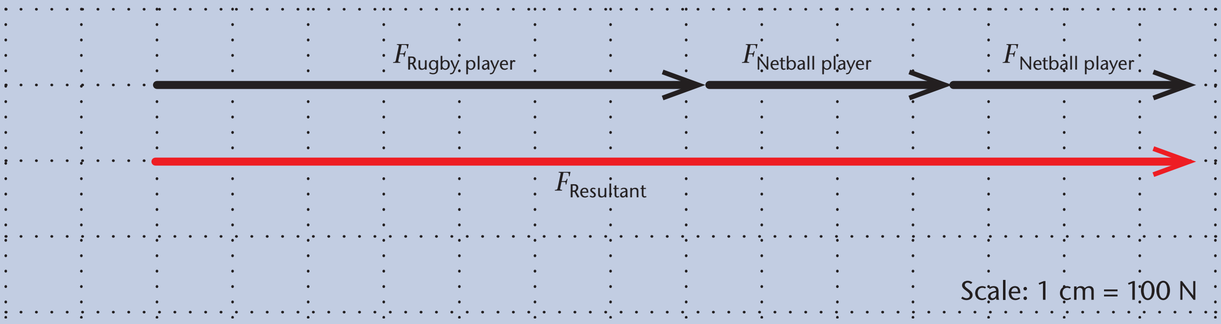
b) calculation

Solutions

a) By the graphical method:

- Select a scale of 1 cm = 100 N.
- Draw force vector $F_{\text{Rugby Player}}$ 9 cm long.
- Draw two force vectors $F_{\text{Netball Player}}$ 4 cm long, head-to-tail.

Figure 3.47



We measure the resultant and find that it is 17 cm long.

The scale is 1 cm = 100 N, so the resultant force vector $F_{\text{Resultant}}$ = 1 700 N.

b) By calculation:

Total force needed to move the car $= F_{\text{Rugby Player}} + F_{\text{Netball Player}} + F_{\text{Netball Player}}$

$= 900 + 400 + 400$

$= 1\ 700$ N

Activity 7 Determine resultant force

For each of the following situations, use both the graphical method and calculation to find the resultant of the forces:

1. +5 N; –15 N; +25 N; –10 N
2. 23 N north; 47 N north; 103 N south; 10 N north
3. 0,05 N up; 0,005 N down; 0,5 N down; 5 N up
4. 21,77 N north-east; 56,16 N south-west; 13,23 N north-east; 0,84 N south-west
5. +55 N; +250 N; –100 N; –150 N
6. 1,77 N north-east; 1,66 N south-west; 1,23 N north-east; 0,97 N south-west
7. 5 000 N up; 4 100 N down; 550 N down; 4 500 N up
8. 2,3 N north; 3,7 N north; 9,1 N south; 13,1 N north

Equilibrant

In a situation where a group of forces is acting on an object, you might need to know what force is needed to balance the resultant of the group of forces. The single force that would balance the resultant is the equilibrant.

Definition: The equilibrant is the force that has the same magnitude as the resultant but acts in the opposite direction.

Worked example: Determine the equilibrant

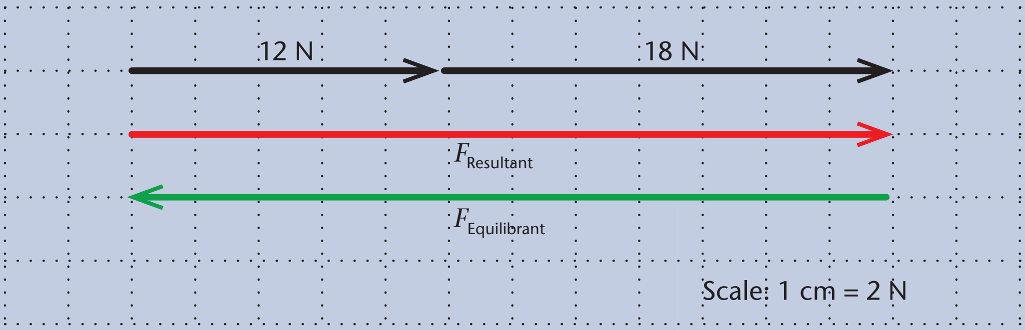
1. Two forces of 12 N and 18 N are acting in an easterly direction. Find the resultant and the equilibrant of the forces, using:

a) the graphical method **b)** calculation

Solutions

a) By the graphical method:

Figure 3.48



We measure the resultant and find that it is 15 cm long. The scale is 1 cm = 2 N, so the resultant force vector $F_{Resultant}$ = 30 N to the right. The equilibrant is the same length but it acts in the opposite direction. So the equilibrant is 30 N to the left.

b) By calculation:

12 N to the right + 18 N to the right = 30 N to the right

Resultant is 30 N to the right

$\therefore$ The equilibrant is 30 N to the left.

Activity 8 Determine the equilibrant

Use both the graphical method and calculation to find the resultant and the equilibrant of the forces in the situations below.

1. +4 N; –12 N; +8 N; –4 N
2. 3 N north; 7 N north; 3 N south; 1 N south
3. 1,5 N up; 0,5 N down; 14 N down; 4 N up
4. 1,8 N south-east; 6,2 N north-west; 3,4 N south-east; 0,8 N north-west
5. +0,8 N; –0,4 N; +0,4 N; –1,2 N
6. 4,7 N north; 7,3 N north; 3,2 N south; 6,6 N south
7. 160 N down; 250 N up; 460 N up; 210 N down
8. 19 m south-east; 31 m south-east; 10 m north-west; 59 m north-west

Experiment 3 Demonstrate that the resultant and the equilibrant are equal

This experiment is the first of the four experiments that will be assessed by your teacher in Grade 10 and for which marks are recorded. It will be marked on the Record of Assessment of Experiment according to the Assessment Rubric. In terms of the Programme for Assessment in CAPS, it will be marked out of 20 which is 6,7% of the mark for Assessment Tasks through the year.

Work in groups of four to fulfill the aim of the experiment:

- Base your work on what you have done in this chapter.
- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Apparatus

- ❑ straight board (16 mm MDF is best) of about 1,2 m × 0,15 m or similar
- ❑ ten 50 mm nails or similar
- ❑ drill and bit to match the nails
- ❑ pencil and long straight edge
- ❑ a large key ring
- ❑ string: one piece of 1,1 m; three pieces of 0,6 m
- ❑ four 10 N spring balances
- ❑ ten wide strips of paper, 10 cm x 20 cm (one for each group)
- ❑ sticky tape

Aim: Demonstrate that the resultant and the equilibrant are equal.

Plan the experiment

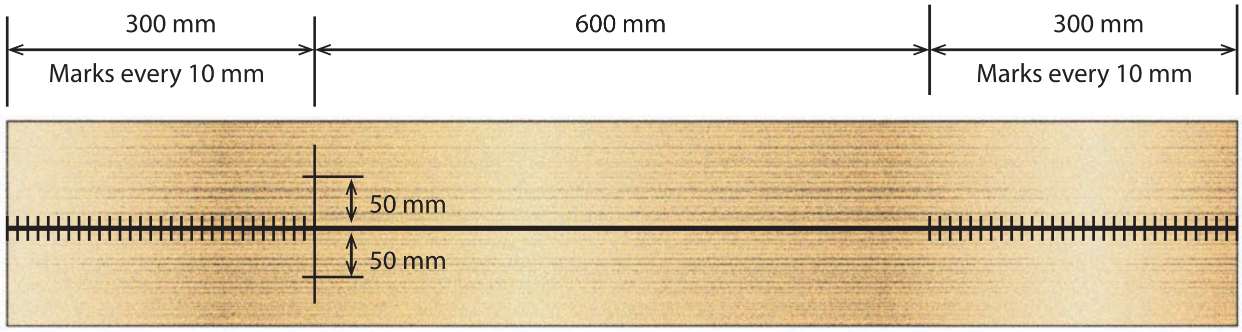
Set up the apparatus as shown in Figure 3.49:

A. Draw a straight line down the middle of the board from end to end.

B. Mark off thirty 10 mm intervals on the line as shown in Figure 3.49 below. Mark points 50 mm to each side of the line, 300 mm from the left end.

C. Drill a 10 mm deep hole at each of the marked points.

Figure 3.49



D. Make 250 mm loops with the short strings and a 500 mm loop with the long string.

E. Attach the loops to the key ring as shown in Figure 3.50.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 97 2016/01/05 3:16 PM

F. Copy the table below into your notebook.

	Balance 1	Balance 2	Balance 3	Balance 4	Questions	Comment
Readings at A					Are the readings all less than between 0,1 N and 0,3 N?	
Readings at B					Is the reading on Balance 1 about 9 N? Are the readings on Balances 2 and 3 about 4,5 N?	
Second readings at B					Is the ring back at Position B? Are the readings both about 9 N?	

Do the experiment

G. Check that the reading on each balance is zero.

H. Hook a spring balance to each of the loops. Label the balances on the short loops 1, 2 and 3. Label the balance on the long loop 4.

I. Put a nail in the board about 15 cm from the right hand end and attach Balance 1. Put nails in the two offset holes and attach Balances 2 and 3.

J. Adjust the position of the nail at Balance 1 and the size of the string loops at Balances 2 and 3, until all three balances have a reading between 0,1 N and 0,3 N (or just registering on the balance).

K. Tape a strip of paper to the plank under the key ring. Mark the position of the ring: Position A. Record the readings on the three balances in the table and comment.

Figure 3.50

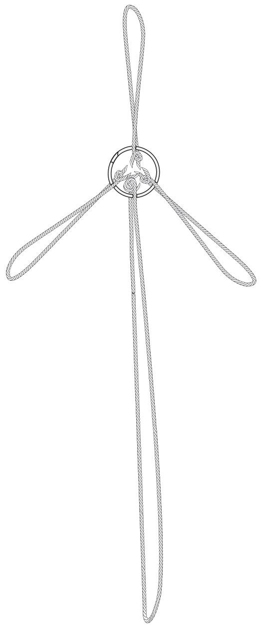
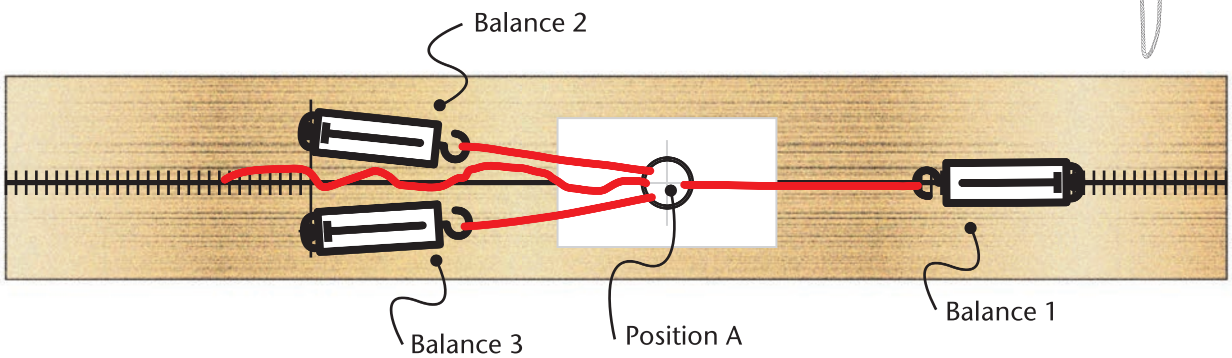


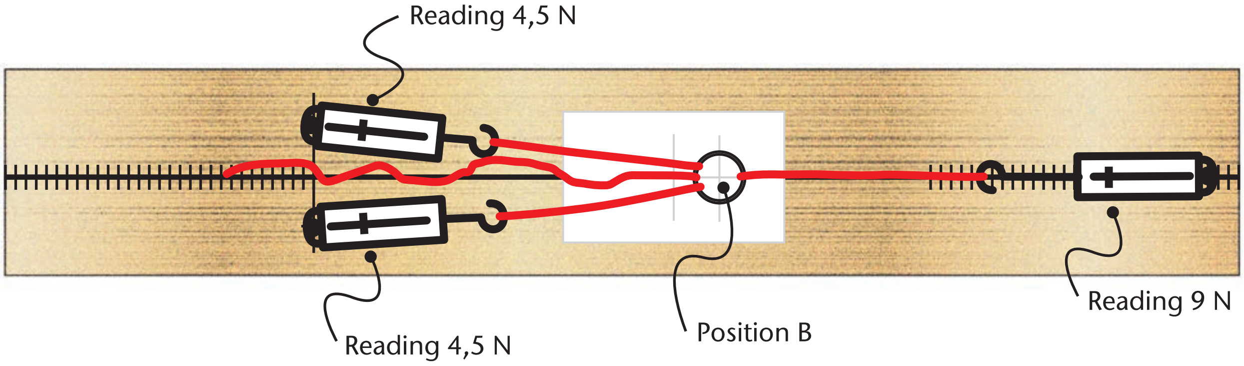
Figure 3.51



L. Reposition Balance 1 so that the reading on Balance 1 is about 9 N and the readings on Balances 2 and 3 are about 4,5 N. Mark the position of the ring and label it: Position B.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 98 2016/01/05 3:16 PM

Figure 3.52



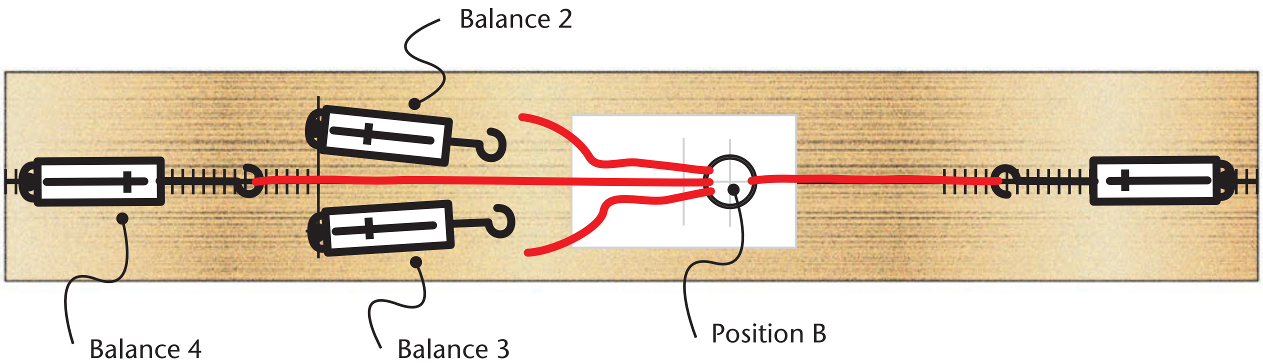
M. Record the readings on the three balances and comment on the following questions:

- Is the reading on Balance 1 equal to the sum of the readings on Balances 2 and 3?
- Can we say that the size of the force that Loop 1 exerts on the ring is equal to the size of the force exerted on the ring by Loops 2 and 3?
- Can we also say that the force that Loop 1 exerts on the ring is in the opposite direction to the force exerted by Loops 2 and 3?
- So can we combine the two previous statements and say that the force that Loop 1 exerts on the ring is equal and opposite in direction to the force exerted by Loops 2 and 3?

N. We are going to replace Loops 2 and 3 with Loop 4:

- Hook Balance 4 to the long loop, move it gently to the left and hook it over a nail so that there is just a little tension in the loop.
- Unhook Balances 2 and 3 and reposition the nail holding Balance 4 so that the ring is at Position B.

Figure 3.53



O. Record the readings on Balances 1 and 4 and comment on the following questions:

- Are the readings on both the balances about the same? Are these readings the same as the reading on Balance 1 in M?
- Can we say that the force that Loop 4 exerts on the ring has replaced the force exerted on the ring by Loops 2 and 3?

- So can we say that the force that Loop 4 exerts on the ring is in the same direction and is equal to the sum of the forces in Loops 2 and 3?
  If your answers to the above questions are yes (or even a qualified yes), then we may say that the force in Loop 4 is equal to the resultant of the forces in Loops 2 and 3.

P. Remove your piece of paper and stick it in your note book.

Q. Remove the nails from the board in preparation for the next group.

Draw a conclusion

Write a conclusion that relates to the aim of the experiment.

Recommend improvements

Suggest how the experiment could be improved.

Equilibrium of forces in one dimension

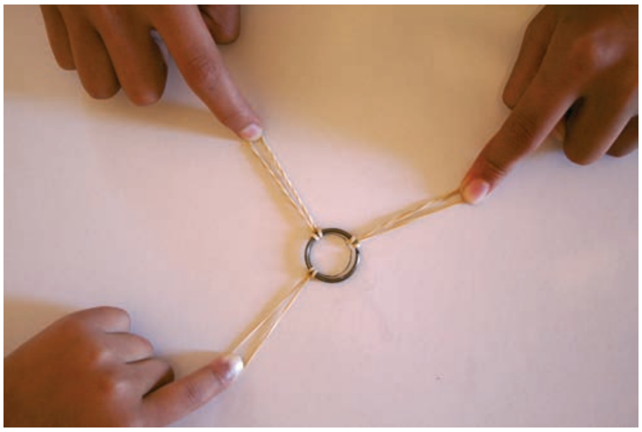
Definition: **A body is in equilibrium when the resultant force on the body is zero.**

We call it "in equilibrium" because all the forces acting on the object are "in balance".

Activity 9 Demonstrate equilibrium (in two dimensions)

We are going to demonstrate an object being held in equilibrium by three different forces. The object is a key ring and the forces are tensile forces in elastic bands.

Figure 3.54



Apparatus

- ❑ a level table
- ❑ a few high quality elastic bands
- ❑ small key ring
- ❑ sheet of paper
- ❑ sticky tape
- ❑ pencil

(**NOTE:** cheap elastic bands are not elastic – they do not return to their original shape. Even high quality elastic bands lose their shape if stretched too far.)

Procedure

A. Stick the piece of paper down in the middle of the table.

B. Thread three elastic bands onto the key ring.

C. Three learners put a hand on the desk, hook a little finger into a band, pull gently, ensure that the ring is on the paper, and then stay motionless by pressing their hands down onto the desk.

D. Mark the position of the ring on the paper.

E. The fourth member of the group pulls the ring gently to one side and then lets it go. Does it return to its original position?

F. The fourth member repeats Step **E** from other positions.

G. What is the minimum number of bands you could use for this demonstration? What is the maximum number?

H. The ring should return to the position it had before the fourth person pulled it aside, because that is where the forces in the bands are in equilibrium – where the resultant of all the forces acting on the ring is zero.

Activity 10 Demonstrate equilibrium in one dimension

Based on what you saw in the demonstration of equilibrium in two dimensions, plan and carry out an experiment to demonstrate equilibrium in one dimension.

Activity 11 Calculate the equilibrant

1. Calculate the force needed for these groups of forces to be in equilibrium:

- **a)** 1,5 N up; 0,5 N down; 4 N up
- **b)** +4 N; –12 N; +9 N
- **c)** 6 N north; 3 N south; 1 N south
- **d)** 1,2 N south-east; 6,2 N north-west; 3,4 N south-east
- **e)** –120 N; +45 N; +95 N
- **f)** 17 N up; 3 N up; 5 N down
- **g)** 1 100 N south-east; 610 N north-west; 330 N south-east
- **h)** 1,3 N south; 1,1 N south; 1,5 N north

Chapter summary

- When there is an **interaction** between two bodies, there is a force on each of the bodies. A force is not something you can see or touch, but you see and feel its effect.
- A force is a push or pull between bodies that are touching each other, or between bodies that are far apart.
  - When two interacting bodies are in contact, the force is a contact force.
  - When two interacting bodies are not in contact, the force is a non-contact force. The gravitational force, the magnetic force and the electric force are non-contact forces.
- A force can change the motion of an object.
- A force has both magnitude and direction, so it is a vector quantity. Its SI unit is the newton (N) and it is represented by the symbol F.

- The Earth's force of gravity is the force with which the Earth pulls everything towards the centre of the Earth.
- The mass of the Earth acts on the mass of an object – it **exerts** an attractive force on the mass. Your weight is the downward force that the Earth **exerts** on you.
- Mass is a measure of the amount of matter in an object.
- Matter is anything that occupies space and has mass.
- The mathematical relationship between mass and weight is:
  $F_g = m\,g$
  where:
  - F_g is the symbol for the weight of an object (the force exerted on it by the Earth) in newtons (N)
  - m is the symbol for the mass of an object in kilograms (kg)
  - $g = 9{,}8$ m/s^2
- The gravitational force is a force of attraction only, whereas the magnetic and electric forces are forces of attraction and repulsion.
- Tension is a pulling force; compression is a pushing force.
- A bending force tends to bend objects; a shear force tends to shear objects.
- The normal force (F_N) is the perpendicular force exerted by a surface on an object that touches the surface.
- The frictional force (F_f) is the force parallel to a surface that opposes the motion of an object across the surface and acts in the direction opposite to the motion of the object.
- A force diagram is a picture of the object of interest with all the forces acting on it drawn as arrows, each acting through its point of application.
- In a free-body diagram, the object of interest is represented by a dot and all the forces acting on it are represented by arrows pointing away from the dot.
- The resultant of two or more forces is the single force that can produce the same effect as the two or more forces.
- The equilibrant is the force that has the same magnitude as the resultant, but acts in the opposite direction.
- A body is in equilibrium when the resultant force on the body is zero.

Challenges and projects

Experiment A: Demonstration

Demonstrate that friction depends on the texture of both surfaces that are in contact.

Experiment B: Demonstration

Demonstrate that friction depends on the normal force between the two surfaces.

CHAPTER 4 Moment of a force

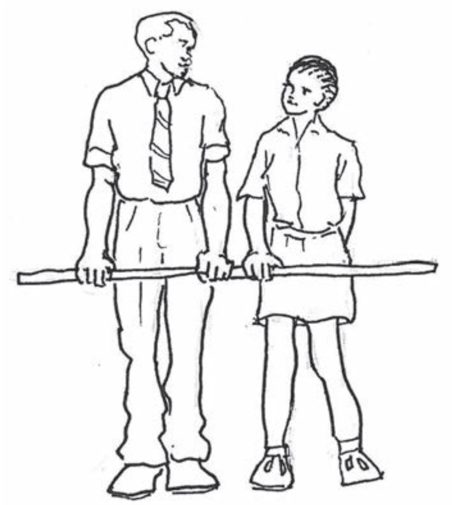
This chapter is about the turning effect of a force, which is called a **moment**.

Unit 4.1 Moment: The turning effect of a force

Quick Activity: Feel a turning effect

- You need a stick about half the length of a broom handle and the same diameter.
- You will hold the stick very firmly and a classmate will try to turn you around using the stick.
- Hold the stick horizontally, with two hands, near your stomach. A classmate holds the stick with one hand very close to your hands. You are the *centre* and your classmate's challenge is to try to turn you around – gently. Can he/she do it?
- Then allow your classmate to hold the stick further away and try again. What happens now?
- Even if you are the biggest learner in the class, the smallest learner will find it easy to turn you if he/she holds the stick far away from the *centre*.

Figure 4.1 *What makes it easier to turn you around?*



The turning effect of a force

If a force is applied to an object which is connected to a **fulcrum*** (say FOOL-kruhm), the force will try to turn the object around the fulcrum. When this happens we say that the force has **a turning effect about the fulcrum.**

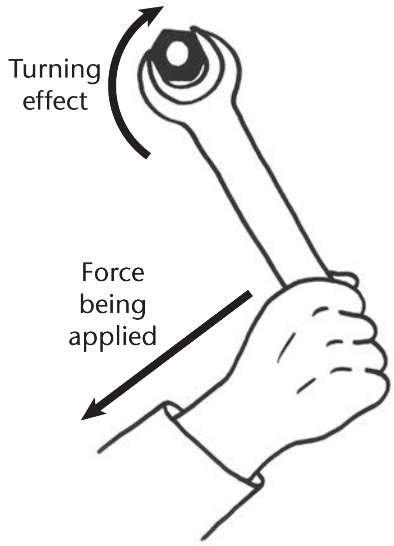
In Figure 4.2, the hand applies a force to the spanner. The spanner and nut experience a turning effect about the bolt.

Definition: **The turning effect of a force about a fulcrum is called the moment of the force, or just the moment.**

Your weight, for example, can have a turning effect. Your weight (measured in newtons) is a force towards the centre of the Earth.

* **Fulcrum** – the support or point of rest about which a lever turns

Figure 4.2 *The force of the hand has a turning effect about the bolt.*

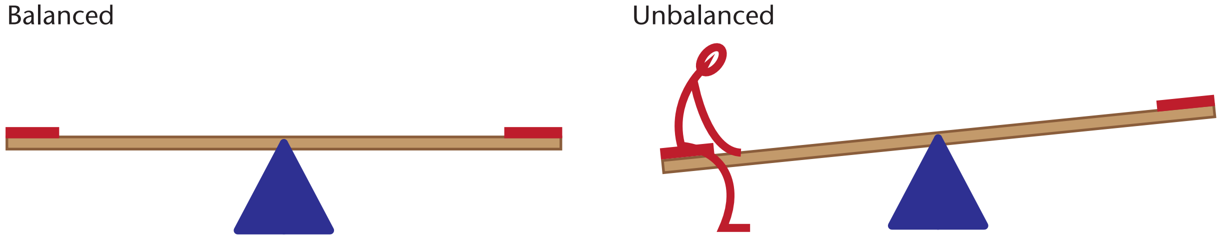


Think about a see-saw like the one you can see in Figure 4.3. There the object that turns is a long pole. The fulcrum is a structure in the middle.

When nobody is on the see-saw, the pole is (or should be) balanced. If a person gets on at one end, their weight (a force) will make that end go down, and the pole will turn around the fulcrum. The force makes the see-saw unbalanced and it turns around the fulcrum.

Figure 4.3 *A seesaw with a heavy duty fulcrum*

Figure 4.4 *A see-saw in balance and an unbalanced see-saw with a person sitting on one side*



A turning effect can be clockwise or anti-clockwise

The hands of a clock are described as turning in a clockwise direction.

We use the words "clockwise" and "anti-clockwise" to describe the direction of the turning effect of a force.

In Figure 4.6a, the force causes a clockwise turning effect. In Figure 4.6b, the turning effect is anti-clockwise.

Figure 4.5 *Clockwise direction*

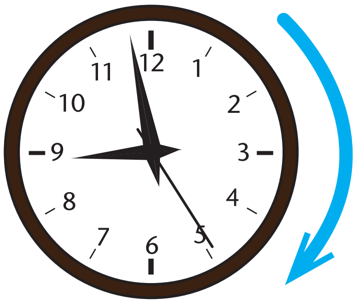


Figure 4.6a *The see-saw turns clockwise.*

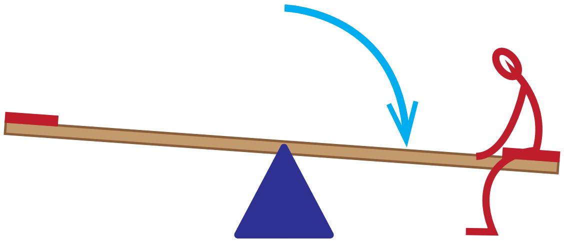
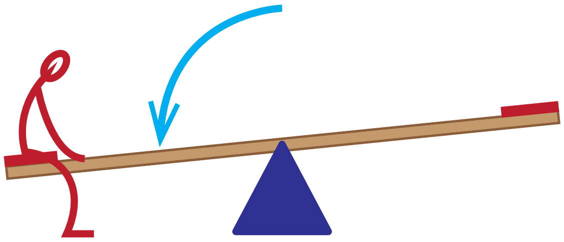


Figure 4.6b *The see-saw turns anti-clockwise.*

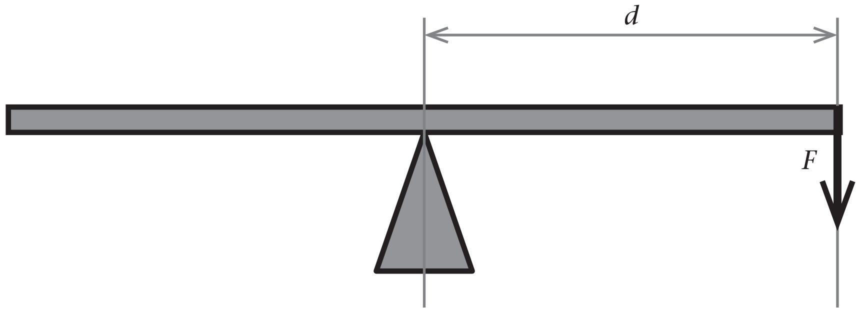


TechSci_G10-LB-Eng-DBE3_9781431522842.indb 104 2016/01/05 3:16 PM

Calculate a moment

Moments are calculated in all branches of engineering, but most especially in structural engineering.

Figure 4.7 *The size of the moment depends on the size of the force F and the distance d.*



Definition: The size of a moment (*M*) depends on the size of the force (*F*) and the perpendicular distance from the fulcrum to line of the force (*d*).

We can describe this in a word formula:

moment = the force × perpendicular distance from the fulcrum to the line of the force

Using symbols and abbreviations the formula is:

$M = F \times d$

where:

- *M* is the symbol for moment measured in newton metres (N m)
- *F* is the symbol for force measured in newtons (N)
- *d* is the symbol for distance measured in metres (m)

NOTE: The SI unit for a moment is derived directly from the units for the two physical quantities that are multiplied together to give a moment: a **newton** multiplied by a **metre** gives a **newton metre**.

A moment is a vector quantity

When you calculate a moment you must remember that force is a vector quantity: it has a magnitude and a direction. So a moment also has a direction – it will usually be described as either clockwise or anti-clockwise.

To calculate a moment we need to know three things:

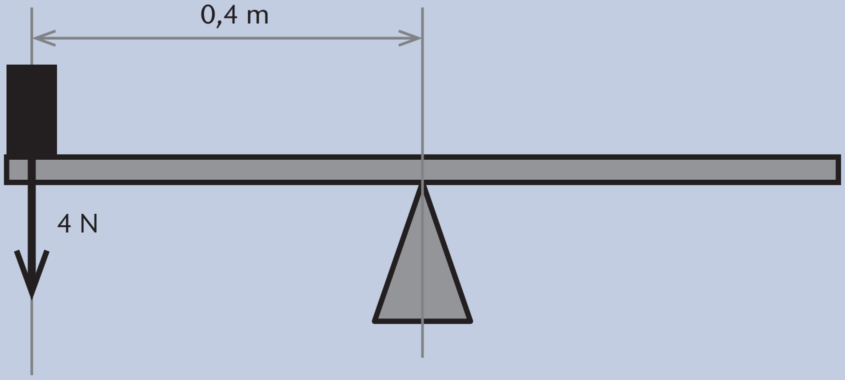
- the distance of the force from the fulcrum
- the magnitude (size) of the force
- the direction of the force

Worked examples: Calculate moments

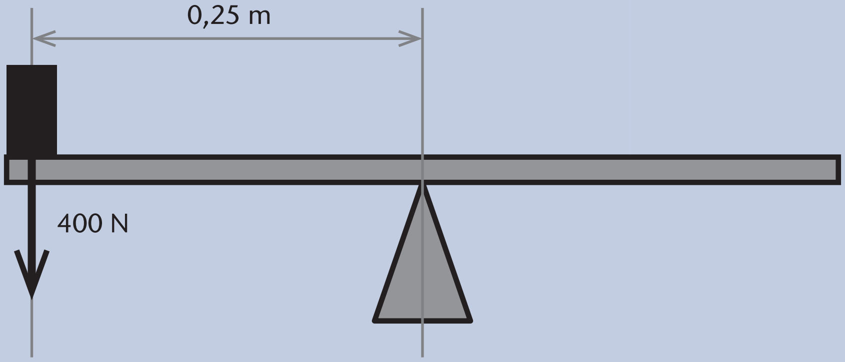
1. Calculate the moment in each diagram in Figure 4.8 below.

Figure 4.8

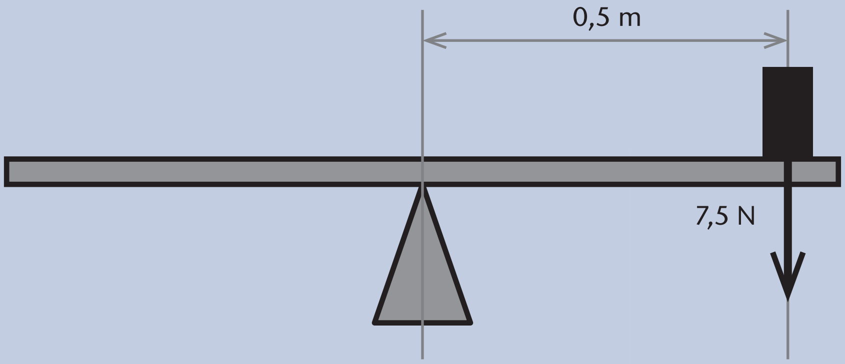
a)



b)



c)



Solutions

a) Given 4 N acts downwards 0,4 m to the left of the fulcrum

Unknown moment

Formula $M = F \times d$

$= 4 \times 0{,}4$ (substitute)

$= 1{,}6$ N m anti-clockwise

b) Given 400 N acts downwards 0,25 m to the left of the fulcrum
Unknown moment
Formula $M = F \times d$
$= 400 \times 0{,}25$ (substitute)
$= 100$ N m anti-clockwise

c) Given 7,5 N acts downwards 0,5 m to the right of the fulcrum
Unknown moment
Formula $M = F \times d$
$= 7{,}5 \times 0{,}5$ (substitute)
$= 3{,}75$ N m clockwise

2. A 2 N force acts downwards 1 m to the right of a fulcrum. Calculate its moment.

Solution

a) Given 2 N acts downwards 1 m to the right of the fulcrum
Unknown moment
Formula $M = F \times d$
$= 2 \times 1$ (substitute)
$= 2$ N m clockwise

3. A 30 N force acts downwards 3 m to the left of a fulcrum. Calculate its moment.

Solution

a) Given 30 N acts downwards 3 m to the left of the fulcrum
Unknown moment
Formula $M = F \times d$
$= 30 \times 3$ (substitute)
$= 90$ N m anti-clockwise

4. A 45 N force acts upwards 2,5 m to the left of a fulcrum. Calculate its moment.

Solution

a) Given 45 N upwards and 2,5 m to the left of the fulcrum
Unknown moment
Formula $M = F \times d$
$= 45 \times 2{,}5$ (substitute)
$= 112{,}5$ N m clockwise

5. A 0,25 N force acts upwards 0,15 m to the right of a fulcrum. Calculate its moment.

Solution

a) Given 0,25 N upwards and 0,15 m to the right of the fulcrum

Unknown moment

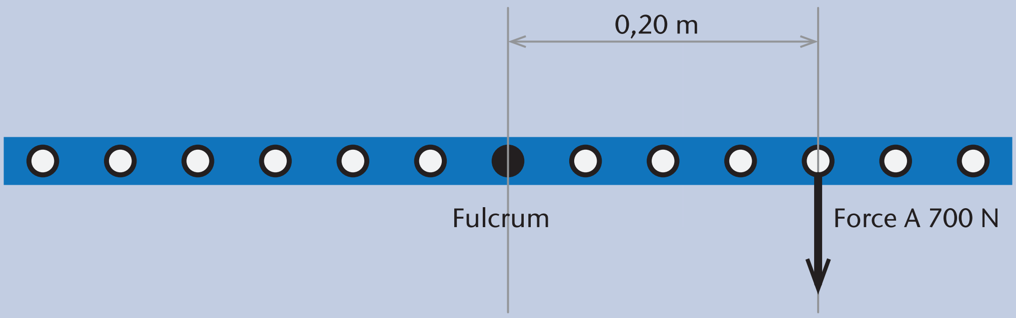
Formula $M = F \times d$

$= 0{,}25 \times 0{,}15$ (substitute)

$= 0{,}0375$ N m anti-clockwise

6. An engineer is trying to balance a link in a machine. The link is 600 mm long and is pivoted at its mid-point. Force A is 700 N and acts vertically downwards 0,2 m to the right of the pivot.

Figure 4.9



a) What is the moment at the fulcrum caused by Force A?

b) Force B is 560 N and acts vertically downwards on the left-hand side of the link. Calculate the distance from the pivot that Force B must act to balance the link.

Solutions

a) Given Force A = 700 N; distance from the fulcrum = 0,2 m

Unknown M_A

Formula $M_A = F \times d$

$= 700 \times 0{,}2$ (substitute)

$= 140$ N m clockwise

b) Given $M_A = 140$ N m clockwise; Force B = 560 N

Unknown M_B

Formula $M_B = F \times d$

$= 560 \times d$ (substitute)

If the link is in balance, then $M_B = M_A$

So $560 \times d = 140$

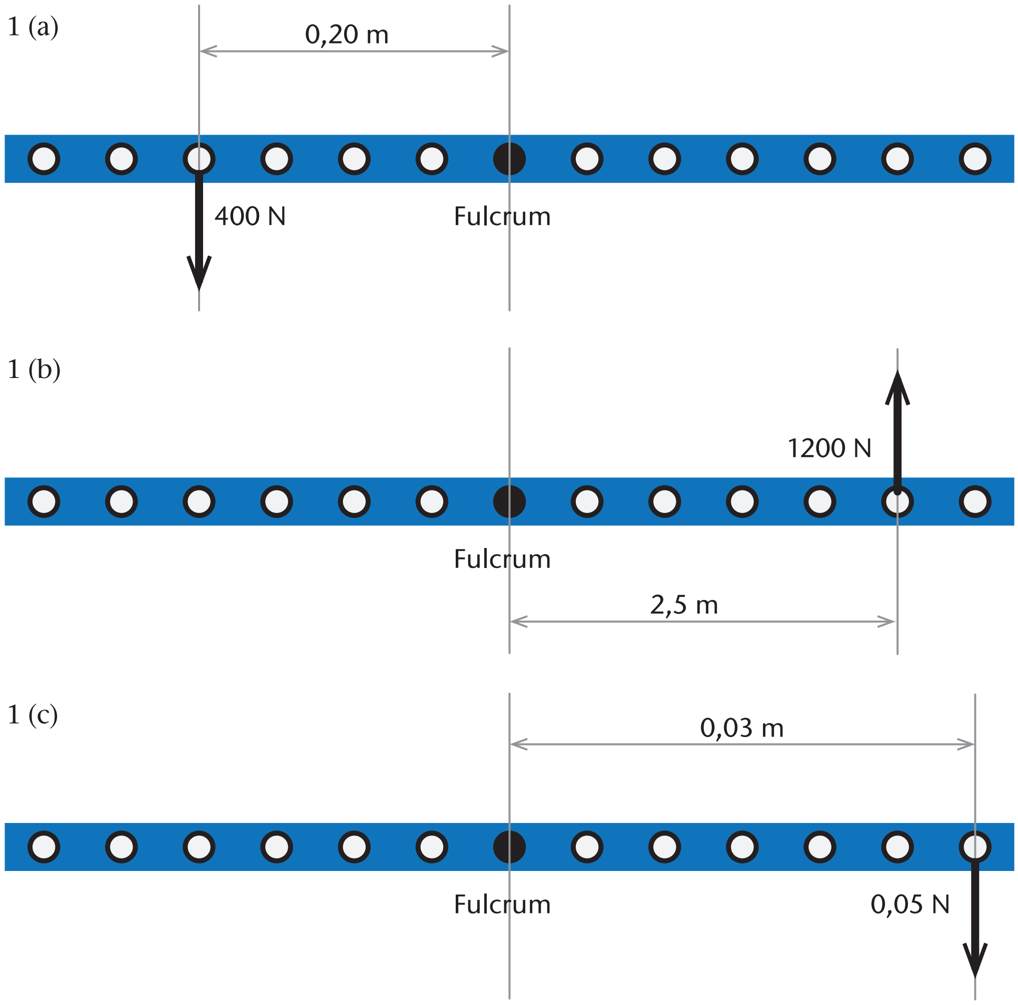
$d = \frac{140}{560}$ (divide both sides by 560)

$= 0{,}25$ m

Activity 1 Calculate moments

1. Calculate the moment in each diagram in Figure 4.10 below.

Figure 4.10



2. A 0,33 N force acts downwards 3,03 m to the left of a fulcrum. Calculate its moment.

3. A 15 N force acts upwards 3,33 m to the left of a fulcrum. Calculate its moment.

4. A 0,25 N force acts upwards 0,25 m to the right of a fulcrum. Calculate its moment.

5. Calculate the moment at a point on a lever:

a) When a 2 kN force acts downwards 2 m to the right of the point.

b) When a 0,4 kN force acts upwards 0,8 m to the right of the point.

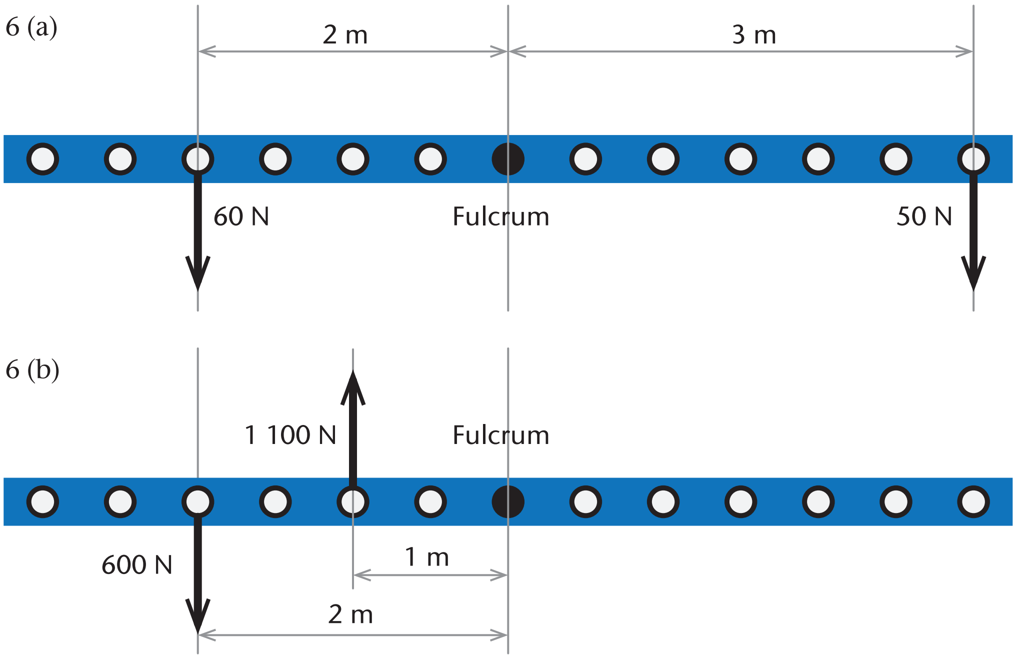
c) When a 2 002 N force acts upwards 1,1 m to the left of the point.

d) When a 0,01 kN force acts downwards 0,1 m to the left of the point.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 109 2016/01/05 3:16 PM

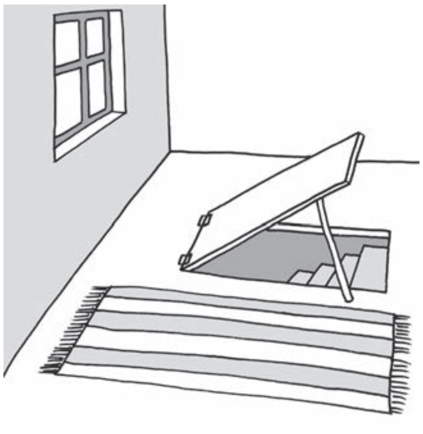
6. In the diagrams in Figure 4.11 below, the moments of the forces acting on each beam oppose each other. Will the beam rotate clockwise or anti-clockwise?

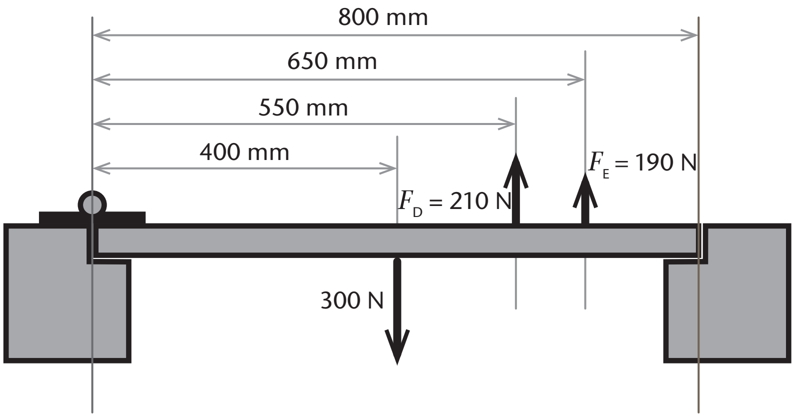
Figure 4.11



7. Which of the two forces acting on the trapdoor in Figure 4.12 will have the biggest turning effect, F_D or F_E? If the trapdoor weighs 300 N, will one of these forces be able to open it? Show your working to prove your answer.

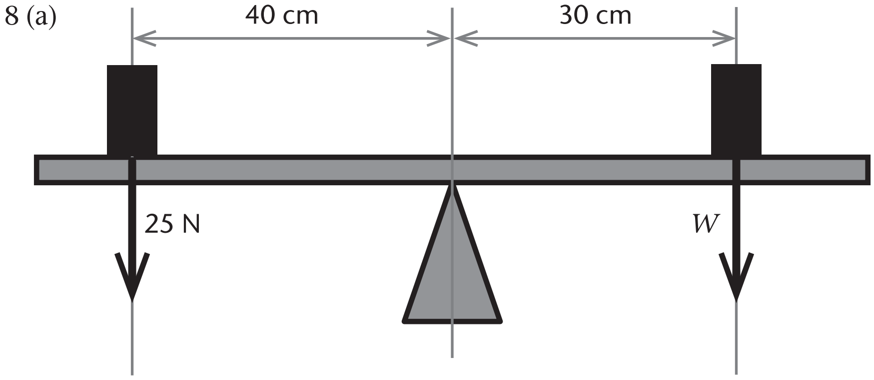
Figure 4.12

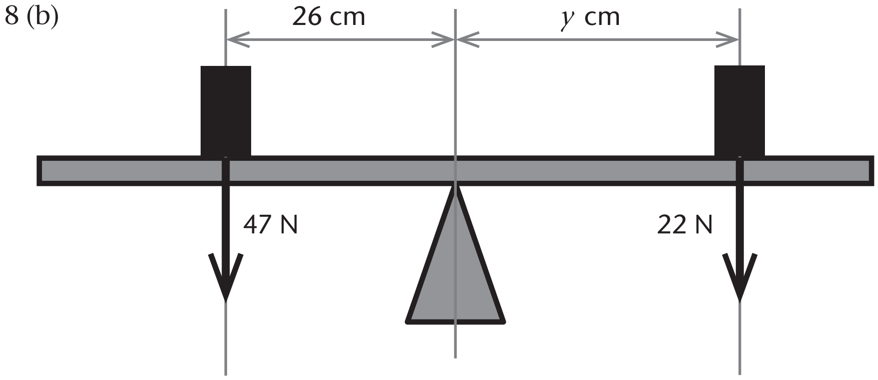




8. Figure 4.13 shows two balanced metre rules. Calculate the unknown quantity in each case.

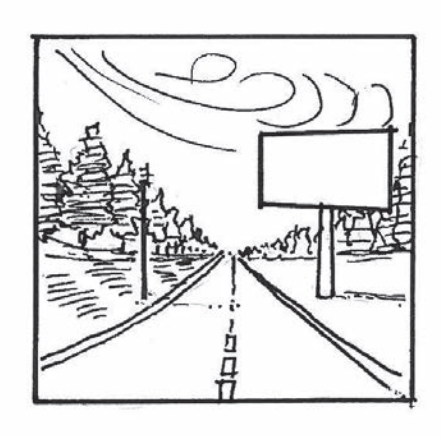
Figure 4.13





9. A tall advertising board on the Golden Highway can survive a gentle breeze. Explain why it is more likely to be blown over in a very strong wind.

Figure 4.14 *Advertising board on the Golden Highway*



Unit 4.2 Torque

The concept of torque (say tawk) is the same as the concept of moment. The word that we choose to use depends on what we are doing:

- Civil engineers talk about bending moments in beams.
- Mechanical engineers use the word torque to describe the turning effect of an engine or the turning effect needed to tighten a nut or bolt.

Definition: Torque is a measure of the turning effect when a force that is exerted on an object causes the object to rotate.

A good example of torque is the turning effect that a car's engine has on the drive shaft, axles and wheels.

Figure 4.15 *The rotation of the engine causes the drive shaft to turn.*

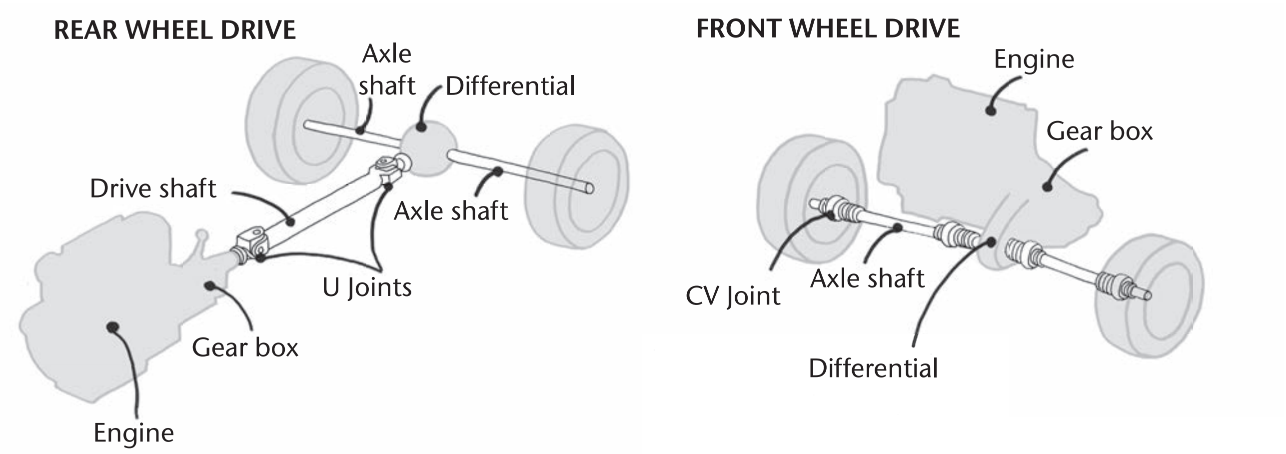


Figure 4.16 *The drive shaft causes the wheel half shafts and wheels to turn.*

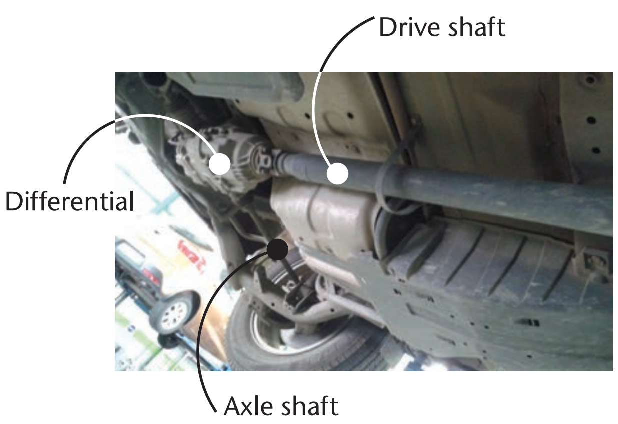
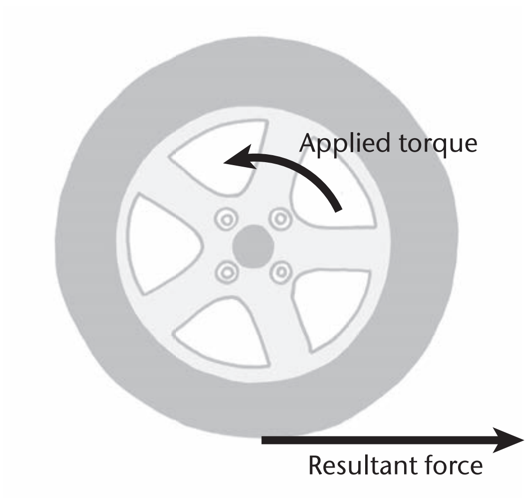


Figure 4.17 *The turning wheel drives the car forward.*



Calculate torque

The formula for torque is:

$$\tau = F \times r_{\perp}$$

where:

- the Greek letter "tau" (τ) is the symbol for torque that is measured in newton metres (N m)
- F is the symbol for force measured in newtons (N)
- $r_{\perp}$ is the symbol for the perpendicular distance from the centre of rotation to the line of the force and is measured in metres

Note that the formula for torque is the same as the formula for moment, except that we use ($r_{\perp}$) for distance in torque and (d) for the distance in moment. This difference points to the contexts in which the words moment and torque are mostly used in engineering:

- The radius ($r_{\perp}$) in the formula for torque suggests that a shaft is causing a turning effect.
- The distance (d) in the formula for moment suggests that the distance is between a position on a beam and the point at which a load is applied.

Figure 4.18 *Torque is measured using a Prony Brake.*

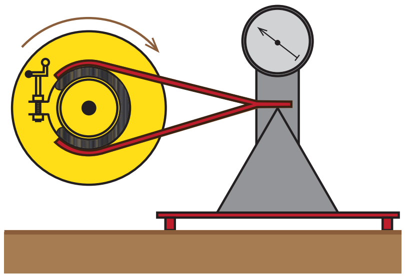


Figure 4.19a *Moment on a structure supporting a cantilever beam*

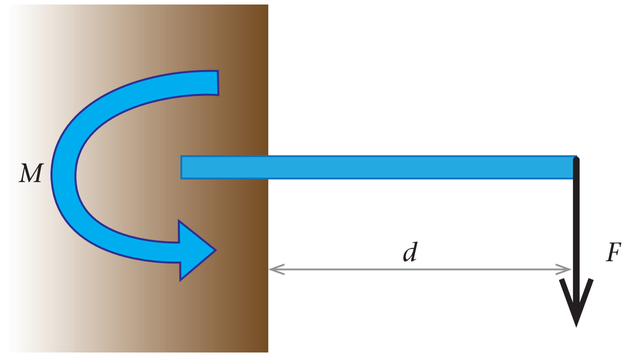


Figure 4.19b *Torque applied to a hub nut*

Did you know?

Some torque wrenches have internal mechanisms that allow you to apply a specific maximum torque.

Figure 4.20

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 113 2016/01/05 3:16 PM

Worked examples: Calculate Torque

1. Calculate the torque if:

a) $r_\perp = 2$ m and $F = 120$ N

b) $F = 4{,}9$ N and $r_\perp = 0{,}07$ m

Solutions

a) Given $r_\perp = 2$ m and $F = 120$ N

Unknown torque

Formula
$$\begin{aligned}\tau &= F \times r_\perp \\ &= 120 \times 2 \\ &= 240 \text{ N m}\end{aligned}$$

b) Given $r_\perp = 0{,}07$ m and $F = 4{,}9$ N

Formula
$$\begin{aligned}\tau &= F \times r_\perp \\ &= 4{,}9 \times 0{,}07 \\ &= 0{,}343 \text{ N m}\end{aligned}$$

2. Calculate the perpendicular distance if:

a) $\tau = 36$ N m and $F = 6$ N

b) $F = 8{,}2$ kN and $\tau = 11{,}2$ kN m

Solutions

a) Given $\tau = 36$ N m and $F = 6$ N

Unknown $r_\perp$

Formula
$$\begin{aligned}r_\perp &= \frac{\tau}{F} \\ &= \frac{36}{6} \\ &= 6 \text{ m}\end{aligned}$$

b) Given $\tau = 11{,}2$ N m and $F = 8{,}2$ N

Unknown $r_\perp$

Formula
$$\begin{aligned}r_\perp &= \frac{\tau}{F} \\ &= \frac{11{,}2}{8{,}2} \\ &= 1{,}37 \text{ m}\end{aligned}$$

3. Calculate the force if:

a) $\tau = 0{,}66$ N m and $r_\perp = 0{,}2$ m

b) $r_\perp = 0{,}5$ m and $\tau = 255$ kN m

Solutions

a) Given $\tau = 0{,}66$ N m and $r_{\perp} = 0{,}2$ m

Unknown F

Formula $F = \dfrac{\tau}{r_{\perp}}$

$= \dfrac{0{,}66}{0{,}2}$

$= 3{,}3$ N

b) Given $r_{\perp} = 0{,}5$ m and $\tau = 255$ kN m

Unknown F

Formula $F = \dfrac{\tau}{r_{\perp}}$

$= \dfrac{255}{0{,}5}$

$= 510$ kN

4. Gugu Zulu was working on his GTX 5. The manual specified a torque of exactly 100 N m for a gearbox nut. His torque wrench was broken so he had to use a ring spanner and a spring balance to apply the correct torque. He hooked the spring balance into the free ring of the 300 mm long spanner. What force did he have to apply to the spring balance to tighten the nut?

Figure 4.21 *The spring balance is attached to the ring of the spanner, with the other end of the spanner on a nut.*

Solution

Given $\tau = 100$ N m; $r_{\perp} = 300$ mm $= 0{,}3$ m

Unknown F

Formula $\tau = F \times r_{\perp}$

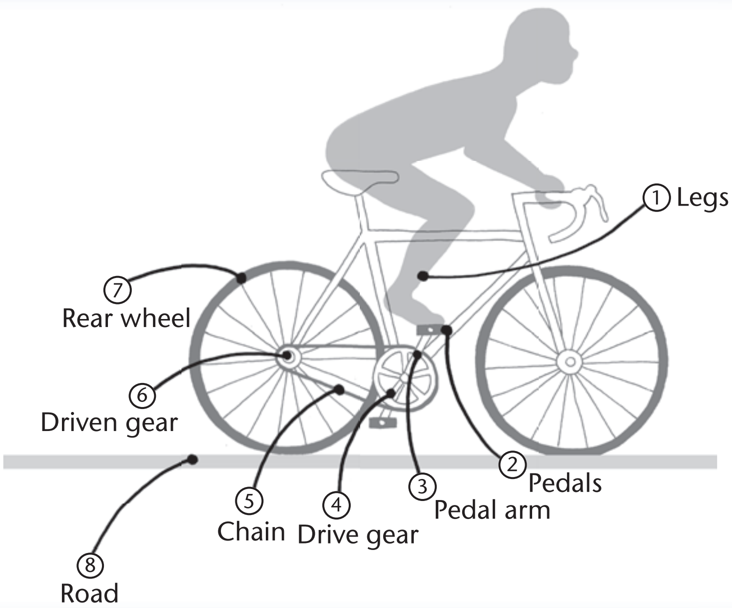
$F = \dfrac{\tau}{r_{\perp}}$ (change the subject)

$F = \dfrac{100}{0{,}3}$ (substitute)

$F = 333$ N

5. South African champion cyclist Daryl Impey is riding energetically up Chapman's Peak on his bicycle. The chain transfers a force of 500 N from the drive gear (the large gear at the pedals) to the driven gears (the small gears on the back wheel).

Figure 4.22 *Force is transferred from the rider's legs to the pedals, to the pedal arm, to the drive gear, the chain, to the driven gear, to the rear wheel and to the road.*



a) If the diameter of the drive gear is 200 mm, what is the torque that Daryl is developing on the drive gear?

b) If the length of the pedal arm is 200 mm, what force is he applying to his pedals to develop this torque?

Solutions

a) Given $F = 500$ N; radius of drive gear $= \frac{200}{2} = 100$ mm $= 0{,}1$ m

Unknown τ

Formula $\tau = F \times r_{\perp}$

$\tau = 500 \times 0{,}1$ (substitute)

$\tau = 50$ N m

b) Given $\tau = 50$ N m; length of pedal arm $= 200$ mm $= 0{,}2$ m

Unknown F

Formula $\tau = F \times r_{\perp}$

$F = \frac{\tau}{r_{\perp}}$ (change the subject)

$= \frac{50}{0{,}2}$ (substitute)

$= 250$ N

Activity 2 Calculate Torque

1. Calculate torque in the following examples:

a) $r_{\perp} = 0{,}5$ m and $F = 6$ N

b) $r_{\perp} = 0{,}303$ m and $F = 3{,}33$ N

c) $r_{\perp} = 6{,}5$ m and $F = 1\ 230$ N

d) $r_{\perp} = 0{,}05$ m and $F = 16$ N

2. Calculate perpendicular distance and force:

a) $\tau = 25$ N m and $F = 5$ N

b) $r_{\perp} = 5{,}1$ m and $\tau = 255$ kN m

c) $\tau = 0{,}66$ N m and $r_{\perp} = 0{,}2$ m

d) $F = 88$ kN and $\tau = 9{,}68$ kN m

3. A mechanic uses a torque wrench to loosen the nuts of a car wheel. He sets it to apply a torque of 70 N m. If the force applied is 400 N, how long is the wrench?

4. Calculate the maximum torque in each situation:

a) You use a force of 200 N to close a door that is 0,8 m wide.

b) You apply 300 N to loosen a nut using a spanner with a length of 25 cm.

5. A mechanic's torque wrench is missing. But he has a spanner with a long handle and a spring with a hook at each end. The hook extends 50 mm when a tension of 100 N is applied. Calculate the required length of the lever arm of his "home-made torque wrench" to apply a torque of:

a) 25 N m

b) 10 N m

6. The safe at Afri Bank contains money and valuables. The safe designer put springs onto the axle of the handle so a torque of 300 N m is required to turn the handle. The handle is like a door handle 0,5 m long. Look at Figure 4.23.

a) What force is needed to turn the handle?

b) The bank manager weighs 650 N. Is she going to have a problem opening the door? Explain.

7. There is a huge fan in the drying tunnel of a dried fruit factory. When the fan turns at the design speed, the torque on the axle is 1 000 N m. The fan has eight blades. The blades are designed for a force acting at a point 0,75 m from the axis of rotation. What force does each blade exert on the air?

Figure 4.23 *A large handle opens the door of a safe.*

Unit 4.3 Law of Moments

In Question 6 of Activity 1, more than one force acted on the beam. The moment of one of the forces was greater than the moment of the other force, so the beam rotated about the fulcrum.

In this unit we study situations in which the moments are balanced, so the object is always in equilibrium.

Activity 3 Balance moments

Apparatus

- ❑ a metre rule with a 5 mm hole drilled at its midpoint
- ❑ a retort stand with a clamp
- ❑ a variety of mass pieces (50 g to 200 g) for use as weights (two of each)
- ❑ a cork with a 4 mm hole drilled through it
- ❑ a 100 mm nail
- ❑ prestik or plasticine
- ❑ thread to suspend the mass pieces

A. Push the nail right through the cork so that the point comes out the other side. Use the clamp on the retort stand to hold the cork so that the nail is horizontal. The nail will be the fulcrum of a balance.

B. Hang the metre rule on the nail. It must hang horizontally – it must be in balance. Stick little pieces of prestik to the *bottom* of the rule, at the ends, to balance it.

C. Choose two equal mass pieces and tie each one to a piece of thread. Make a loop at the free end of each piece of thread.

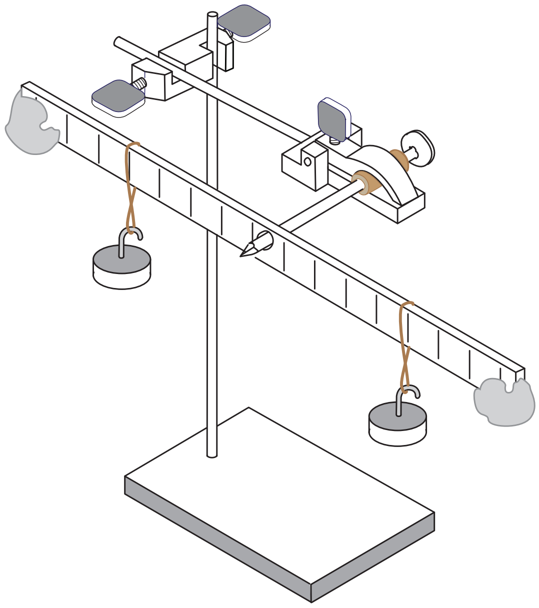
D. Hang a mass piece on either side of the fulcrum, anywhere along the rule, so that the rule is balanced. Record the position of the masses on the rule.

E. Repeat Step D at another position.

F. Determine the distance from the position of the mass to the fulcrum, for each of your four measurements.

G. Comment on the distances you have just determined.

Figure 4.24 *Set up the apparatus like this.*



Questions

1. Why did you need to balance the metre rule before adding any masses? What would happen if it wasn't balanced before doing the rest of the activity?
2. Do Steps D to G with two mass pieces that are not the same as each other.
3. Answer the following question with a full sentence:
   Do you need to move a large mass closer to the fulcrum or further from the fulcrum to balance a smaller mass?

Define the Law of Moments

In Activity 3 we discovered the need to balance the metre rule for it to work properly. Without knowing it, we applied an important law: The Law of Moments.

Definition: **The Law of Moments states that for a body to be in equilibrium (in balance), the sum of the clockwise moments must equal the sum of the anti-clockwise moments about a point.**

Scientists use the phrase "in equilibrium" rather than "in balance".

We can describe the Law of Moments in a word formula:

sum of the clockwise moments = the sum of the anti-clockwise moments about a point

Using symbols and abbreviations, the formula is:

$$M_{CW} = M_{ACW}$$

where:

- M_{CW} is the symbol for clockwise moment measured in newton metres (N m)
- M_{ACW} is the symbol for anti-clockwise moment measured in newton metres (N m)

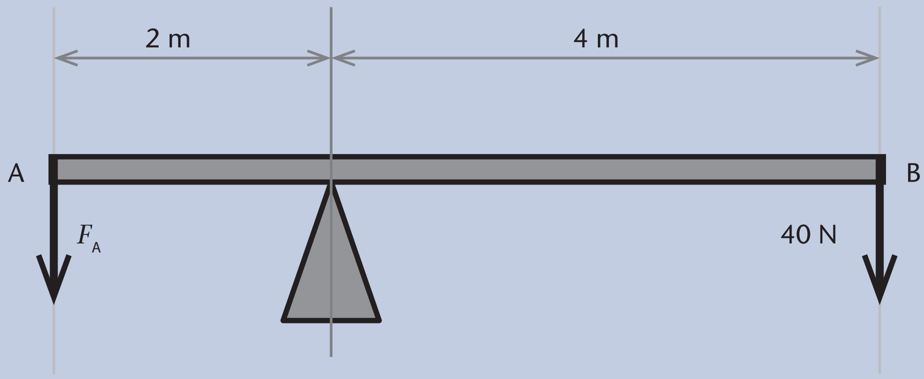
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 119 2016/01/05 3:17 PM

Apply the Law of Moments

Worked examples: Apply the Law of Moments

1. Calculate the magnitude of the unknown force at A in order to balance the weightless beam in Figure 4.25 below.

Figure 4.25



Solution

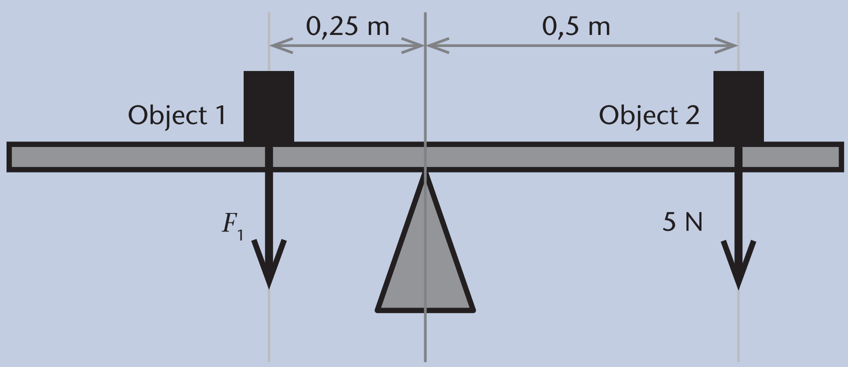
Given $d_A = 2$ m; $d_B = 4$ m; $F_B = 40$ N

Unknown F_A

Formula
$$M_{CW} = M_{ACW}$$
$$F_B \times d_B = F_A \times d_A$$
$$F_A = \frac{F_B \times d_B}{d_A} \quad \text{(change the subject)}$$
$$= \frac{40 \times 4}{2} \quad \text{(substitute)}$$
$$= 80 \text{ N}$$

2. Object 1 balances Object 2 in Figure 4.26. The fulcrum is at the beam's midpoint. What is F_1, the weight of Object 1?

Figure 4.26



Solution

Given 5 N acts downwards 0,5 m to the right of the fulcrum

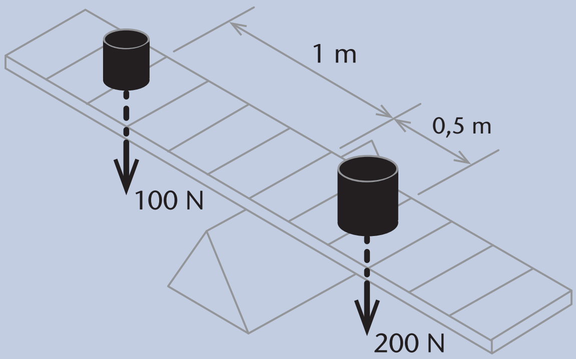
F_1 acts downwards 0,25 m to the left of the fulcrum

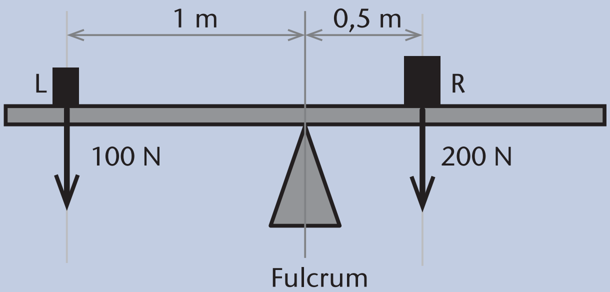
Unknown F_1

Formula
$$M_{CW} = M_{ACW}$$
$$F_1 \times d_1 = F_2 \times d_2$$
$$F_1 \times 0{,}25 = 5 \times 0{,}5 \qquad \text{(substitute)}$$
$$F_1 = 10\ \text{N}$$

3. Determine whether the beam in Figure 4.27 below is in equilibrium or not.

Figure 4.27





Solution

According to the Law of Moments, if the beam is in equilibrium, then:

the anticlockwise moment = the clockwise moment

or $M_{ACW} = M_{CW}$

So $M_{ACW} = F_R \times d_R$

$= 100 \times 1{,}0$

$= 100$ N m

And $M_{CW} = F_L \times d_L$

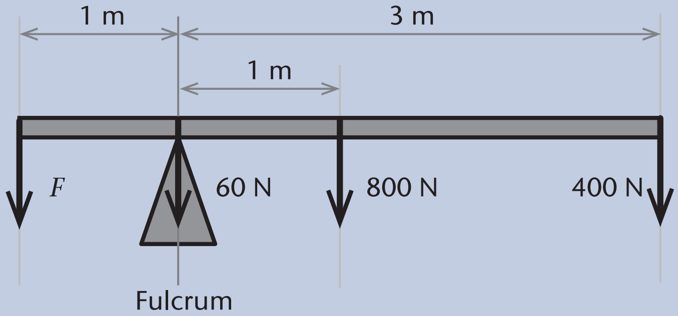
$= 200 \times 0{,}5$

$= 100$ N m

∴ Both sides are the same, so the beam is in equilibrium.

4. The beam in Figure 4.28 weighs 800 N. What force *F* must be applied downwards at the left end to balance the beam?

Figure 4.28



Solution

Given the beam is 4 m long with fulcrum 1 m from the left end
400 N acts downwards on the right 3 m from the fulcrum
800 N acts downwards on the right 1 m from the fulcrum
60 N acts downwards at the fulcrum
F acts downwards 1 m left of the fulcrum

NOTE: The 60 N force has no turning effect, because it acts through the fulcrum.

Unknown F

Formula $M_{ACW} = M_{CW}$

So $M_{ACW} = F \times 1$

$= F$ N m

And $M_{CW} = 800 \times 1 + 400 \times 3$

$= 2\,000$ N m

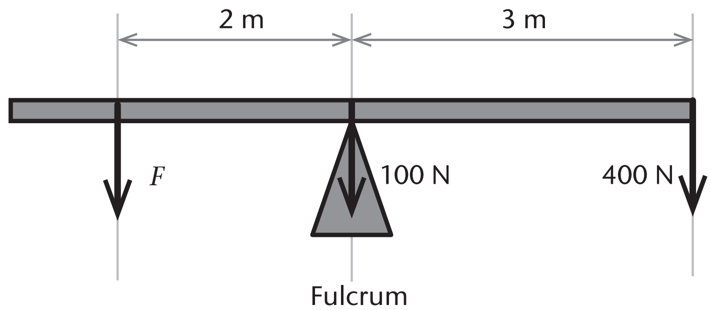
$\therefore F$ N m $= 2\,000$ N m

$\therefore F = 2\,000$ N (divide both sides by 1 m)

Activity 4 Apply the Law of Moments

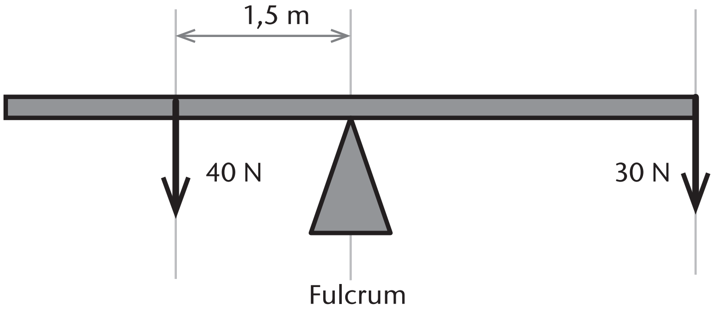
1. The uniform beam in Figure 4.29 is balanced when no loads are on it. It weighs 100 N. Calculate the force *F* that must be applied to keep the beam in equilibrium.

Figure 4.29



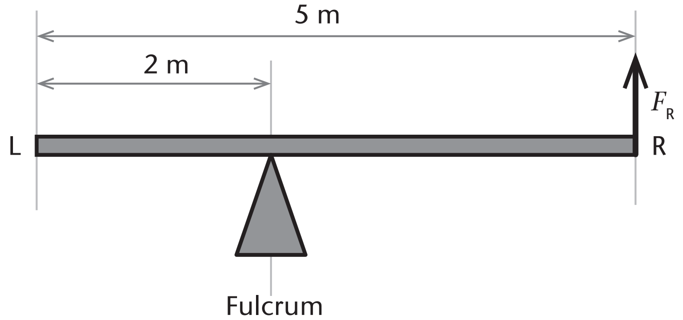
2. The beam in Figure 4.30 is balanced at its midpoint. Calculate the length of the beam.

Figure 4.30



3. Figure 4.31 shows a uniform beam LR that is 5 m long. Its fulcrum is 2 m from end L. Force F_R acts upwards on the beam at R. The weight of the beam is 200 N.

Figure 4.31



a) What is the distance from the fulcrum of the force that represents the weight of the beam?

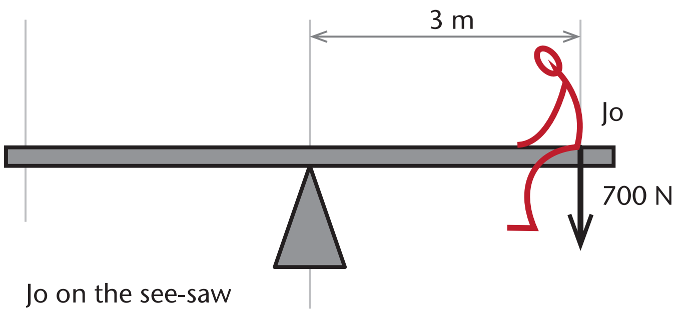
b) What is the size of the force F_R that keeps the beam in equilibrium?

c) When F_R is applied, what is the value of the normal force at the pivot and in what direction does it point?

4. Jo is sitting at the right-hand end of a see-saw, 3 m from the fulcrum. The fulcrum is in the middle of the see-saw. Jo's weight is 700 N.

a) What is the moment that Jo causes on the see-saw?

Figure 4.32



Jo on the see-saw

b) Mo's weight is 600 N. She climbs onto the other end of the see-saw. What is going to happen when they lift their feet off the ground? Take a guess and then prove it mathematically.

5. Jopi makes a simple balance by balancing a uniform metre rule at its centre. He hangs a dead frog at the 80 cm mark. By placing a 3 N mass at the 12,5 cm mark, he balances the ruler. What is the weight of the frog?
6. Calculate the unknown values to keep beams A and B in equilibrium.

Beam	Force F_1 (N)	Distance d_1 (m)	Anti-clockwise moment (N m)	Force F_2 (N)	Distance d_2 (cm)	Clockwise moment (N m)
A	10	0,4		20		
B		0,2	8		0,5	

Experiment 4 Prove the Law of Moments

This experiment is the second of the four experiments that will be assessed by your teacher and for which marks are recorded. It will be marked on the Record of Assessment of Experiment 4 according to the Assessment Rubric for Experiment 4. It will be out of 30 marks, which is 10% of the mark for Assessment Tasks through the year.

Your task

- Working in groups of four and using the apparatus your teacher gives you, follow a scientific process to confirm the Law of Moments.
- Your notebook must reflect your ideas and your understanding. Do not copy the work of others or allow others to copy your work.

Apparatus

- ❑ a set of masses, up to 100 g
- ❑ string
- ❑ a metre rule with a hole drilled at its centre
- ❑ a retort stand and clamp
- ❑ a fulcrum such as a cork with a nail
- ❑ a small amount of plasticine or prestik

Practise using the apparatus

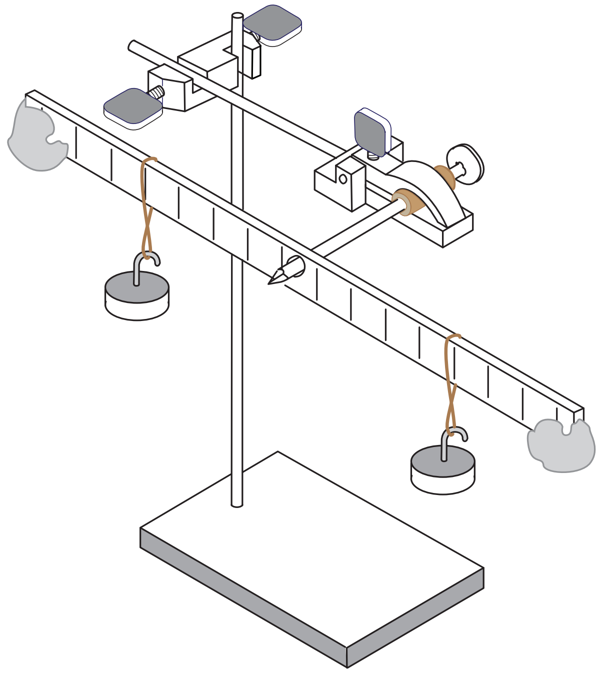
Set up the apparatus as in Figure 4.33 on the next page and practice using it:

- Hang a weight on one side of the fulcrum.
- Balance the weight by hanging a second weight on the other side of the fulcrum and moving it until the metre rule is balanced again.

Aim

The aim of this experiment is to confirm the Law of Moments: For a body to be in equilibrium, the sum of the clockwise moments must equal the sum of the anti-clockwise moments about a point.

Figure 4.33 *Experimental set-up*



Describe the experiment in writing

1. Discuss the experiment in your group and give it a name.

2. Describe, in a full sentence, the concept that you need to confirm.

3. Describe what you need to do. Think about the following:

- What are the variables?
- What is the range of each of the variables?
- What will you keep constant and what will you vary, each time you take a set of measurements?
- What data (words and numbers) will you write down for each set of measurements?
- How many measurements should you take?
- What calculations will you do with the numbers?
- What numbers will you compare to confirm the theory?

Plan the experiment

A. Write a list of materials and equipment that you will need.

B. Write down the steps you need to take – this is called **the method**.

- Write the steps in the order in which you will do them.
- Use short phrases to describe the steps and number them.

C. Share the tasks – each member should have equal work to do.

D. Before you start doing the experiment:

- Draw up a table for the results that you get. The results of the investigation are called data.
- Think about how you will use the data to create useful information. Will you, for example, compare numbers in a table, sketch a diagram, or write a sentence?

Do the experiment

E. Do the experiment just as you planned it. You may need to try several times before your results are satisfactory.

F. Work safely, be helpful to others and do not waste materials.

G. Write down the results.

Use the data to create information

Study the data (the results) to create useful information in the way in which you had planned.

Draw a conclusion

Describe, in a written sentence, how the information that you have created confirms the concept that you set out to prove, or does not prove it.

Recommend improvements

Think about the experiment:

- What made it difficult to do the experiment?
- What did you do to overcome the difficulties?

Write down suggestions for how to do it better.

Record of Assessment of Experiment 4: Prove the Law of Moments

Work assessed	Checklist for tick or cross	Mark awarded 1 to 4	Weighting of the mark	Possible mark	Mark
1. Describe the experiment.			1	4	
Give the experiment a name.					
Describe the concept you intend to prove.					
Describe what you need to do to prove the theory.					
2. Plan the experiment.			2	8	
Describe the variables and the constants.					
Write a list of the materials, equipment or other resources.					
Write the method.					
Share the tasks amongst the group.					
What calculations do you need to do to analyse your results?					
Draw up a table for the results.					
Decide how to use the data.					
3. Do the experiment.			2	8	
Do the experiment as planned.					
Work safely, considerately and conservatively.					
Write down the results.					
4. Use the data to create information.			1	4	
5. Draw a conclusion.			0,5	2	
6. Recommend improvements.			1	4	
Total				**30**	

Chapter summary

- If a force is applied to an object which is connected to a fulcrum, the force will try to turn the object around the fulcrum – the force has a **turning effect** about the fulcrum.
- A turning effect can be clockwise or anti-clockwise.
- The fulcrum is the point about which a lever turns.
- A turning effect of a force about a fulcrum is called a moment.
- The size of the moment (M) depends on the size of the force (F) and the perpendicular distance from the fulcrum to line of the force (d): $M = F \times d$
  where:
  - M is the symbol for moment measured in newton metres (N m)
  - F is the symbol for force measured in newtons (N)
  - d is the symbol for distance measured in metres (m)
- To work out a moment we need to know three things:
  - the distance of the force from the fulcrum
  - the magnitude of the force
  - the direction of the rotation
- A moment is a vector.
- Torque is a measure of the turning effect when a force is exerted on an object, such as an axle, a wheel, a nut, or a bolt. The formula for torque is: $\tau = F \times r_{\perp}$
  where:
  - the Greek letter "tau" (τ) is the symbol for torque that is measured in newton metres (N m)
  - F is the symbol for force measured in newtons (N)
  - $r_{\perp}$ is the symbol for the perpendicular distance from the centre of rotation to the line of the force and is measured in metres
- The Law of Moments: For a body to be in equilibrium (in balance), the sum of the clockwise moments must equal the sum of the anticlockwise moments about a point: $M_{CW} = M_{ACW}$
  where:
  - M_{CW} is the symbol for clockwise moment measured in newton metres (N m)
  - M_{ACW} is the symbol for anti-clockwise moment measured in newton metres (N m)

Challenges and projects

1. Use recycled materials to design and make a weighing balance (a weighing scale) that uses the principle of moments to measure the weight of objects with a maximum weight of 10 N.
2. Use the principle of levers to design and make a machine to shoot an eraser into a large bowl five metres away.

CHAPTER 5 Beams

In Senior Phase Technology, you built a number of different structures. You learnt about the stability of structures, rigidity of structures, the strength of structural members and joining techniques.

When engineers design structures like bridges and the frames of buildings they do many calculations. In this section we will learn to calculate bending moments and shear forces in beams.

We also think about the way that beams are joined to the rest of a structure.

Unit 5.1 An introduction to beams

Definition: A beam is a rigid horizontal structural member designed to carry a vertical load.

A beam is able to carry a load because it is designed not to bend or shear when it is loaded.

Figure 5.1a *Force and reactions that cause bending in a simply supported beam*

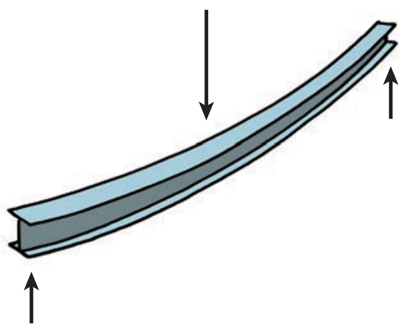
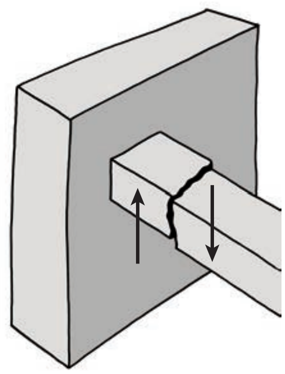


Figure 5.1b *Force and reaction that cause shear in a cantilever beam*



A beam is designed to resist bending moments and shear forces caused in the beam by:

- the loads on the beam
- the reactions to the loads at the points where it is supported

The loads on a beam are:

- the weight of the load placed on it (called the live load), which includes people, machines, stored materials, etc.
- the weight of the beam itself (called the dead load), which includes floor-tiles, brickwork, roof-tiles, etc.

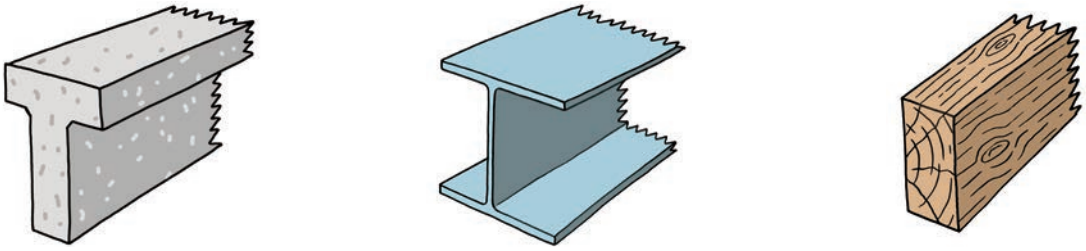
The reactions at the points at which the beam is supported depend mainly on:

- the loads on the beam
- the way in which the beam is supported: it can be either fixed or can allow movement
- the distance between the supports

There are many different types of beam. A beam may be described by:

- the material it is made of
- the shape of its cross-section
- the distance between the supports (known as the span of the beam) or the length of the beam
- the way in which it is supported

Figure 5.2 *Typical concrete, steel and wood beam cross sections*



Bending moments

It is the ability of a beam to resist bending moments and shear that sets it apart from other structural members.

Familiar examples of beams subject to bending are:

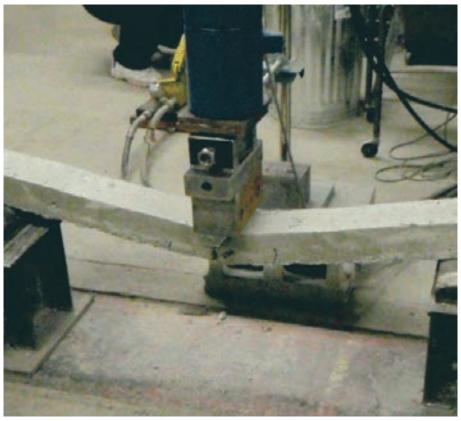
- the precast lintels above windows and doors in our homes
- the horizontal structural members in a steel or concrete framed building
- the wood or steel purlins (that rest on roof trusses) that support the "corrugated iron" cladding on most roofs in South Africa
- the gantry crane in an industrial workshop (a moving beam)

The bending moment is often greatest in the middle of a beam. The moment in the middle of the beam in Figure 5.3 is resisted by the compressive strength of the material in the top of the beam and by the tensile strength of the material in the bottom of the beam.

If a beam is overloaded it might fail by deflecting – by bending too much. Later it might fail by fracturing – by bending and breaking. It is the structural engineer's job to choose the proper materials, size, shape and type of support to ensure that the beam does not fail.

Figure 5.3 *This concrete beam is being tested with a load at its midpoint.*

Figure 5.4 *The concrete beam has failed at its midpoint.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 130 2016/01/05 3:17 PM

Quick Activity: Bending force

One learner lies on his back on the floor. Four others take a shoulder or foot and lift him just 10 cm off the floor. He will bend in the middle.

A bending moment causes a beam on which it acts to bend.

Shear force

When unaligned forces on opposite sides of an object act in opposing directions, the object will tend to deform and might even fail as shown in Figure 5.5.

The steel bolt in Figure 5.5 failed in shear as a result of unaligned forces in opposite directions in the two steel plates.

Forces that have a shearing action are called shearing or shear forces. A pair of tinsnips cuts a sheet of metal with a shearing action. A sheet metal punch also works with a shearing action.

Figure 5.5 *The steel bolt failed in shear.*

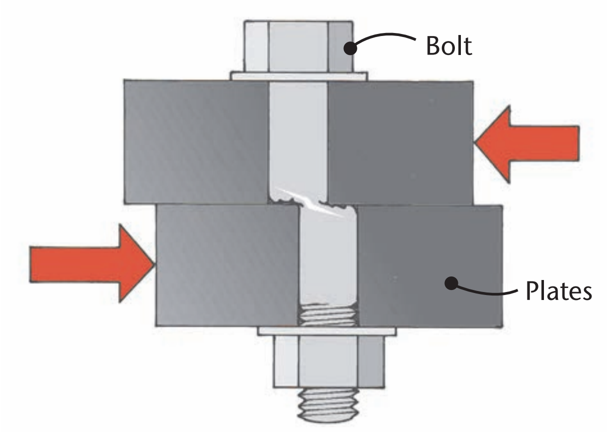
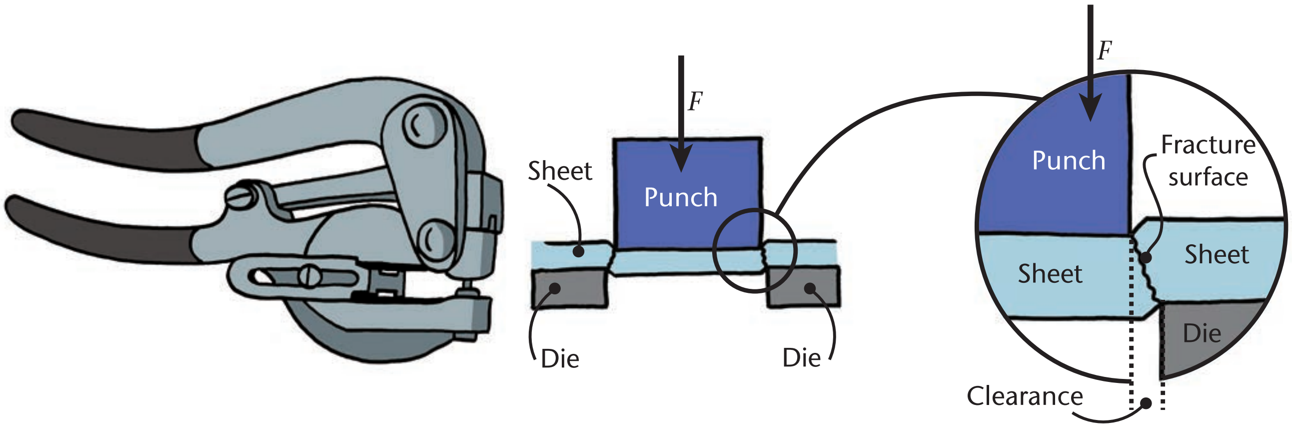


Figure 5.6 *A sheet metal punch works with a shearing action.*

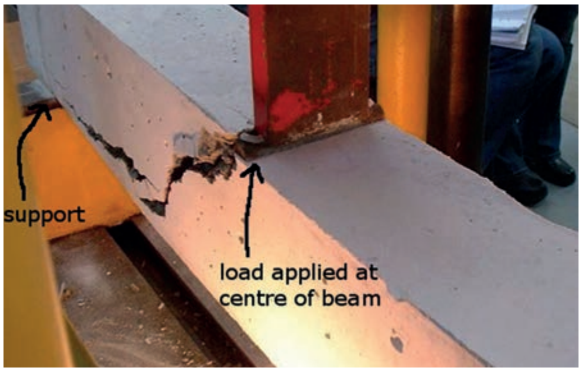


Quick Activity:

Hang from your fingers from a window sill close to the ground – feel the shear forces in your finger joints.

Concrete columns, beams and slabs are more likely to fail in shear than most other structural members. The first sign of shear failure in a concrete structure is the appearance of diagonal cracks. The next step is usually catastrophic failure of the member. The shear forces are typically greatest near the points at which structural members are supported.

Figure 5.7 *Shear failure in a concrete column and a beam*



Unit 5.2 Simply supported beam with a point load

The simplest beam that we can analyse is a simply supported beam with a point load.

Simply supported

Definition: **A simply supported beam is a beam supported in such a way that the supports do not prevent the beam from bending/ flexing*/deflecting in any way when it is loaded.**

* The trunk of a tall tree **flexes** in a high wind – it bends a bit without breaking.

The supports just hold the beam up, but they don't hold it tight.

Figure 5.8 *Ancient beams were usually simply supported.*

Today, heavy beams that are simply supported might have a pinned joint at one end and a sliding or rolling joint at the other end as in Figure 5.9 alongside. The pinned joint on the left allows flexing but no movement along the line of the beam. The rolling and sliding joints in the middle and on the right allow the beam to flex and to move back and forth a little. The movement might be the result of the beam bending under a load or because of expansion and contraction due to hot and cold weather.

Figure 5.9a *A pinned joint*

Figure 5.9b *A roller support for a bridge*

Figure 5.9c *A sliding bearing*

Figure 5.9d *There is a bearing between each of these supporting columns and the bridge structure above.*

When we discuss simply supported beams we talk about **joints**, but the objects you see in the pictures are called **bearings**.

A concrete simply supported beam is shown in Figure 5.10a and a typical graphic representation is shown in Figure 5.10b. The pinned joint is on the left of the beam in the graphic representation and the sliding/roller joint is on the right. Figure 5.10c shows the simplified representation of the beam that we use.

Figure 5.10a *Simply supported beams in a bridge*

Figure 5.10b *The graphic representation of a simply supported beam that is used by engineers*

Figure 5.10c *The simplified representation of a simply supported beam that we use*

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 133 2016/01/05 3:17 PM

Point loads

> **Definition:** **A point load on a beam is a load that acts at a point on the beam. It is not distributed along the beam.**

A man with two heavy tool cases walking along a small wood beam is an example of a point load.

We represent a point load with a single arrow. The arrow tells us where the load is and in what direction it is acting. A number next to the arrow indicates the magnitude of the load, which is a force in newtons.

In Figure 5.12 on the right, a 200 N point load is acting in the middle of a simply supported beam.

Figure 5.11

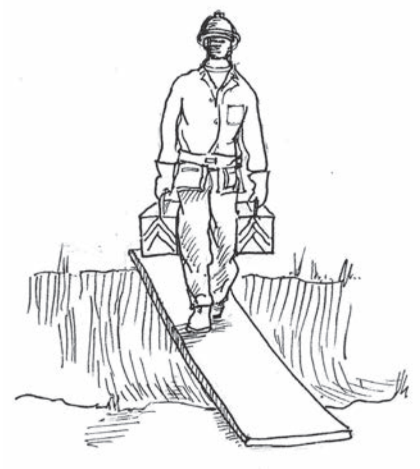
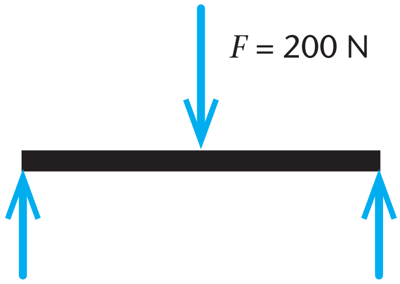
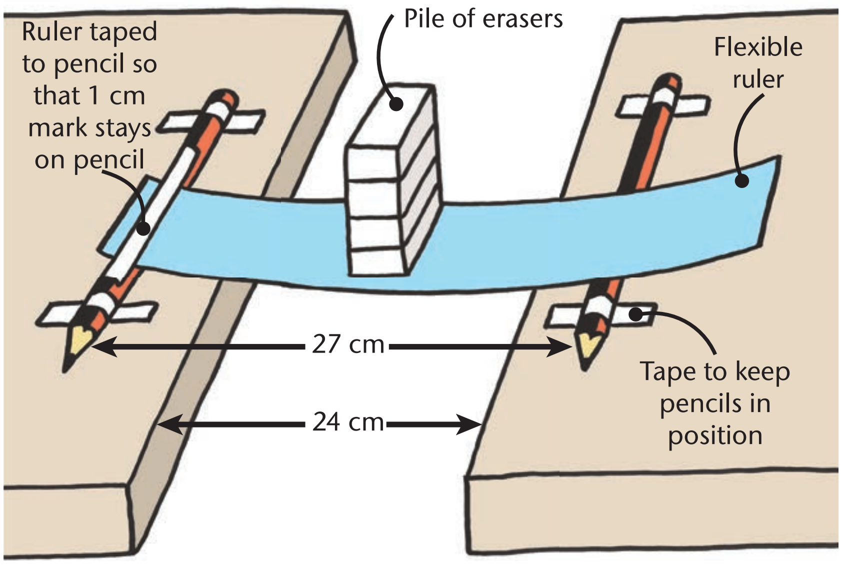


Figure 5.12 *A 200 N point load on a simply supported beam*



Activity 1 Simulate the effect of a point load on a bridge, with a pinned joint at one end and sliding joint at the other end

Figure 5.13



Apparatus

- ❑ two desks
- ❑ two pencils
- ❑ a very flexible 30 cm ruler
- ❑ sticky tape
- ❑ a pile of erasers (any little weight that won't slip off)

A. Position the two desks about 24 cm apart.

B. Place the two pencils, one on each desk, parallel to each other, 27 cm apart.

C. Tape the pencils down (near their ends).

D. Position the very flexible ruler on the pencils so that the 1 cm mark is on the one pencil. Place a piece of tape from the one end of the pencil, over the ruler, to the other end of the pencil. It must allow the ruler to flex but the 1 cm mark must not move off the ruler.

E. Load erasers, one by one, at the midpoint of the ruler and observe how:
- the ruler flexes and deflects between the pencils
- the 28 cm mark moves off the pencil

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 134 2016/01/05 3:17 PM

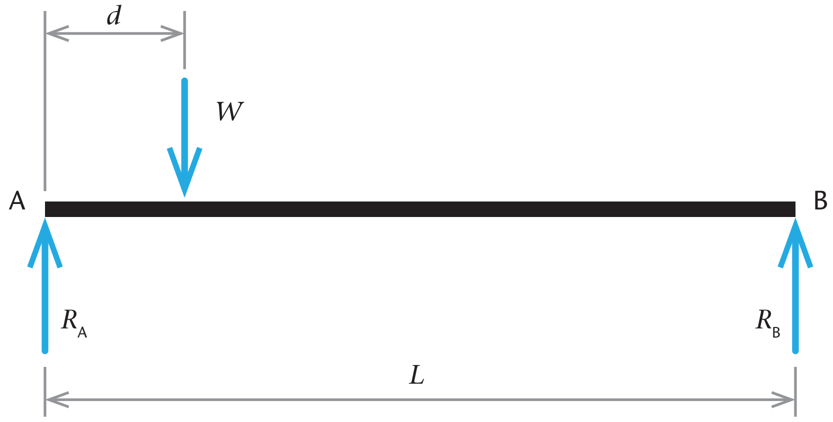
Space diagram for a simply supported beam

Definition: **A space diagram shows the object and the forces acting on the object.**

Engineers use the words "space diagram" to describe a graphic representation of the object of interest and all the forces acting on it. Scientists and mathematicians usually call it a force diagram.

In Figure 5.14, we show a simply supported beam AB that is L metres long, with a point load of W that acts at a distance d from A.

Figure 5.14 *Simply supported beam AB*



We must describe all the forces. The only other load is the dead load (own weight) of the beam. But in this case we have assumed that the beam has no weight (it is weightless).

Reactions at the supports

We know what the load on the beam is, but we do not yet know the reaction forces (R) at the supports. From our work on forces, we know that there is an upward reaction (which we call the normal force) on the beam at each of the supports. The reaction at point A is called R_A and the reaction at point B is R_B.

Calculate the reactions at the supports

In Chapter 4 we learnt the Law of Moments: For a body to be in equilibrium, the sum of the clockwise moments must equal the sum of the anti-clockwise moments about a point.

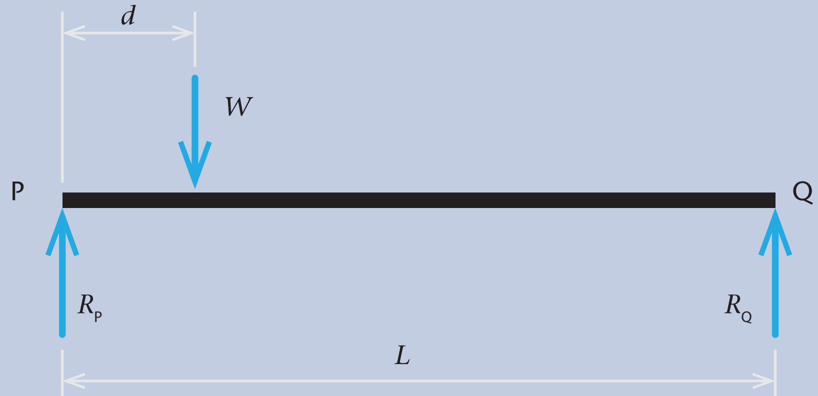
The Law of Moments applies only if the body is in equilibrium. In this case we know that the beam can carry the load, that it is not failing and that there is no movement. It is therefore in equilibrium, so we can apply the law.

Worked examples: Calculate Reactions

1. In Figure 5.15 below, $L = 5$ m; $d = 2$ m and $W = 200$ N. Calculate the following in the figure, using the Law of Moments, and show all your working:

a) R_Q **b)** R_P **c)** Verify the reactions.

Figure 5.15 *Simply supported beam PQ*



Solutions

a) To find the reaction at Q we take moments about point P:

Clockwise moment at P $\quad M_{CW} = W \times d$

$= 200 \times 2$

$= 400$ N m

Anti-clockwise moment at P $\quad M_{ACW} = R_Q\, L$

$= R_Q\, 5$

From the Law of Moments $\quad M_{CW} = M_{ACW}$

So $\quad 5\, R_Q = 400$

$R_Q = 80$ N (divide both sides by 5)

b) To find the reaction at P we take moments about point Q:

Clockwise moment at Q $\quad M_{CW} = R_P\, 5$

Anti-clockwise moment at Q $\quad M_{ACW} = W\,(L - d)$

$= 200\,(5 - 2)$

$= 600$ N m

From the Law of Moments $\quad M_{CW} = M_{ACW}$

So $\quad 5\, R_P = 600$

$R_P = 120$ N (divide both sides by 5)

c) Verify the reactions:

Downward force $= 200$ N

Upward force $= 120 + 80$

$= 200$ N

$\therefore$ Downward force $=$ Upward force

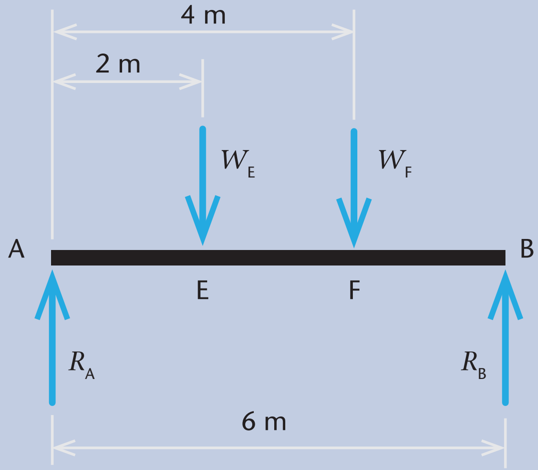
2. For enrichment: Calculate the reactions of a simply supported beam with multiple point loads.

A simply supported beam AB is 6 m long. A point load of 3 kN is placed at E, which is 2 m from A. Another point load of 4 kN is placed at F, which is 4 m from A. Calculate the reactions at the supports.

Given: AB = 6 m; AE = 2 m; AF = 4 m; $W_E = 3$ kN; $W_F = 4$ kN

Figure 5.16

Scale of the space diagram: 1 cm = 1 m



Solution

Unknown: R_A and R_B

Moments at A:

$$M_{CW} = W_E \times 2 + W_F \times 4$$
$$= 2 \times 3 + 4 \times 4$$
$$= 22 \text{ kN m}$$
$$M_{ACW} = R_B \times 6$$

From the Law of Moments:

$$M_{ACW} = M_{CW}$$
$$R_B \times 6 = 22$$
$$R_B = \frac{22}{6}$$
$$= 3{,}67 \text{ kN}$$

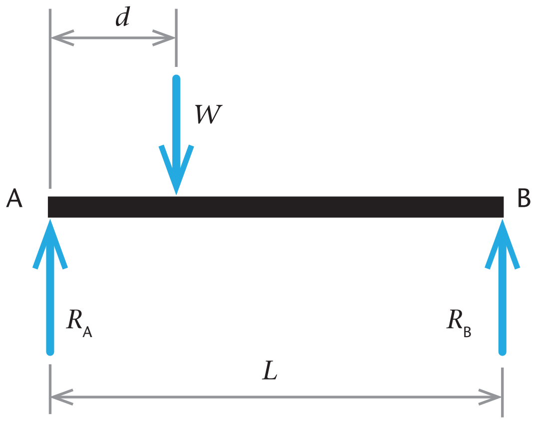
Beam is in equilibrium:

$$R_A + R_B = W_E + W_F$$
$$R_A = W_E + W_F - R_B$$
$$= 3 + 4 - 3{,}67$$
$$= 3{,}33 \text{ kN}$$

A general formula for reactions at the supports of a simply supported beam with a point load

We will use the Law of Moments to develop a general formula for R_A and R_B in Figure 5.17.

Figure 5.17 *The values of the contact forces at A and B*



Step 1: To find R_B we take moments about point A

Clockwise moment at A $\quad M_{CW} = W \times d = W\,d$

Anti-clockwise moment at A $\quad M_{ACW} = R_B \times L$

Form the Law of Moments $\quad M_{CW} = M_{ACW}$

So $\quad W\,d = R_B \times L$

$R_B \times L = W\,d$ (turn the equation around)

$R_B = \dfrac{Wd}{L}$ newtons (divide both sides by L)

Step 2: To find R_A we take moments about point B

Clockwise moment at B $\quad M_{CW} = R_A \times L = R_A\,L$

Anti-clockwise moment at B $\quad M_{ACW} = W \times (L - d)$

$= W\,L - W\,d$

From the Law of Moments $\quad M_{CW} = M_{ACW}$

So $\quad R_A\,L = W\,L - W\,d$

$R_A = W - \dfrac{Wd}{L}$ newtons (divide both sides by L)

Step 3: Verify the reaction forces

Load $= W$

Reactions $= \dfrac{Wd}{L} + W - \dfrac{Wd}{L}$

$= W$

$\therefore$ Load = Reactions

We have developed a general formula that can be used to calculate the reactions for any simply supported beam with a point load.

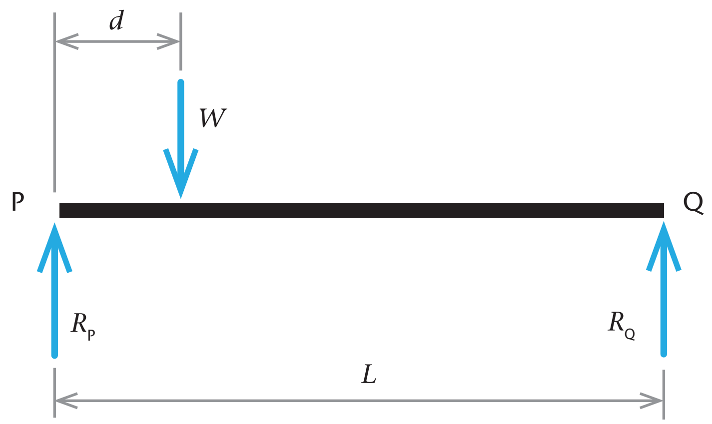
There are two methods for calculating reactions for a simply supported beam with a point load:

1. We can use the Law of Moments (this is called "working from first principles").
2. We can use the formulae.

Activity 2 Calculate reactions

1. a) Find R_P and R_Q in Figure 5.18 below, where $L = 6$ m; $d = 1$ m and $W = 100$ N. Work from first principles and show all your working.

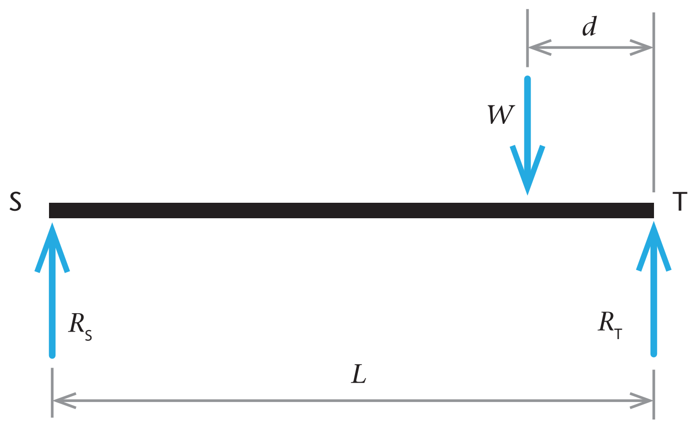
Figure 5.18



   b) Check your answers in (1a) by using the general formulae that we developed.
   NOTE: This is not as easy as it seems. We encourage you to do this type of problem by working from first principles and using the Law of Moments.

2. Find R_S and R_T in Figure 5.19 below, from first principles, and show all your working. Then check your answers using the formulae.
   In the figure: $L = 4$ m; $d = 1$ m and $W = 300$ N.

Figure 5.19

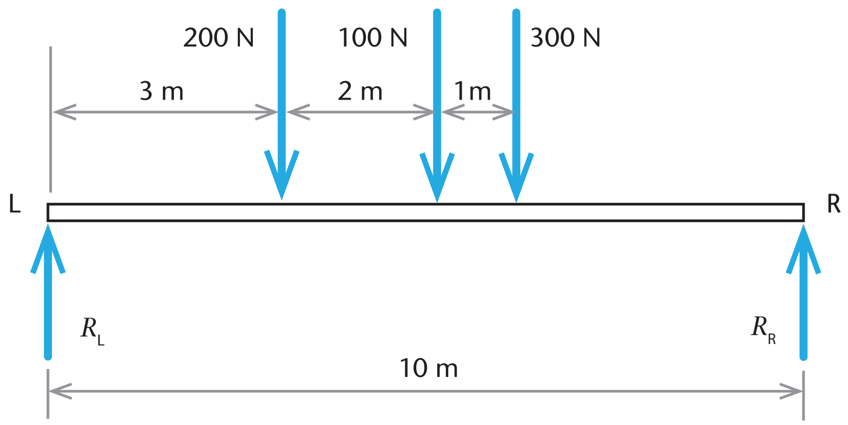


3. A beam LR is 8 m long and simply supported. A point load of 7 000 N is placed 3 m from the left end of the beam. Calculate the reactions at the supports.
4. Beam MN is 2,5 m long. It is simply supported. Calculate the reactions at the supports if a load of 1 kN is placed 1 m from the left support.
5. The reactions at the ends of simply supported beam GH are R_G = 5 kN and R_H = 7 kN. The beam is 4 m long. Calculate the size of the point load and its position relative to G.
6. A simply supported beam DF is 7,5 m long. A point load of 3,5 kN is placed 2,5 m from D. Another point load of 5,6 kN is placed at the midpoint of the beam. Calculate the reactions at the supports.

For Enrichment: Simply supported beams with multiple point loads

7. A 7,1 m long beam is simply supported. A point load of 3,75 kN is placed 3 m from the left end of the beam. Another load of 6,25 kN is place at a distance *x* from the left end. The reaction at the left support is R_L = 5,5 kN. Calculate R_R and distance *x*.
8. Calculate the reactions at L and R in Figure 5.20.

Figure 5.20



Unit 5.3 Shear forces and shear stresses in beams

Definition: **Shear forces are unaligned forces that push one part of an object in one direction, and another part of the object in the opposite direction.**

Two examples of the effect that shear forces can have

- If you pinch your skin with a pair of pliers, you feel pain and you see damage in the form of broken skin and blood. The damage is the visible result of the shear stress caused by shear forces.
- If you use the pliers to cut a piece of wire, the "pain" that the wire feels is shear stress caused by shear forces and its "broken flesh" is the shiny surface of the cut wire.

Warning: This paragraph is not for sissies!

Quick Activity:

Look at the two pictures in Figure 5.21. Where are these tools most likely to fail in shear?

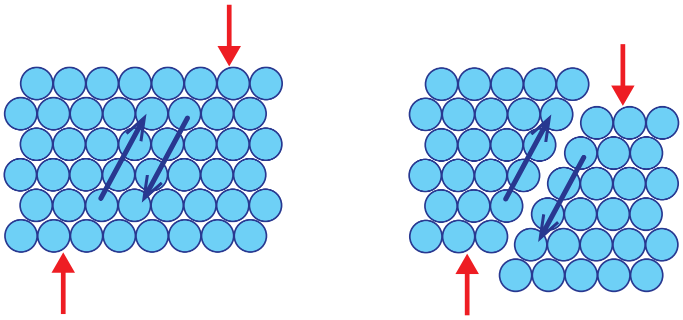
Figure 5.21

Under normal circumstances, when you use a chair, a bicycle, or a spanner it does not break. It does not break because the shear force applied usually does not exceed the strength in shear of the material.

When unaligned forces act in opposite directions on a material, **shearing** can happen when the shear forces exceed the strength in shear of the material. This happens when the force applied is large enough to overcome the forces that hold the particles of the material together.

At a **microscopic level***, when the shear stress exceeds the shear strength at some position in the material, particles of the material start to separate by one particle sliding over the other.

Figure 5.22 *When adjacent microscopic particles start separating because of shear, a shear plane is formed.*



* **microscopic** – so small that it cannot be seen without using a microscope

When a number of **adjacent*** microscopic particles start separating because of shear forces, a shear plane is formed in the material. The shear plane is the surface along which the particles have separated.

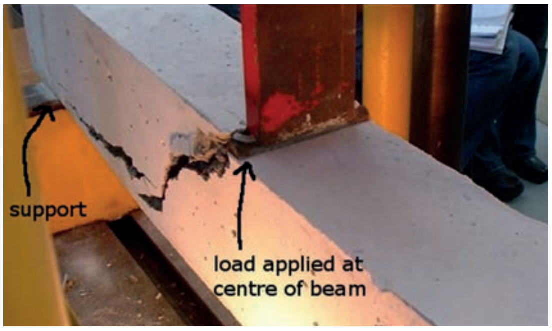
A **microscopic** shear plane is too small for you and me to see.

When a **visible crack** appears, we describe it as a **macroscopic*** shear plane. For a macroscopic shear plane to appear, the shear forces must overcome both the cohesion between the particles and the friction of one rough surface moving across another. Look at Figure 5.24 alongside.

> * **adjacent** – next to, or in line with
> * **macroscopic** – visible without using a microscope

Figure 5.23 *A good example of a shear plane in nature. This landslide occurred at La Conchita, California in 2005, following winter storms.*

Figure 5.24 *Shear cracks in a concrete beam – they start at the support.*



Quick Activity: Shear a banana or a lump of plasticine

A. Wash your hands and peel the banana. Or work a lump of plasticine into a banana shape.

B. Hold the banana horizontally in front of you, with your palms facing down and your hands as tight up against each other as possible.

C. Try not to squeeze the banana too hard while you push one of your hands away from you and pull the other towards you, slowly. Feel the shear!

D. Think about the force needed to shear something. Could you, with your bare hands, shear a half-ripe pear? A thick carrot? A 6 mm wooden dowel? A 2 mm steel rod? Discuss your answers.

Apparatus

- ❑ a banana or a lump of plasticine or play dough or salt dough

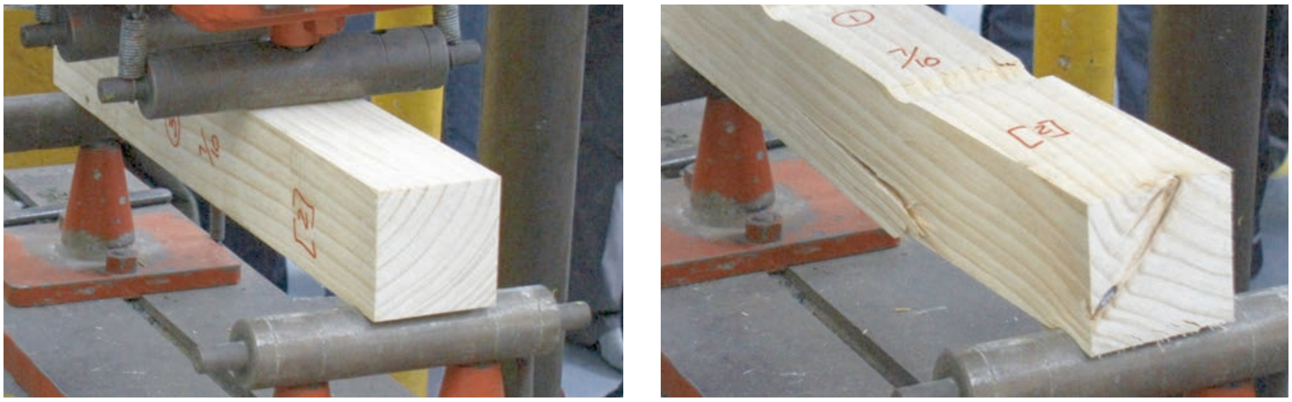
Shear in different beams

Think about shear in concrete beams compared to shear in wood or steel beams. Say what you think shear in these materials would look like. In which material would it be most obvious?

- Failure by shear is more obvious in concrete beams than in steel and wood beams. This is because of the nature of the material. Concrete is generally equally strong at all places and in all directions and when a shear plane develops it tends to continue in that direction.
- In a piece of wood the failure of a group of fibres at a point of stress generally leads to splitting along the grain of the wood away from the point.

- Steel doesn't shear like concrete and wood. The evidence of shear failure in steel is often limited to local deformation of the steel. Steel beams tend to buckle and stretch when subjected to extreme shear forces. This is because steel is ductile.

Figure 5.25 *Shear in this piece of wood probably started when the fibres at the bottom of the beam failed in tension.*



Activity 3 Feel the shear force

Apparatus
- ❑ a broom
- ❑ a 100 N balance
- ❑ a bathroom scale

A. One strong learner stands on the bathroom scale. He or she holds the broom in the middle of the handle horizontally and very tightly, with one hand on each side of his or her body at hip level.

B. A second person will read the bathroom scale. A third person will write it down.

C. The fourth person hooks the balance over the broom handle right up against the broom holder's hands and pulls gently, vertically downwards with a force of 90 N. Read and record the two scales. Repeat the process with the balance 20 cm away from the broom holder's hands and again 40 cm away.

Figure 5.26 *Feel the shear force.*

Questions:

1. The load on the broom handle is a constant 90 N. What effect does the position of the point at which the load is applied have on the bathroom scale?
2. What does that tell us about the shear force, caused by the 90 N downward force, at any position along the broom?
3. Now read the definition of shear force below and try to make sense of it.

Definition: The shear force at a section of a beam is the sum of the perpendicular forces to one side of that section.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 143 2016/01/05 3:17 PM

Determine the shear forces in a simply supported beam with a point load: draw a shear force diagram

A **shear force diagram** is a tool used by a structural designer to determine the value of the shear force at any point on a structural member such as a beam.

How to draw a shear force diagram

> * In this chapter we use the word **axis** to describe an imaginary line that runs through the middle of a beam, from end to end.

A. Work on 1 cm grid paper or graph paper.

B. First draw the space diagram to an appropriate horizontal scale and calculate the reactions at each of the supports.

C. Draw a horizontal line across the page a few centimetres below the space diagram. The line represents the **axis*** of the beam in the shear force diagram.

D. From the space diagram, draw light vertical lines down to the shear force diagram from:
- each end of the beam
- the load(s) on the beam

E. Select an appropriate vertical scale. It must allow for the size of the force vectors which represent the load(s) and the reactions – you will learn by trial and error.

F. In a shear force diagram, upward forces are positive and downward forces are negative. The area above the axis is positive and the area below the axis is negative.

Start on the left of the diagram. There is an upward force at that point – the reaction at the support on the left. With its tail on the horizontal line, draw an arrow to represent the reaction vector.

G. From the head of the first reaction vector, draw a horizontal line to the right. Stop when it intersects with the line along which the load acts.

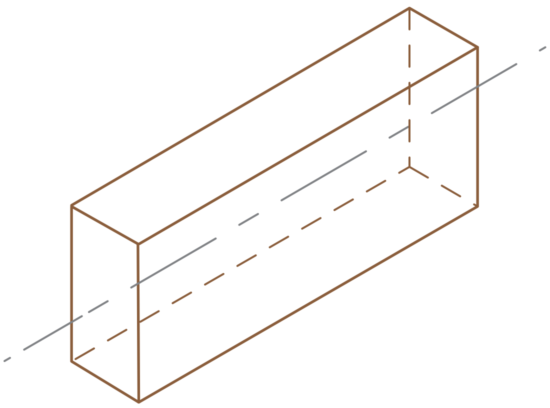
H. From that point, draw a downward arrow to represent the load vector.

I. From the head of the load vector, draw a horizontal line to the right until it intersects with the line along which the support on the right acts.

J. From that point, draw an upward arrow to represent the reaction vector at the support on the right. Its head should be on the axis of the beam.

K. Label each vector with its name and its magnitude in newtons.

Figure 5.27 *The axis of a beam*



Worked examples: Draw a shear force diagram

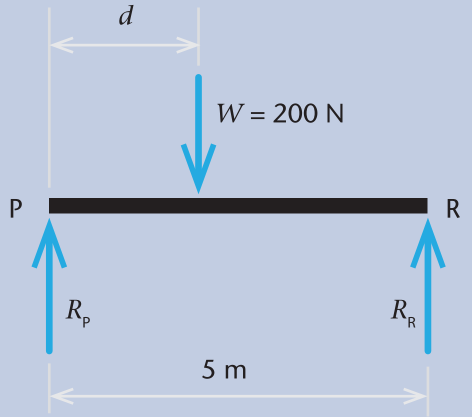
1. Draw the shear force diagram for the beam in **Worked Examples: Calculate Reactions (1)** on page 136.

- We were told that $L = 5$ m; $d = 2$ m and $W = 200$ N.
- We have calculated that $R_P = 120$ N and $R_Q = 80$ N.

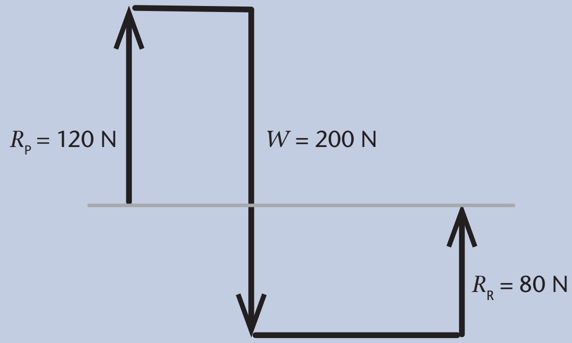
Solution

Figure 5.28

Scale of space diagram: 1 cm = 1 m



Scale of shear force diagram: 1 cm = 40 N

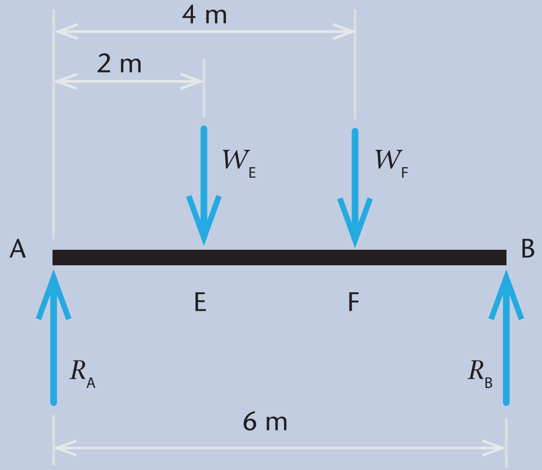


2. **For Enrichment:** Draw the shear force diagram for the beams in **Worked Examples: Calculate Reactions (2)** on page 137.
   - We were given: AB = 6 m; AE = 2 m; AF = 4 m; $W_E = 3$ kN; $W_F = 4$ kN
   - We calculated: $R_A = 3{,}33$ kN; $R_B = 3{,}67$ kN

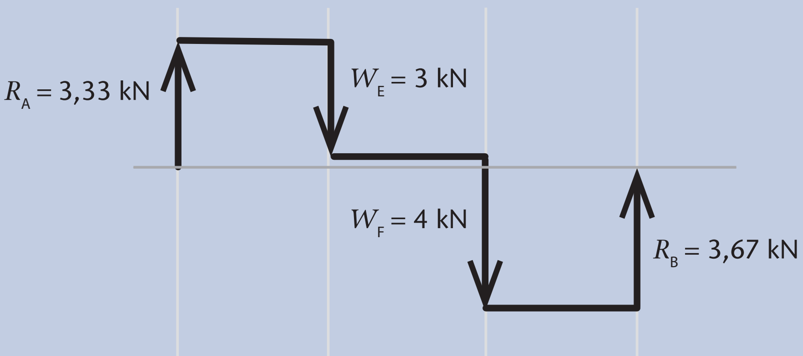
Solution

Figure 5.29

Scale of space diagram: 1 cm = 1 m



Scale of shear force diagram: 1 cm = 2 kN



Activity 4 Draw a shear force diagram

1. Draw the shear force diagram for the beams in Questions 1 to 4 of **Activity 2: Calculate reactions**, starting on page 139.
2. For enrichment: Draw the shear force diagram for the beams in Questions 7 and 8 of **Activity 2: Calculate reactions** on page 140.

Unit 5.4 Bending moments and bending stresses in beams

When you paint a high wall, you might rest a plank on two drums and then stand on the plank to reach the top. Is the plank going to hold your weight or will it bend and break in the middle?

The bending moment resulting from a point load on a simply supported beam is greatest at the point of application of the load (where the load is).

Excessive bending moments can cause concrete, steel and wood beams to fail as in Figure 5.31a and b:

Figure 5.30 *Is the plank going to hold his weight?*

Figure 5.31a *The concrete beam fails in tension at the bottom of the beam.*

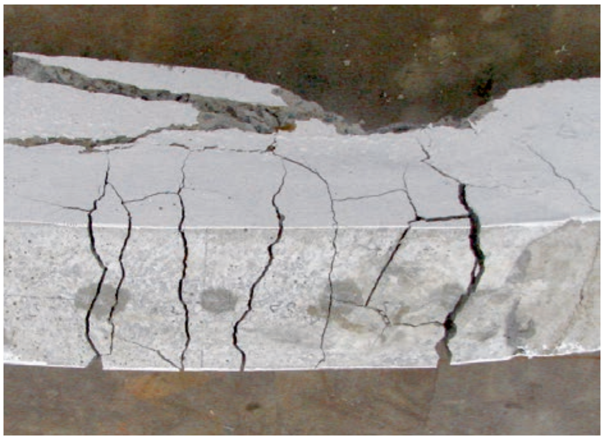


Figure 5.31b *The square-section wood beam shows failure in tension at the bottom, splitting due to compression at the top and shear planes in the middle.*

Activity 5 Bend a plasticine beam by hand

A. Work the plasticine until it is soft.

B. Make a neat beam about 15 cm long, 2 cm wide and 4 cm deep.

C. Scratch neat vertical lines on the beam 1 cm apart.

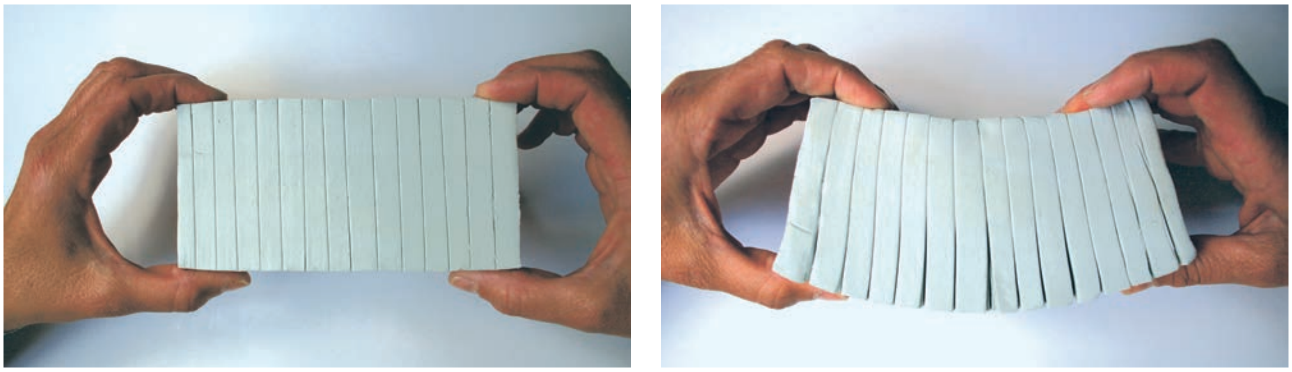
D. Hold the ends of the beam carefully to prevent distortion by your fingers.

E. Slowly apply a **positive bending moment** to the beam.

Apparatus

- ❑ a handful of plasticine (or putty or a foam)
- ❑ six erasers
- ❑ sharpeners or other objects

Figure 5.32 *Positive bending moment in a plasticine beam*



The top (which is in compression because of bending) is squeezed together; the bottom (which is in tension because of bending) is stretched.

Activity 6 Bend a plasticine beam by loading it with weights

You are on your own for this activity. Just do it. Have fun!

Determine the bending moments in a simply supported beam with a point load

A bending moment diagram is a tool that structural designers use to determine the value of the bending moment at any point on a structural member such as a beam.

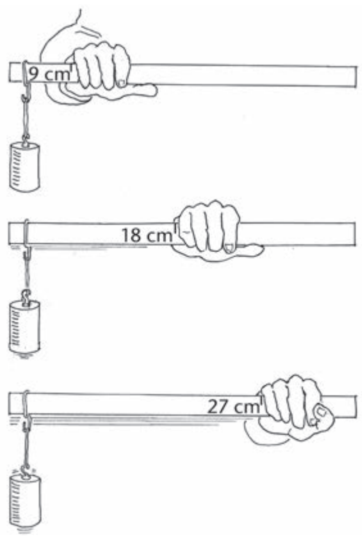
Definition: The bending moment at a point on a beam is the sum of the moments of the forces to one side of the point.

Quick Activity: Feel the bending moment

A. Hold the ruler as in the three diagrams in Figure 5.33. The load on the ruler is constant, but what happens to the moment that your hand is resisting? How does the moment change?

B. Write a rule to describe how the moment changes as the distance to the point of application of the force increases.

Figure 5.33 *Feel the bending moment.*



Apparatus

- ❑ a rigid wood or plastic ruler, or a stick about 30 cm long
- ❑ an elastic band
- ❑ a paper clip as a hook
- ❑ an object that weighs about 5–10 N

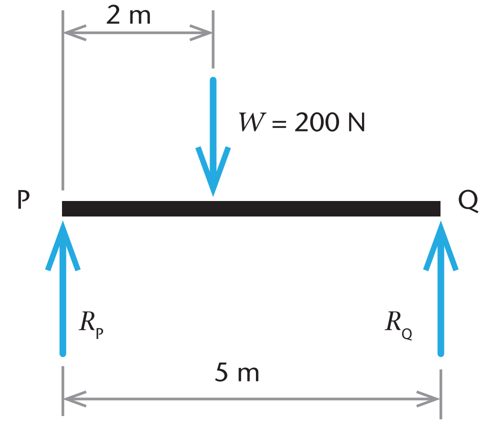
How to draw a bending moment diagram

How to draw a bending moment diagram for the beam in Figure 5.34 below

- We are given that $L = 5$ m; $d = 2$ m and $W = 200$ N and the beam has no weight.
- We have already calculated that $R_P = 120$ N and $R_Q = 80$ N (see **Worked Examples: Calculate Reactions** on page 136).

Figure 5.34

Scale of the space diagram: 1 cm = 1 m



Work on 1 cm grid paper or graph paper.

A. First draw the space diagram to an appropriate horizontal scale (e.g. 1 cm on paper = 1 m in reality) and calculate the reactions at each of the supports.

B. Draw a horizontal line across the page a few centimetres below the space diagram. The line represents the axis of the beam in the bending moment diagram.

C. From the space diagram, extend (draw) light vertical lines down to the line you have just drawn, from:
- each end of the beam
- the load(s)

D. Select an appropriate vertical scale for the moment diagram; for example 1 cm on the paper equals 50 N m in reality.

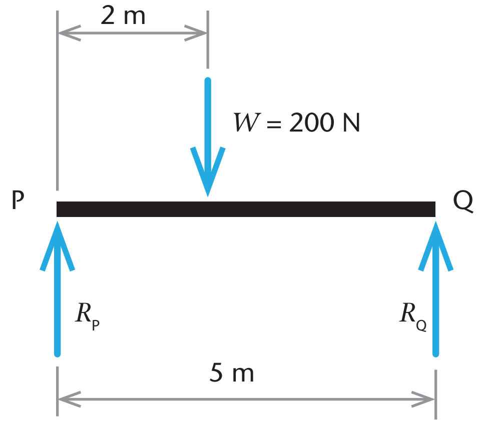
E. Now we calculate bending moments in the beam:
- The bending moment resulting from a point load is greatest at the point of application of the load. So we will calculate the moment M_{PL}.
- Start on the left of the diagram. At P there is an upward reaction: $R_P = 120$ N.
- Determine the distance from the line of the load to the line of R_P. The distance is $d = 2$ m.
- So M_{PL} = distance × force
  = 2 × 120
  = 240 N m
- In a bending moment diagram upward forces are positive and downward forces are negative, so the moment vector is positive.
- To check the calculation, repeat the process to the right of the load.

F. Plot the value on the line of the load. Write the name and the magnitude of the moment (in newton metres) at the appropriate position.

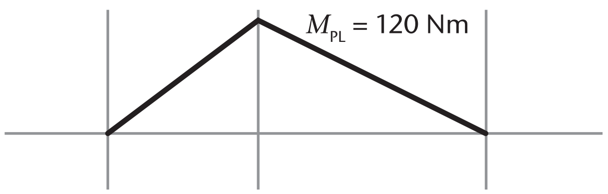
G. Complete the bending moment diagram triangle as in Figure 5.35.

Figure 5.35

Scale of the space diagram: 1 cm = 1 m



Scale of the bending moment diagram:
1 cm = 80 N m



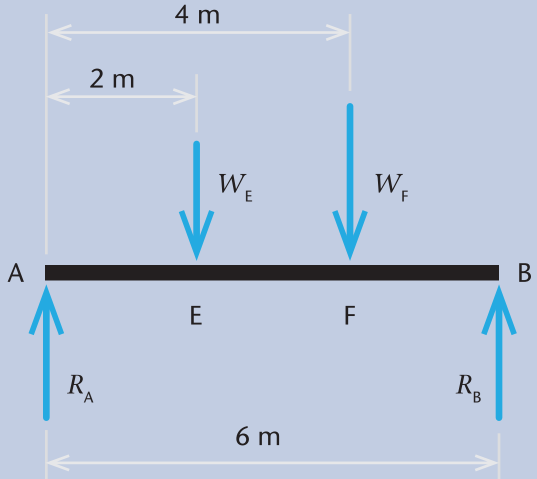
Worked example: Draw the bending moment diagram for a simply supported beam with multiple point loads (Enrichment)

1. Draw the bending moment diagram for the **Worked Examples: Calculate Reactions (2)** on page 137.

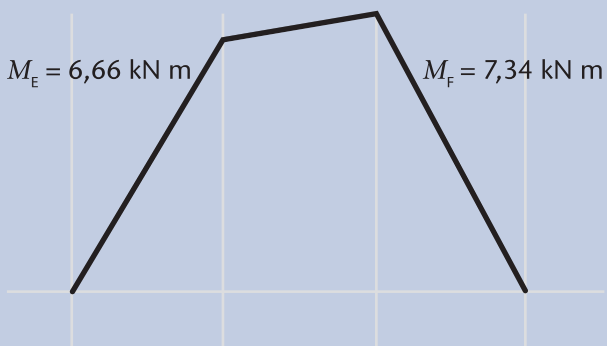
In this example you were given the following information:
A simply supported beam AB is 6 m long. A point load of 3 kN is placed at E, which is 2 m from A. Another point load of 4 kN is placed at F, which is 4 m from A.

Solution

Figure 5.36
Scale of the space diagram: 1 cm = 1 m



Scale of bending moment diagram: 1 cm = 2 kN m



On page 137 we calculated the reactions:
$R_A = 3{,}33$ kN; $R_B = 3{,}67$ kN

Unknown M_E and M_F

Formula
$$M_E = R_A \times 2$$
$$= 3{,}33 \times 2$$
$$= 6{,}66 \text{ kN m}$$
$$M_F = R_B \times 2$$
$$= 3{,}67 \times 2$$
$$= 7{,}34 \text{ kN m}$$

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 151 2016/01/05 3:17 PM

Activity 7 Draw the bending moment diagram for a beam with a point load

Follow the procedure set out in Steps A to G above to draw bending moment diagrams for Questions 1 to 8 of **Activity 2: Calculate Reactions**, starting on page 139.

Activity 8 Calculate reactions, draw shear force diagrams and draw bending moment diagrams

1. Beam NM is 5 m long. It is simply supported. A point load of 3 kN is placed 1 m from the right support. Draw the shear force and bending moment diagrams.
2. A simply supported beam RL is 4 m long. A point load of 3 500 N is placed 1,5 m from the left end of the beam. Draw the shear force and bending moment diagrams.
3. The reactions at the ends of simply supported beam ST are R_S = 4 kN and R_T = 8 kN. The beam is 6 m long. Calculate the size of the point load and its position relative to S. Draw the shear force and bending moment diagrams.
4. **For Enrichment:** A simply supported beam AB is 2,5 m long. A point load of 5,5 kN is placed at the midpoint of the beam. Another point load of 4,5 kN is placed 0,5 m from A. Draw the shear force and bending moment diagrams.

Unit 5.5 Cantilever beams

Definition: The cantilever beams that we study this year are fixed at one end and free to move at the other end.

Because the beams are rigid, all forces that act on the beam are transferred along the beam towards a fixed point.

So, at any section on the cantilever beam in Figure 5.37a below, all forces that act on the beam to the right of the section are resisted by the materials in the beam at that section.

Figure 5.37a *The forces that act at section AA*

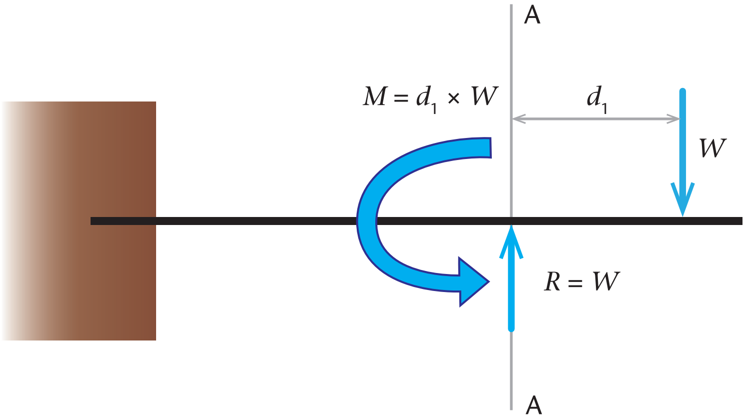


Figure 5.37b *At the fixed end, the forces are transferred to the structure to which the beam is fixed.*

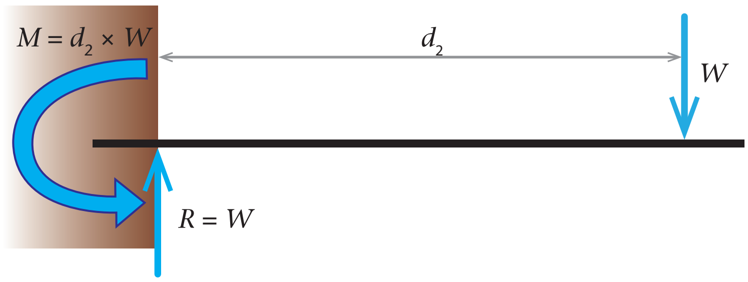
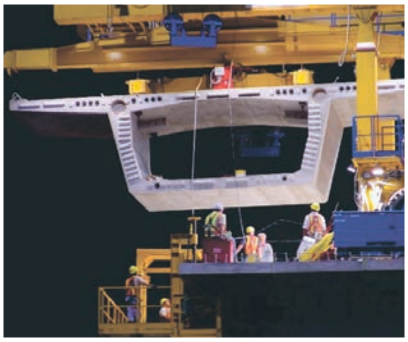


Figure 5.38 *Three different cantilevers: to support shade cloth; to support a canopy over a door; as part of a precast bridge section*

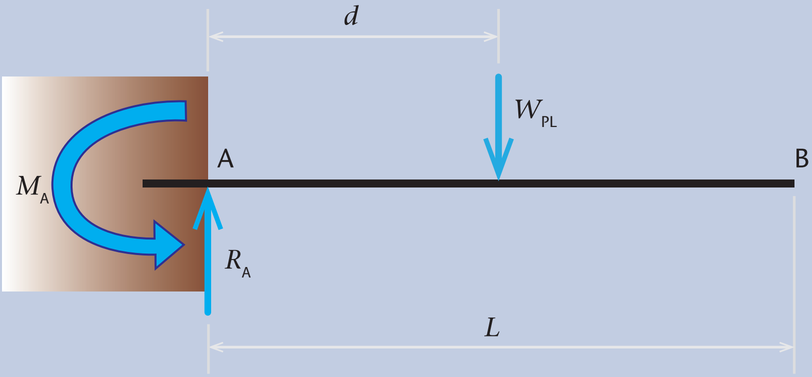


TechSci_G10-LB-Eng-DBE3_9781431522842.indb 153 2016/01/05 3:17 PM

Worked example: Draw the shear force diagram and the bending moment diagram for a cantilever with a point load

In Figure 5.39 below, W_{PL} = 400 N; d = 3 m; L = 4 m and the beam has no weight.

Figure 5.39 *Space diagram for a cantilever beam with a point load*



Draw the following for the cantilever with a point load shown in Figure 5.39:

a) the shear force diagram

b) the bending moment diagram

Solutions

- In Figure 5.39 there are just two forces: the downward point load W_{PL} and the reaction at the wall R_A.
- Because the beam is rigid, all forces that act on the beam are transferred up the beam to the fixed point.
- The beam is in equilibrium, so $R_A = W_{PL} = 400$ N.

a) Shear force diagram for a cantilever with a point load

To draw the shear force diagram for this cantilever, follow the steps on page 144 under the heading: **How to draw a shear force diagram**.

Figure 5.40 *Shear force diagram*
Scale of the shear force diagram: 1 cm = 200 N

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 154 2016/01/05 3:17 PM

b) Bending moment diagram for a cantilever with a point load

To draw the bending moment diagram for this cantilever, follow the steps on page 149 under the heading: **How to draw a bending moment diagram**.

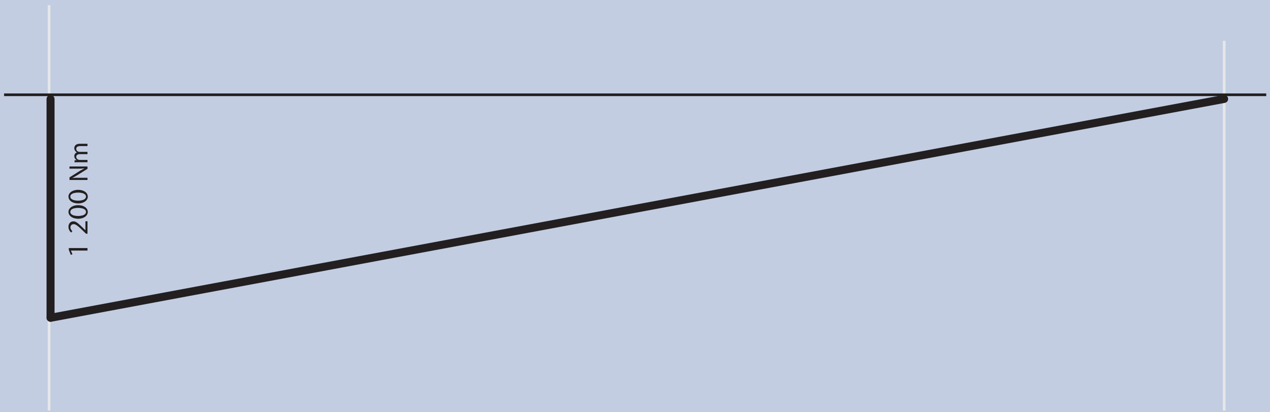
Calculate the bending moment at A: $M_A = d\,W_{PL}$

$= 3 \times 400$

$= 1\,200$ N m

Figure 5.41 *Bending moment diagram*

Scale of the bending moment diagram: 1 cm = 300 N m

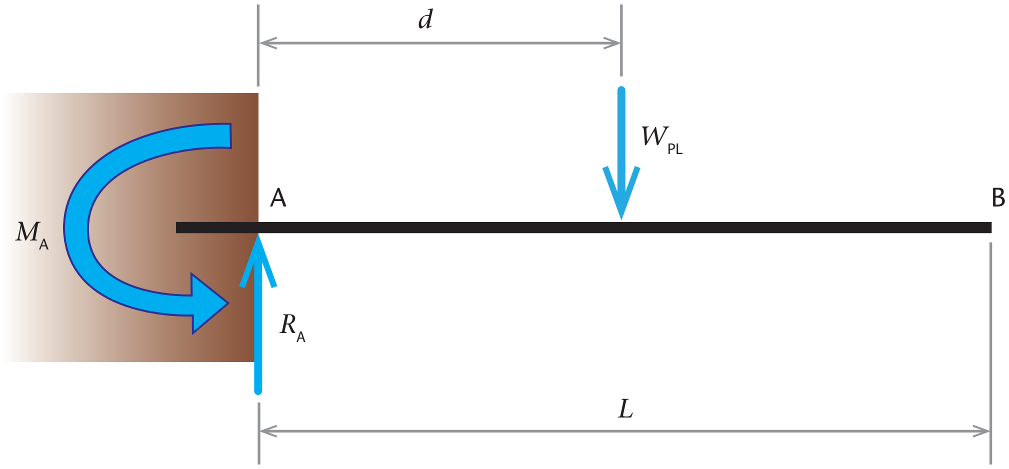


NOTE: The cantilever will bend in this shape: , so it is a negative moment and must be drawn below the line.

Activity 9 Draw the shear force diagram and the bending moment diagram for a cantilever with a point load

1. In the space diagram below, $W_{PL} = 30$ kN; $d = 2$ m; $L = 5$ m and the beam has no weight. Calculate the reaction and the bending moment at the fixed end.

Figure 5.42 *Space diagram*



2. In the space diagram in Figure 5.42 on the previous page, $W_{PL} = 1\ 200$ N; $d = 5$ m; $L = 7$ m and the beam has no weight. Draw the shear force diagram and the bending moment diagram.
3. A vertical point load of 44,6 kN acts downwards on the end of a fixed cantilever 4,2 m long. Calculate the reaction and the bending moment at the fixed end.
4. A fixed cantilever 3 m long has a vertical point load of 60 kN acting at the free end. Calculate the reaction and the bending moment:
   a) 1 m from the load
   b) 2 m from the load
   c) at the fixed end

   In each case above, draw the space diagram, the shear force diagram and the bending moment diagram.
5. A fixed cantilever 6 m long has a vertical load of 20 kN acting at the free end and another load of 10 kN that is 2 m from the free end. Calculate the reaction and the bending moment at the fixed end.
6. A vertical load of 2 800 N acts at a distance *d* from the fixed end of a cantilever. The bending moment at the fixed end is 5 200 Nm. Draw the space diagram, calculate *d* and draw the shear force and the bending moment diagrams.
7. Calculate the load that acts vertically downwards at the end of a fixed cantilever that is 4 m long, if the bending moment at the fixed end is 2 400 Nm.
8. A simply supported beam ABC is 5,5 m long. It is supported at A and B, which are 4,5 m apart. The section from B to C is a cantilever. A point load of 2 kN acts downwards at C and another point load of 3 kN acts downward at 1 m from A. Draw the space diagram and calculate the reactions at A and B.

Chapter summary

- A beam is a horizontal structural member designed to carry a vertical load. It is able to carry a load because it is designed not to bend or shear when it is loaded.
- The reactions at the points at which a beam is supported depend primarily on:
  - the loads on the beam
  - the way in which the beam is supported: it can be either fixed/rigid or it can allow movement
  - the distance between the supports
- The bending moment is usually greatest in the middle of a beam, where it is resisted by the compressive strength of the material in the top of the beam and by the tensile strength of the material in the bottom of the beam.
- The shear forces are typically greatest near the points at which the beam is supported.
- A simply supported beam is a beam supported in such a way that the supports do not prevent the beam from bending/flexing/deflecting in any way when it is loaded.
- A point load on a beam is a load that acts at a point on the beam. It is not distributed along the beam.
- We represent a point load with a single arrow, which tells us where the load is and in which direction it is acting. A number next to the arrow indicates the magnitude of the load (which is a force) in newtons (N).
- A force diagram shows the forces acting on an object.
- We use the Law of Moments to calculate the reactions at the supports.
- The shear force at a section of a beam is the sum of forces perpendicular to the axis of the beam, to one side of that section.
- A shear force diagram is a tool used by a structural designer to determine the value of the shear force at any point on a beam.
- A positive bending moment bends a member in this way: 
- A negative bending moment bends a member in this way: 
- The bending moment at a point on a beam is the sum of the moments to one side of the point.
- A bending moment diagram is a tool used by a structural designer to determine the value of the bending moment at any point on a beam.
- The cantilever beams that we study are fixed at one end and free to move at the other end.
- Because cantilever beams are rigid, all forces that act on the beam are transferred along the beam towards a fixed point. At any section on the beam, all forces that act on the free end of the beam, to one side of the section, are resisted by the materials in the beam at that section.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 157 2016/01/05 3:17 PM

Challenges and projects

Who can make the strongest beam?

Work in teams of four and use the given materials to make 30 cm long beams. You may use any resources you have to shape and cure your beam – but you may not use anything else as an "ingredient" in the beam. Unfortunately, we do not have concrete to make our beams, but we do have salt dough.

As a class:

A. Devise a fair method to test the weight that the beam can carry as a point load at its midpoint.

B. Make salt dough:

- Measure the flour and put it into the bowl.
- Then measure the salt and put it into the bowl.
- Mix the flour and the salt well, using your hands.
- Make a hole in the middle of your mixture.
- Pour the water into the hole.
- Fold (gently push) the mixture into the water and mix it well.
- Knead the dough until it is smooth: it must not be sticky or crumbly.

Apparatus

- ❑ 2 cups of cake flour
- ❑ 1 cup of salt
- ❑ $\frac{3}{4}$ cup of water and a bowl
- ❑ 1 m of 2 mm diameter wire
- ❑ a pair of pliers

C. Shape the dough and bake it in the sun or in an oven.

D. Test the beams and give the winners a hug!

Are you having problems with your "concrete"?

- If the dough is too wet, sprinkle a little flour onto the work surface and work it in.
- If the dough is too dry, spread the dough out and sprinkle water onto it and work it in.
- If the beam does not harden in the sun, find a hotter spot or put it into an oven for 2 hours at 120 degrees.
- To make it stronger, bake it at a higher temperature for longer.

CHAPTER 6 Simple machines

In this chapter the simple machines we study are levers. You will calculate the mechanical advantage, load, effort, length of load arm and length of effort arm.

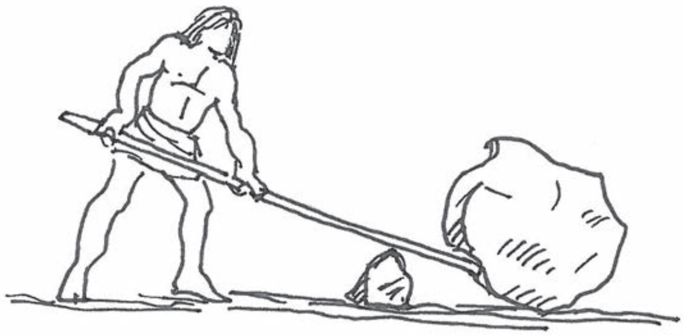
Unit 6.1 Levers are simple machines

When early people walked on Earth, their first implement was possibly a heavy stick, used for killing to eat or for defence. The stick might also have been used to dig for roots, or to move a rock.

When it moved a rock, that stick was being used as a lever. The lever made the job of moving the rock feel easier – it gave early people what we call a **mechanical advantage**. Today, we call things that give mechanical advantage **machines**.

So that early stick was a simple machine.

Figure 6.1 *Early man's stick was a simple machine.*



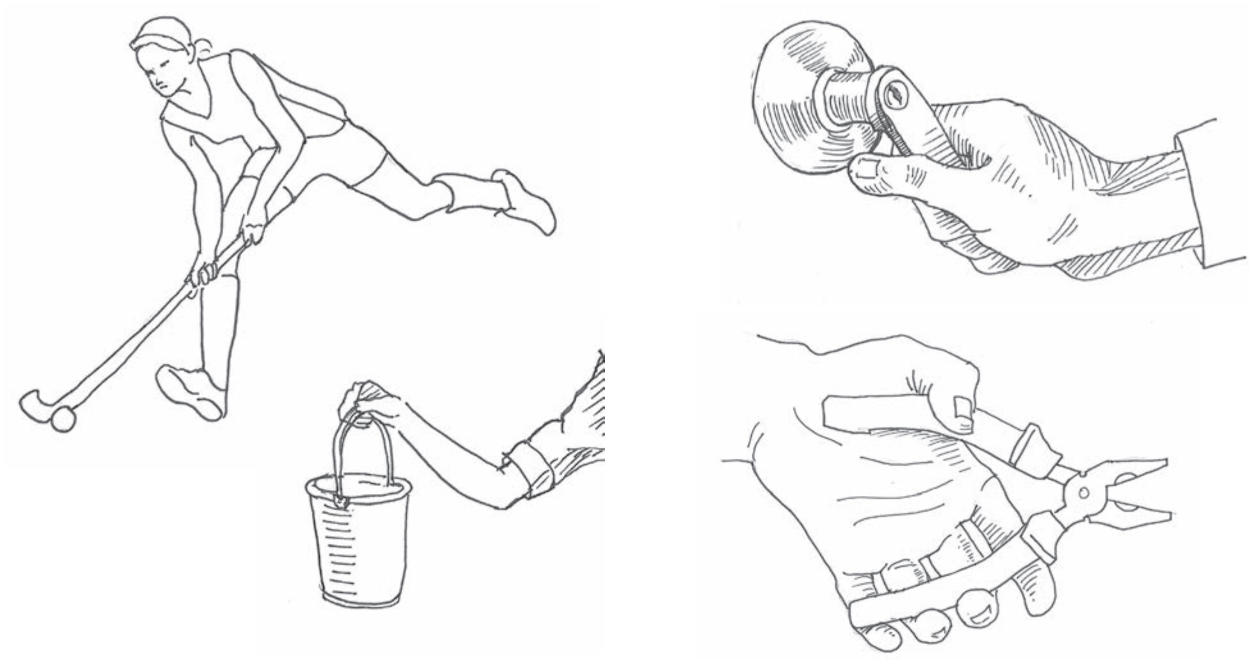
Machines make a physical job easier by changing the magnitude of the input force needed to do the work. Machines multiply our efforts and make it easier for us to do our work.

In Technology you worked with each of the three types of levers. For each type of lever you learned to:

- describe the positions of the fulcrum, load and effort relative to each other
- state if a lever gives mechanical advantage (MA) of >1, or =1, or <1
- give examples of devices that use the different types of levers as single or paired levers

You use a lever whenever you turn the handle of a door, staple two pieces of paper together, or cut a piece of paper.

Figure 6.2 *Levers we use every day*



Quick Activity:

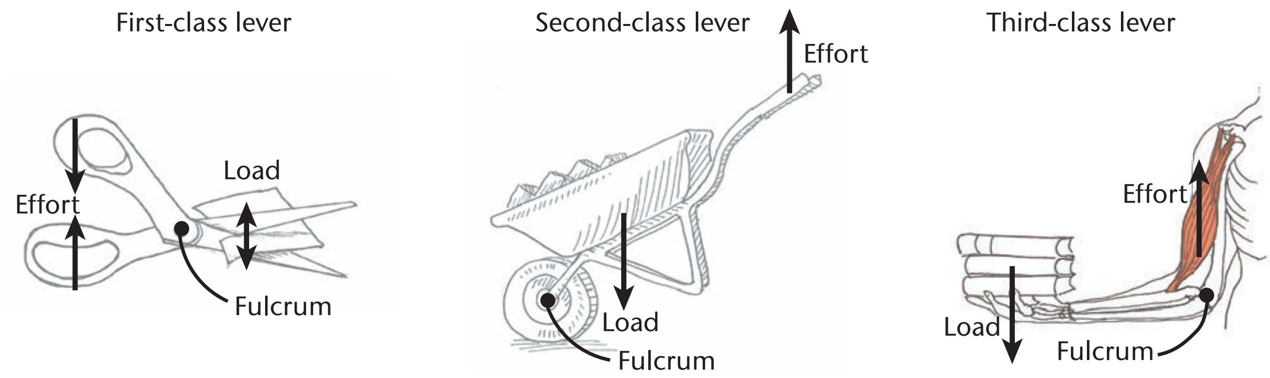
In your workbook, list six of any type of lever that you use every day.

All levers have three things in common:

- a fulcrum, which is the point around which the lever rotates as it does its job
- an effort (input), which is applied to the lever by the person using the lever to do a job
- a load (output), which the person using the lever intends to overcome or balance by using the lever

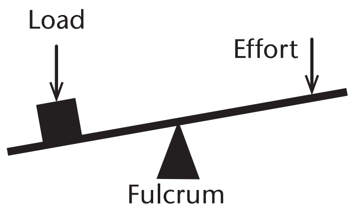
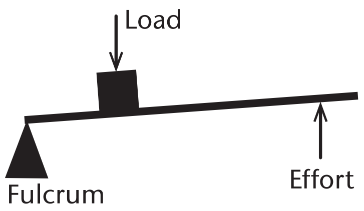
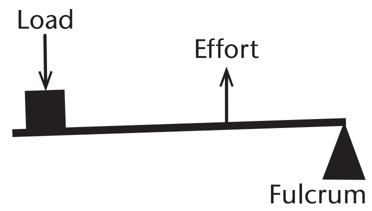
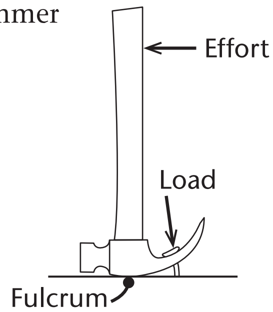
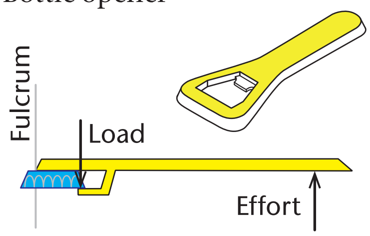
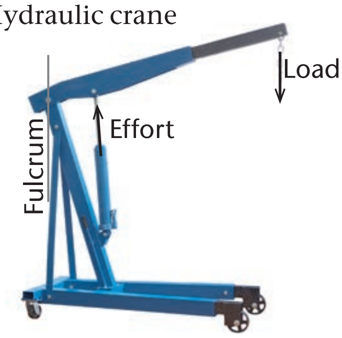
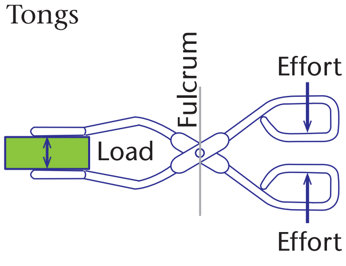
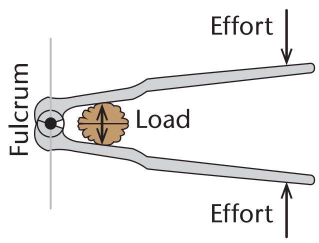
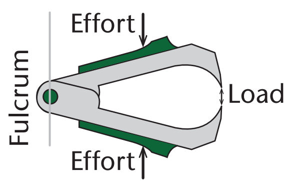
Types of levers

Figure 6.3 *Every lever has a fulcrum, a load and an effort.*



Have a look at Table 6.1 below. It is a summary of what you have learnt previously.

Table 6.1 Characteristics of the three types of levers

	Type 1	Type 2	Type 3
Positions	load/fulcrum/effort	effort/load/fulcrum	load/effort/fulcrum
Force diagram			
MA **> 1**	Yes	Yes	No
MA **= 1**	Yes	No	No
MA **< 1**	Yes	No	Yes
Examples	Hammer 	Bottle opener 	Hydraulic crane 
	Tongs 	Nut cracker 	Staple remover 

Quick Activity:

Who has a hammer, a bottle opener, a fishing rod, a pair of scissors, a nut cracker or a staple remover at home? Arrange to bring all the objects in the table above, or similar objects, to the next Technical Science lesson.

Once you have all handled all the objects, answer the following questions:

1. What is the difference between the pairs of objects in the two bottom rows in Table 6.1?

2. If the objects in the first row of examples are called levers, what do we call the objects in the second row of examples?

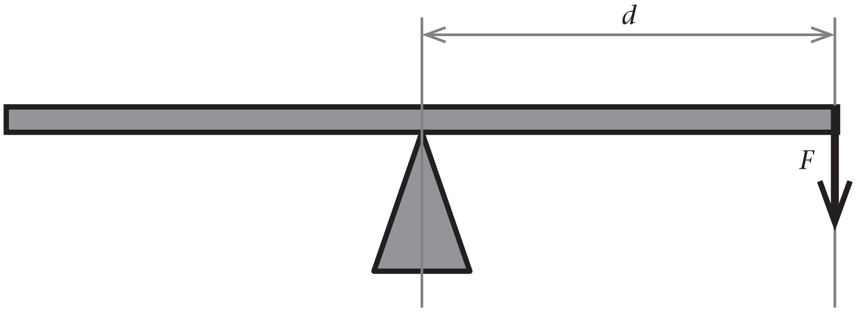
Unit 6.2 The Law of Moments in levers

By tradition, the input force of a lever is called the **effort** and the output force is called the **load**. We will continue to use those words, but you must remember that they are forces.

In Unit 4.1 in Chapter 4 we learnt that we need to know three things in order to calculate a **moment**:

- the **perpendicular distance** from the line of the force to the fulcrum in metres
- the **magnitude/size** of the force in newtons
- the **direction of the rotation**: clockwise or anti-clockwise

Figure 6.4 *The size of the moment (the turning force) depends on the size of F and the distance d.*



In Figure 6.4 above, the size of the moment is given by the formula:

moment = force × perpendicular distance from the fulcrum to the line of the force

or, in symbols:

$M = F \times d$

where:

- M is the symbol for moment measured in newton metres (N m)
- F is the symbol for force measured in newtons (N)
- d is the symbol for distance measured in metres (m)

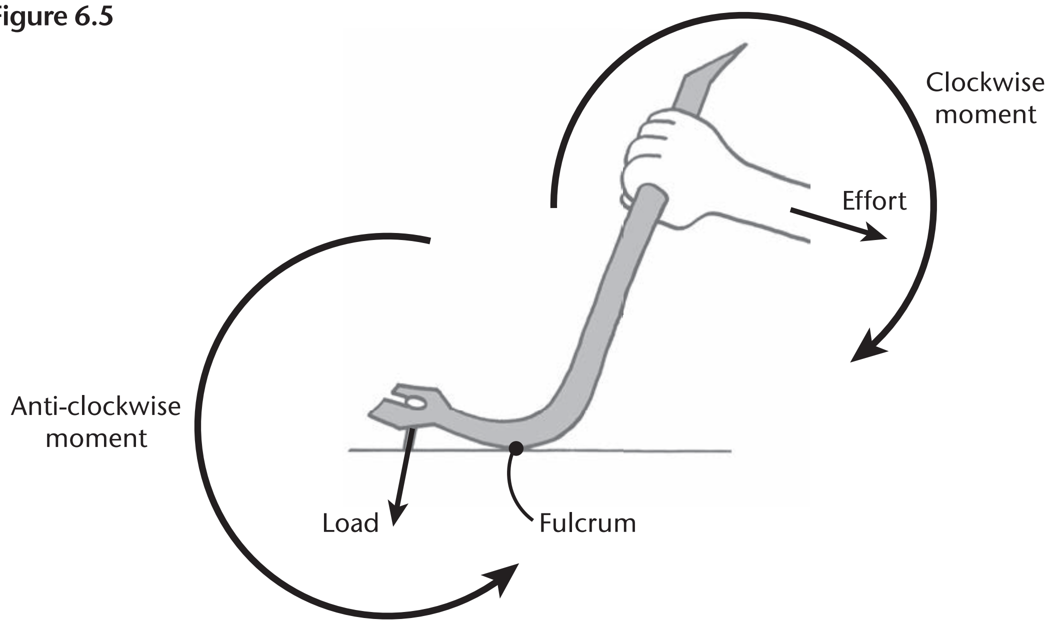
The direction of the moment in the diagram is clockwise.

In Unit 4.2 in Chapter 4 we learnt how the Law of Moments applies to levers:

- When a force is applied to a lever it rotates.
- A moment (or turning effect) is created in a lever when an effort is applied to a lever. That moment is resisted by the load that the lever is trying to move.
- The two moments oppose one another: one will be clockwise and one will be anti-clockwise.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 162 2016/01/05 3:17 PM

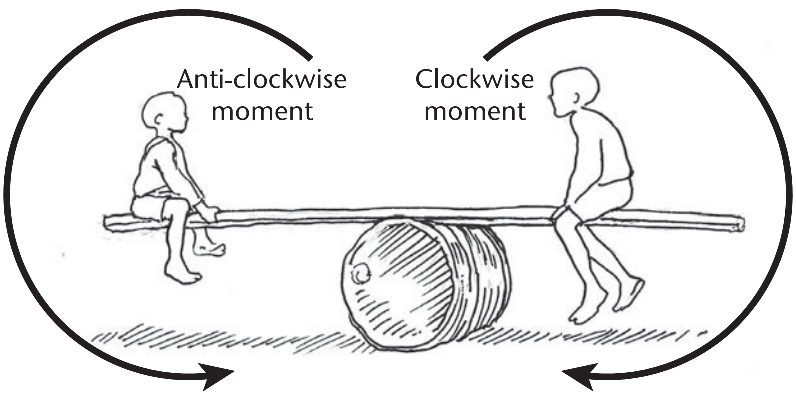
Figure 6.5



Levers in equilibrium

When we calculate moments in a lever, we have to freeze the action – the lever must not be rotating when we analyse it. If the rotation has stopped, it means that the input moment is balanced by the output moment. When the moments balance, we say that the lever is "in equilibrium". Look at the see-saw in Figure 6.6.

Figure 6.6 *The sum of the clockwise moments equals the sum of the anti-clockwise moments, so this see-saw is in equilibrium.*



Use the **Law of Moments** to analyse a lever in equilibrium:

sum of the clockwise moments = sum of the anti-clockwise moments

or, in symbols:

$M_{\text{CW}} = M_{\text{ACW}}$

where:

- M is the symbol for moment measured in newton metres (N m)

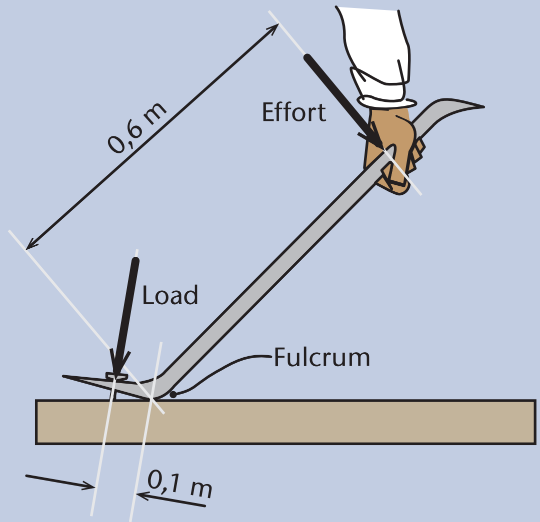
Worked examples: Analyse levers using the Law of Moments

In these examples and the activities that follow we use the following notation:

- F_L is the load measured in newtons (N)
- F_E is the effort measured in newtons (N)
- d_E is the length of the effort arm measured in metres (m)
- d_L is the length of the load arm measured in metres (m)

1. The crowbar in Figure 6.7 is a Type 1 lever. It is being used to extract a nail from a piece of wood. A force of 100 N is required to remove the nail. What force must be applied to the crowbar?

Figure 6.7



Solution

Given $d_L = 0{,}1$ m; $d_E = 0{,}6$ m; $F_L = 100$ N

Unknown F_E

Formula $M_{CW} = M_{ACW}$

$$F_E \times d_E = F_L \times d_L$$

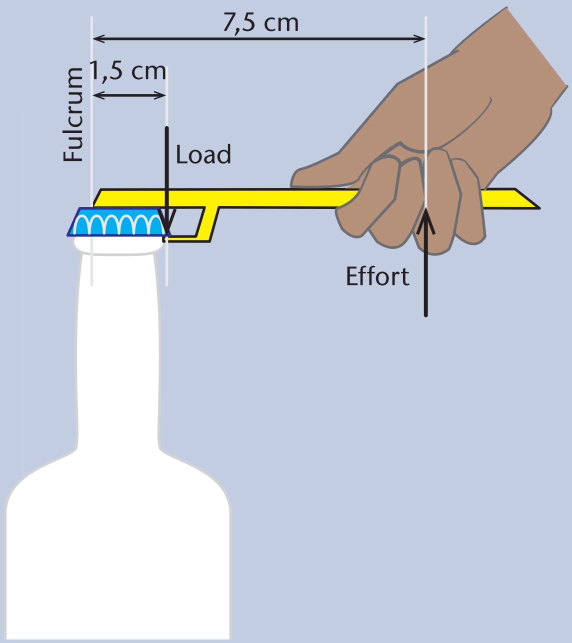
$$F_E = \frac{F_L \times d_L}{d_E} \quad \text{(isolate } F_E\text{)}$$

$$= \frac{100 \times 0{,}1}{0{,}6} \quad \text{(substitute)}$$

$$= 16{,}7 \text{ N}$$

2. The bottle top remover in Figure 6.8 is a Type 2 lever. It is used to remove the cap of a bottle. The cap requires a force of 150 N to lift it. What force must be applied to the opener?

Figure 6.8



Solution

Given $d_L = 1{,}5$ cm; $d_E = 7{,}5$ cm; $F_L = 150$ N

Unknown F_E

Formula $M_{CW} = M_{ACW}$

$$F_L \times d_L = F_E \times d_E$$

$$F_E = \frac{F_L \times d_L}{d_E} \quad \text{(isolate } F_E\text{)}$$

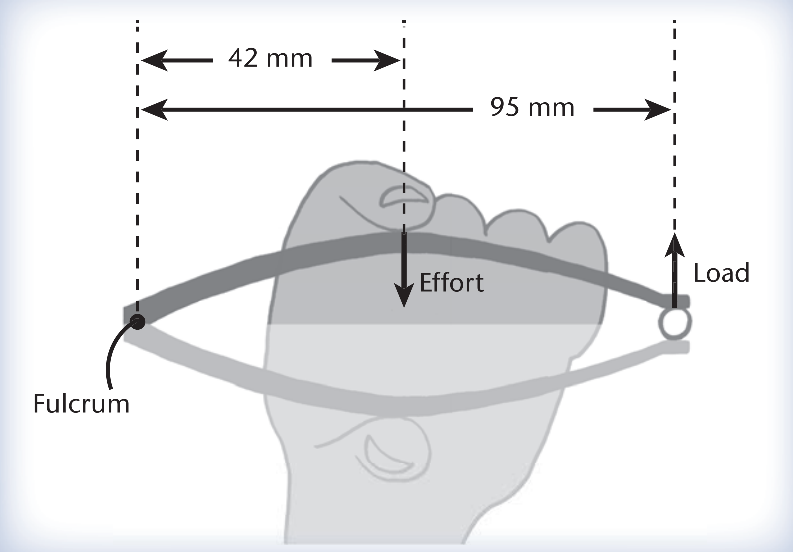
$$= \frac{150 \times 1{,}5}{7{,}5} \quad \text{(substitute)}$$

$$= 30 \text{ N}$$

3. The pair of tweezers in Figure 6.9 is a pair of Type 3 levers. A nano-technician called Techlet is using it to pick up a very delicate glass tube. If a force of 2 N is applied to the tube it will break. What is the maximum force that may be applied to the pair of tweezers?

NOTE: To solve this problem we can analyse either the top or the bottom arm of the pair of tweezers. Here we choose the top arm.

Figure 6.9



Solution

Given $d_L = 95$ mm; $d_E = 42$ mm; $F_L = 2$ N

Unknown F_E

Formula $M_{CW} = M_{ACW}$

$$F_E \times d_E = F_L \times d_L$$

$$F_E = \frac{F_L \times d_L}{d_E} \qquad \text{(isolate } F_E\text{)}$$

$$= \frac{2 \times 95}{42} \qquad \text{(substitute)}$$

$$= 4{,}5 \text{ N}$$

Unit 6.3 Mechanical advantage

Calculate mechanical advantage in a lever

Mechanical advantage (MA) is the advantage you gain when you use a machine. It tells you by how much the input force is multiplied when you use the machine. MA is expressed as a number without a unit.

When we work with levers we can define mechanical advantage in two different ways:

- MA is the ratio of the load to the effort

so $MA = \dfrac{F_L}{F_E}$

- MA is the ratio of the length of the effort arm to the length of the load arm

so $MA = \dfrac{d_E}{d_L}$

Worked examples: Calculate the mechanical advantage of a lever

1. You have a lever that enables you to move a load of 700 N with an effort of 350 N. What is the MA of the lever?

Solution

Given $F_L = 700$ N; $F_E = 350$ N

Unknown MA

Formula $MA = \dfrac{F_L}{F_E}$

$= \dfrac{700}{350}$ (substitute)

$= 2$

2. You have a lever with an effort arm of 1,2 m and a load arm of 0,3 m. What is the MA of the lever?

Solution

Given $d_E = 1{,}2$ m; $d_L = 0{,}3$ m

Unknown MA

Formula $MA = \dfrac{d_E}{d_L}$

$= \dfrac{1{,}2}{0{,}3}$ (substitute)

$= 4$

3. It is not possible to fit a circlip with your fingers. A simple machine, circlip pliers, makes it possible.

A circlip is a flexible clip that fits into a groove on an axle. It allows rotation but prevents **axial movement*** of something on the axle. It has the shape of a metal ring "with a gap". Little pins at the points of circlip pliers are inserted into little holes on the circlip to fit or remove the clip.

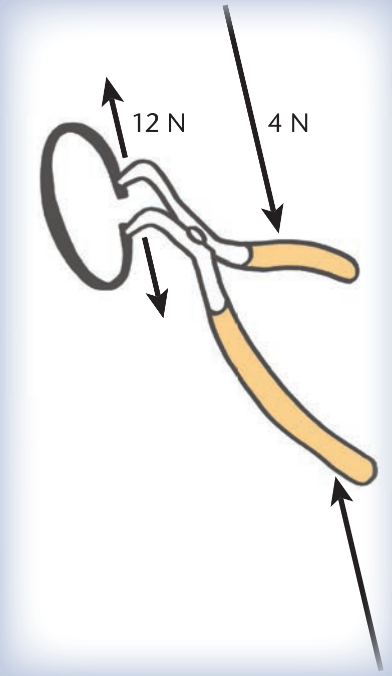
> * **axial movement** – movement along the line of the axle

Look closely at Figure 6.10 below. Do you see the gap, the two little holes and the pins?

Figure 6.10 *Circlips and circlip pliers*

a) The force required to open the gap (the load) of the circlip in Figure 6.11 is 12 N. If the force applied to the handle of the pliers (the effort) is just 4 N, what mechanical advantage does the pair of pliers give?

Figure 6.11



Solution

Given $F_E = 4$ N; $F_L = 12$ N

Unknown MA

Formula $MA = \frac{F_L}{F_E}$

$= \frac{12}{4}$ (substitute)

$= 3$

b) The length of the load arm of the circlip pliers in Figure 6.12 is 3,5 cm. If length of the effort arm of the pliers (to where the fingers press) is 7,0 cm, what mechanical advantage does the pair of pliers give?

Solution

Given $d_L = 3,5$ cm; $d_E = 7,0$ cm

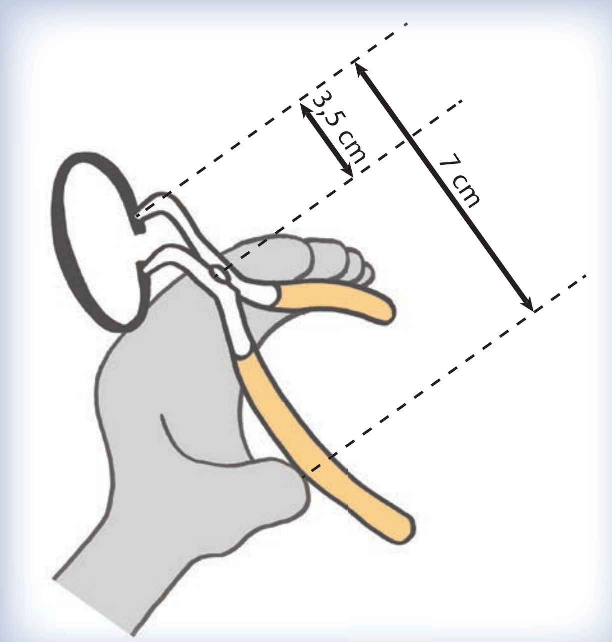
Unknown MA

Formula $MA = \frac{d_E}{d_L}$

$= \frac{7}{3,5}$ (substitute)

$= 2$

Figure 6.12



Activity 2 Calculate the mechanical advantage of a lever

1. Calculate the following for Type 1 or Type 2 levers, and in each case say which type/s of lever it could be:

a) MA where $F_L = 10$ N; $F_E = 2$ N

b) MA where $d_E = 0,6$ m; $d_L = 1,8$ m

c) MA where $F_L = 0,9$ N; $F_E = 2,7$ N

d) MA where $d_L = 1,6$ m; $d_E = 0,2$ m

2. Calculate the following for Type 1 or Type 3 levers:

a) MA where $F_L = 100$ N; $F_E = 200$ N

b) MA where $d_E = 0,03$ m; $d_L = 0,99$ m

c) MA where $F_L = 67$ N; $F_E = 9$ N

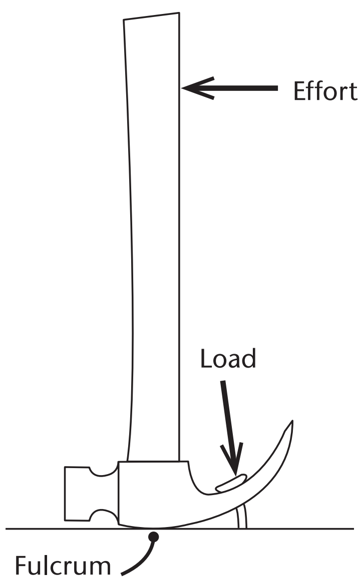
d) MA where $d_L = 0,03$ m; $d_E = 0,99$ m

3. A carpenter is using a hammer to extract nails from a wooden truss. A force of 400 N must be applied to the head of a certain nail to extract it.

a) The carpenter exerts an effort of 50 N to get the nail out. What is the MA of the hammer?

b) Another carpenter is using a different hammer. The effort arm of the hammer is 44 cm and the load arm is 4 cm. What is the MA of the hammer?

Figure 6.13



4. Staple removers are being used to remove staples from old exam papers so that the paper can be recycled.
   a) An output force of 25 N is required to remove a staple holding 10 sheets of paper together. The teacher's input force of 50 N gets the staple out. What is the MA of the staple remover?
   b) Another teacher is using a different staple remover. The effort arm of the staple remover is 4,4 cm and the load arm is 7 cm. What is the MA of the staple remover?

Figure 6.14 *A staple remover*

Calculate load or effort on a lever if the mechanical advantage is given

If you are given the MA and either the load or the effort, then by rearranging the formula you can calculate the missing quantity.

To calculate the load:

$$F_L = MA \times F_E \text{ (newtons)}$$

To calculate the effort:

$$F_E = \frac{F_L}{MA} \text{ (newtons)}$$

Worked examples: Calculate load or effort on a lever if the mechanical advantage is given

1. You have a crowbar that gives a mechanical advantage of 5. If the load is 1 000 N, what is the effort required?

Solution

Given $MA = 5$; load = 1 000 N

Unknown F_E

Formula $F_E = \frac{F_L}{MA}$

$= \frac{1000}{5}$ (substitute)

$= 200$ N

2. You have a bolt cutter that gives a mechanical advantage of 15. If the load needed to cut a 12 mm bolt is 3 000 N, and you are able to apply a force of 300 N, will you be able to cut the bolt?

Solution

Given $MA = 15$; load = 3 000 N; maximum effort possible = 300 N

Unknown F_L

Formula $F_L = F_E \times MA$

$= 300 \times 15$ (substitute)

$= 4\,500$ N

∴ Yes, you will be able to cut the bolt.

Activity 3 Calculate load or effort in a lever if the mechanical advantage is given

1. Calculate the unknown quantity in the following levers. In each case say which type/s of lever it can be.
   a) F_L where $MA = 7$; $F_E = 7$ N
   b) F_E where $MA = 0{,}25$; $F_L = 15$ N
   c) F_L where $MA = 1{,}1$; $F_E = 0{,}9$ N
   d) F_E where $MA = 0{,}5$; $F_L = 15$ N
2. An effort of 600 N is required to move a load. The MA of the machine is 0,5. What is the load?
3. If a load of 800 N is moved by a lever with an MA of 1,5, what is the effort required?
4. You have a pair of fire tongs (in the form of a Type 3 lever) to lift a piece of steak out of a braai fire. The steak weighs 3 N. You can apply a force of only 8 N because your thumb is sore. The MA of the fire tongs is 0,3. Is the steak going to burn, or will you be able to lift it out of the fire? Discuss this question before doing the calculation.

Calculate the length of the load arm or effort arm in a lever if the MA is given

If you are given the MA and either the load arm or the effort arm, then by rearranging the formula, you can calculate the missing quantity.

To calculate the length of the load arm:

$$d_L = \frac{d_E}{MA} \text{ (metres)}$$

To calculate the length of the effort arm:

$$d_E = d_L \times MA \text{ (metres)}$$

Worked examples: Calculate the length of the load arm or effort arm in a lever if the MA is given

1. You have a lever set up to give an MA of 6. If the load arm is 0,2 m, what is the length of the effort arm?

Solution

Given $MA = 6; d_L = 0{,}2$ m

Unknown d_E

Formula $d_E = d_L \times MA$

$= 0{,}2 \times 6$ (substitute)

$= 1{,}2$ m

2. You have a pair of fire tongs (in the form of a Type 1 paired lever) which gives an MA of 0,2. The effort arm is 0,1 m. There is a grid in front of the fire through which the tongs can fit but which is too small for your hand. Will you be able to reach coals 0,5 m behind the grid?

Solution

Given $MA = 0{,}2; d_E = 0{,}1$ m

Unknown d_L

Formula $d_L = \frac{d_E}{MA}$

$= \frac{0{,}1}{0{,}2}$ (substitute)

$= 0{,}5$ m

∴ You will be able to reach coals 0,5 m away.

Activity 4 Calculate the length of the load arm or effort arm in a lever if the MA is given

1. Calculate the unknown quantity in the following levers. In each case say which type/s of lever it can be.

a) d_E where $MA = 0{,}4; d_L = 0{,}6$ m

b) d_L where $MA = 0{,}8; d_E = 1{,}33$ m

c) d_E where $MA = 3{,}5; d_L = 0{,}25$ m

d) d_L where $MA = 1{,}2; d_E = 1{,}33$ m

2. In a mechanism in a brass clock, the effort arm is 36 mm and $MA = 2$. What is the length of the load arm?

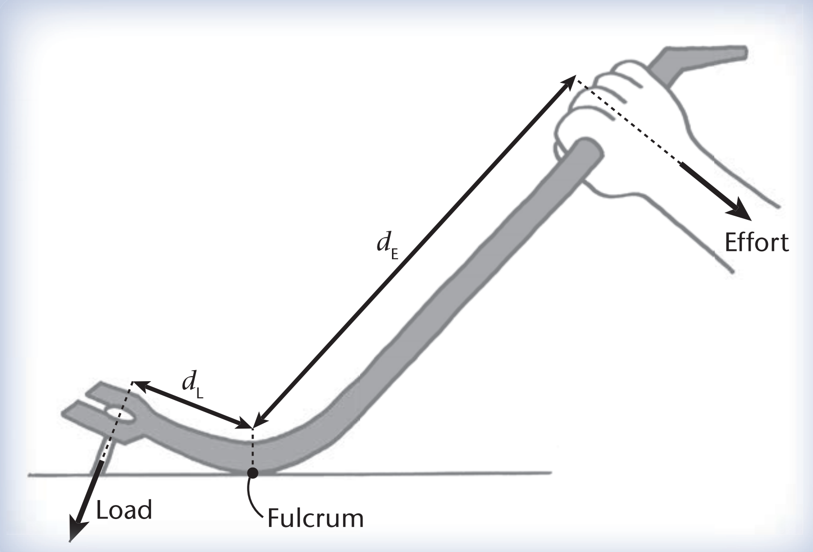
3. In another mechanism of the same clock, where the MA is 0,5, the load arm is 18 mm. What is the length of the effort arm?

4. You are designing a winch to haul water out of a well. Your granny will operate the winch and she will be able to rotate the handle of the winch with a force of 40 N only. If a pail of water weighs 100 N and the drum of the winch has a radius of 0,1 m, what must be the minimum length of the crank of the drum?

Worked examples: Using $MA = \frac{F_L}{F_E}$ and $MA = \frac{d_E}{d_L}$

1. In Figure 6.15 below, a crowbar is being used to remove a big nail from a thick plank of wood.

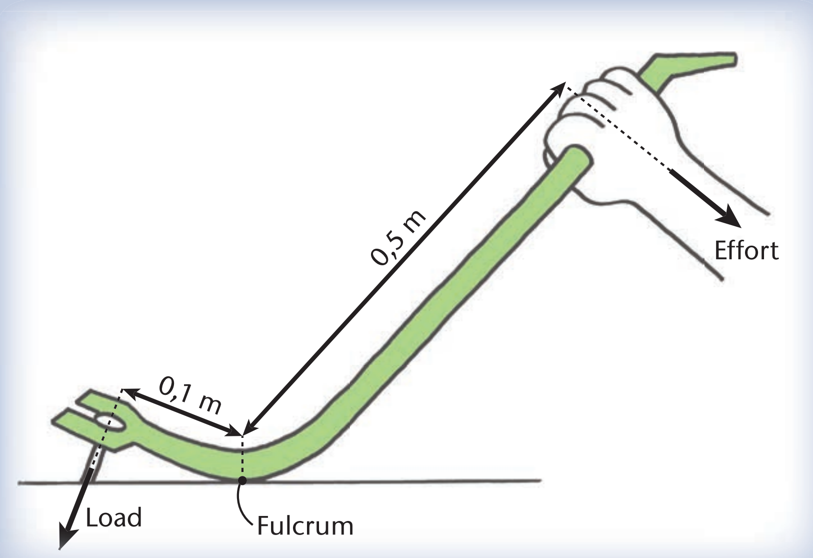
Figure 6.15 *The crowbar gives a mechanical advantage (MA).*



The mechanical advantage of a crowbar depends on the length of the load arm (d_L) and the length of the effort arm (d_E) for the particular crowbar. It will be different for each crowbar.

For the green crowbar in Figure 6.16, d_L is 0,1 m and d_E is 0,5 m.

Figure 6.16 *The green crowbar*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 172 2016/01/05 3:17 PM

a) What is the MA for the green crowbar in Figure 6.16?

Solution

Given $d_L = 0{,}1$ m; $d_E = 0{,}5$ m

Unknown MA

Formula $MA = \frac{d_E}{d_L}$

$= \frac{0{,}5}{0{,}1}$ (substitute)

$= 5$

b) If the force required to pull a typical big nail out is 200 N (i.e. the load is 200 N), what effort must be applied to the green crowbar to remove the nail?

Solution

Given $MA = 5$; load = 200 N

Unknown effort

Formula effort = $\frac{\text{load}}{MA}$

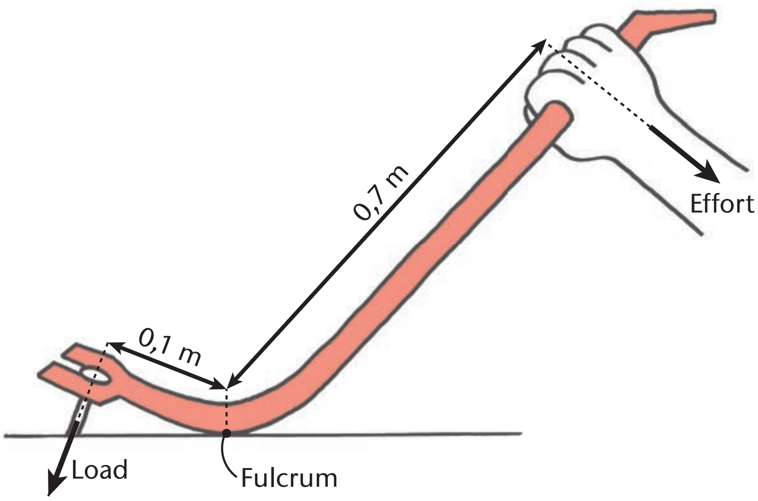
$= \frac{200}{5}$ (substitute)

$= 40$ N

Activity 5 Using $MA = \frac{F_L}{F_E}$ and $MA = \frac{d_E}{d_L}$

1. For the red crowbar in Figure 6.17, d_L is 0,1 m and d_E is 0,7 m.

Figure 6.17 *The red crowbar*



a) What is the MA for the red crowbar?

b) If you are able to apply only 50 N of effort, what force will you be able to exert on the nail by using the crowbar?

Experiment 5: Determine the mechanical advantage of a Type 1 lever

This is the third of ten experiments that will be assessed informally.

Work in groups of four to fulfill the aim of the experiment:

- Base your work on what you have done in this chapter.
- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Describe the experiment

We know that:

- The mechanical advantage of a lever can be calculated using the formulae:

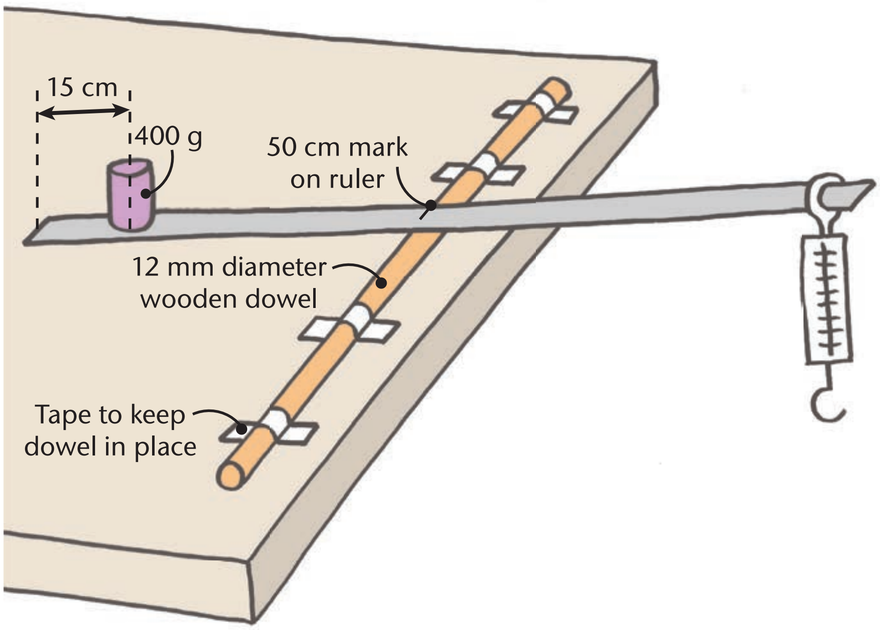
  $MA = \frac{F_L}{F_E}$ or $MA = \frac{d_E}{d_L}$.
- Mechanical advantage is determined at the point of equilibrium; that is at the point where the effort balances the load.

We aim to confirm that for a Type 1 lever in equilibrium, $\frac{F_L}{F_E} = \frac{d_E}{d_L}$.

We will do this by showing that at the point of equilibrium, $\frac{F_L}{F_E} = \frac{d_E}{d_L}$ across a range of different values of F_L, F_E, d_E and d_L.

Plan the experiment

Figure 6.18 *The experimental set-up*



Apparatus

- ❑ a steady table
- ❑ metre rule
- ❑ 12 mm diameter wooden dowel or similar
- ❑ masking tape
- ❑ 400 g or similar mass piece
- ❑ 10 N spring balance

A. Tape the dowel firmly down at the edge of the table as in Figure 6.18.

B. Position the metre rule so that the 50 cm mark is directly over the dowel and position the 400 g mass piece so that it is centred on the 15 cm mark.

C. Hang the spring balance at the 95 cm mark.

D. Draw a copy of the table below in your workbook.

1	2	3	4	5	6	7	8
Reading	Position of balance on metre rule (cm)	d_E Length of effort arm (cm)	F_E Reading on scale (N)	d_L Length of load arm (cm)	F_L Weight of the 400 g mass piece (N)	$\frac{F_L}{F_E}$	$\frac{d_E}{d_L}$
1	95	95 – 50 = 45		35	4		
2	85			35	4		
3	75			35	4		
4	65			35	4		

Do the experiment

E. Hang the scale at the 95 cm point and check that the dowel is at the 50 cm mark and the mass piece is at the 15 cm mark.

F. Pull down the spring balance scale until the effort arm *just lifts* off the table and the metre rule is *in equilibrium*.

G. Read the spring balance scale and record the reading in Column 4.

H. Repeat steps E, F and G for each of the four positions in Column 2.

I. Complete the table.

Use the data to create information

J. Compare the values in Column 7 and Column 8 for each row of data.

K. If each of the pairs of numbers is "just about the same*", you have proved that for a Type 1 lever in equilibrium, $\frac{F_L}{F_E}$ is equal to the value of $\frac{d_E}{d_L}$.

L. If the pairs of numbers are not "just about the same", then the theory is wrong or there is something wrong with the experiment. Which do you think it is?

> ***Experimental error:** When you do an experiment, because the equipment and the conditions are not perfect and because the people doing the experiment might not be careful enough, experimental errors creep in. So experimenters, such as us, have to develop judgement about what is an acceptable experimental error.

Draw a conclusion

Describe, in a written sentence, how the information that you have created confirms the concept that you set out to prove.

Recommend improvements

Think about the experiment and write down suggestions on how to do it better.

Chapter Summary

- Machines make a physical job easier by changing the magnitude of the input force needed to do the work. A lever is a simple machine.
- There are three types of levers: Type 1, Type 2 and Type 3. Refer to Table 6.1 to:
  - describe the positions of the fulcrum, load and effort
  - state if a lever gives a mechanical advantage (MA) of > 1, or = 1, or < 1
  - give examples of devices that use the different types of levers
- All levers have three things in common:
  - a fulcrum, which is the point round which the lever rotates
  - an effort (input), which is applied to the lever by the person using the lever
  - a load (output), which the person using the lever intends to overcome or balance by using the lever
- We use the Law of Moments to analyse a lever in equilibrium: $M_{\mathrm{CW}} = M_{\mathrm{ACW}}$.
- When we work with levers, we can define mechanical advantage in two different ways:
  - MA is the ratio of the load to the effort: $MA = \frac{F_{\mathrm{L}}}{F_{\mathrm{E}}}$.
  - MA is the ratio of the length of the effort arm to the length of the load arm: $MA = \frac{d_{\mathrm{E}}}{d_{\mathrm{L}}}$.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 176 2016/01/05 3:18 PM

Challenges and projects

1. Lift a lathe with a lever

Record this in your workbook.

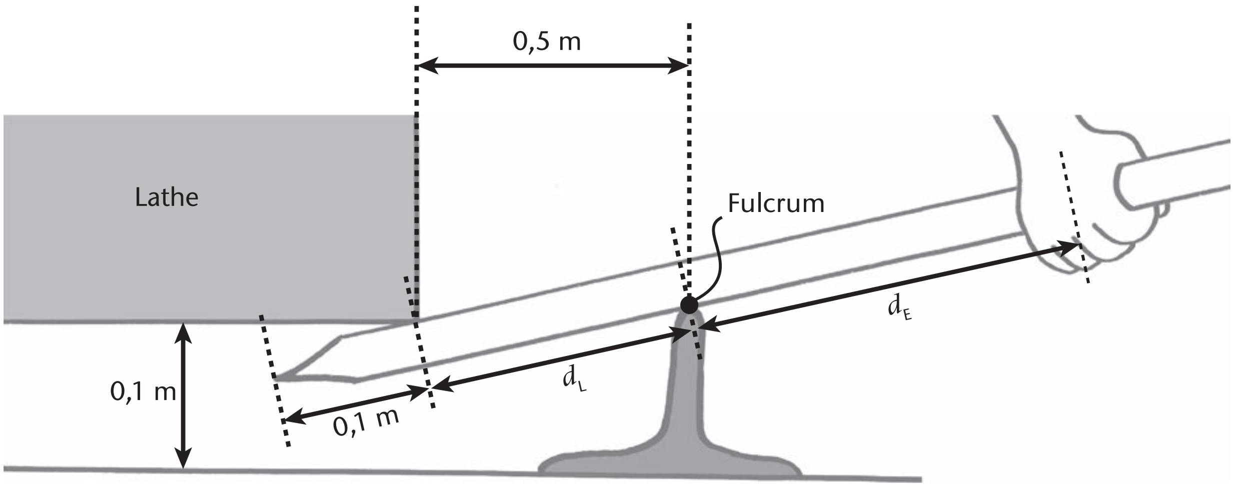
A tall lathe operator has back problems from leaning over a low lathe, so the lathe will have to be raised using a block of hard wood under each corner. The blocks will be inserted by lifting one end of the lathe at a time.

Just two maintenance workers are available to do the job, so one will use a lever to raise the lathe, while the other inserts the blocks. Have a look at Figure 6.19.

Specifications:

- The blocks of wood are 10 cm high.
- The machine weighs 4 000 N, so a force of 2 000 N is needed to lift one end.
- The lever is a 2,5 m long piece of 32 mm reinforcing steel bar; the fulcrum is a length of steel T-section.

Figure 6.19 *The lever and the lathe*



Questions

a) If d_L = 0,5 m and d_E = 1,5 m, what force will be needed on the lever?

b) The larger worker weighs 650 N. Will she be able to push the lever down? If not, suggest where the fulcrum should be moved to so that they can get the job done.

2. The cost of mechanical advantage

The law of the conservation of energy says that if you gain a mechanical advantage, it will cost you something else. For example, if the advantage you gain is a greater output force, you will have to apply the input force over a greater distance.

So, there is a price to pay for gaining a mechanical advantage greater than 1.

Imagine that you have a lever which gives you an MA greater than one. The MA enables you to move a greater load. The price you pay is having to apply the input force through greater distance.

The greater the mechanical advantage, the greater the movement of the input force.

Example: The cost of mechanical advantage

If the MA is 4, the effort has to move a distance 4 times the distance that the load moves:

- If you need to move the load 10 cm, your hands have to move 40 cm.
- If you need to move the load 2 cm, your hands have to move 8 cm.

Task: The cost of mechanical advantage

Use **Challenge 1: Lift a lathe with a lever** as your context and draw a picture to show that when a simple machine gives a mechanical advantage greater than 1, the effort has to move through a greater distance than the load.

CHAPTER 7 Energy

Part of this course is based on what you learnt about energy in Natural Sciences, including the following:

- **Forms of energy**: potential energy and kinetic energy
  Potential energy can take various forms, such as gravitational potential energy, strain energy and chemical energy.
- **Energy in transfer**: electrical energy, heat energy, light energy and sound energy

You can summarise what you learnt about energy in Natural Sciences with a simple statement: **Energy is needed for life and to make things work**.

We will study forms of energy in this chapter, and we will study temperature, heat and energy in transfer in Chapter 16 on Heat and Thermodynamics.

Unit 7.1 Gravitational potential energy

Because of the force of gravity, everything on Earth has weight – a boat on the sea, the international space station orbiting the Earth, a particle of gas – everything that you can see or cannot see has weight!

Because an object has weight (and mass), it takes energy to lift it up. As an object is lifted up from one position to a higher position, the energy that is used to lift it up is transferred to the object. The object gains energy as it is lifted up.

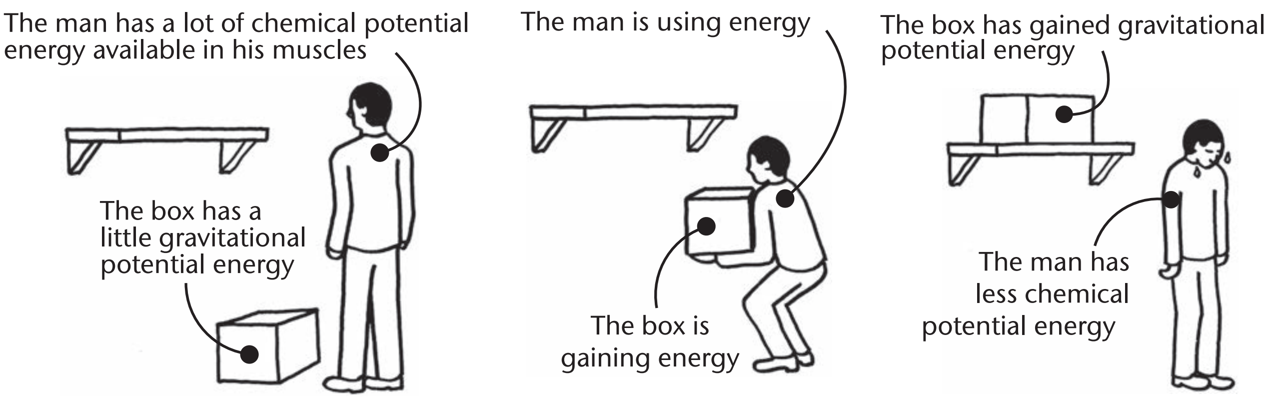
The energy that an object gains as it is physically lifted up from one position to a higher position is **gravitational potential energy**.

Definition: The gravitational potential energy of an object is the energy it has because of its position in the gravitational field.

The description "gravitational potential" is full of meaning.

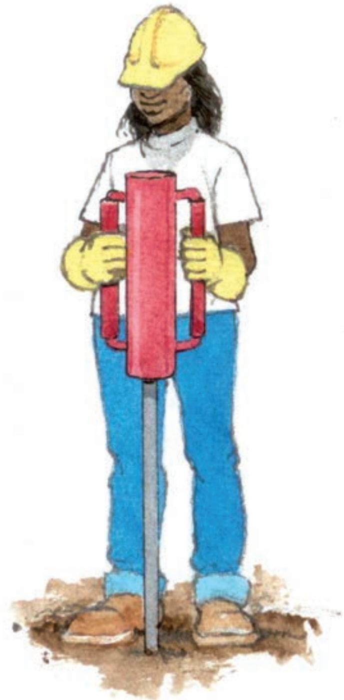
- The word "gravitational" shows that the energy is **the result of the gravitational attraction of the Earth** for the object.
- The word "potential" shows that the **energy can be used later to do work**.

Figure 7.1



For example, the heavy head of the pole-driver in Figure 7.2 gains potential energy when it is lifted up. When the heavy head is dropped down, the energy of the head drives the pole into the ground.

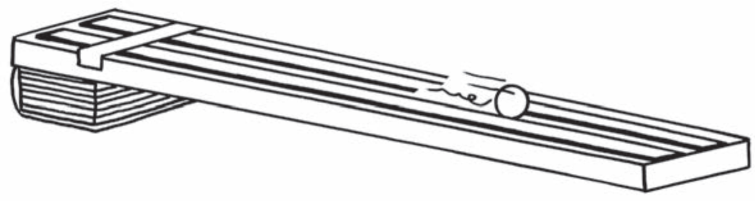
Figure 7.2 *The gravitational potential energy of the driver head when it is lifted up is used to drive the pole into the ground.*



Activity 1 Investigate the effect of height and mass when a ball rolls down a ramp

In this investigation, balls will roll down a ramp and across a smooth, level floor. You will investigate the effect of **(a)** the mass of the ball or **(b)** the height from which it is released, on the distance that the ball rolls.

Figure 7.3 *Investigate the effect of height and mass.*



Apparatus

- ❑ three steel balls (from recycled ball bearings), of different sizes (bigger than 8 mm in diameter) and of known mass
- ❑ a metre rule
- ❑ a plank and strips of card, or recycled curtain rail about 1 m long
- ❑ a few books

A. Divide the class into two groups, one to investigate the effect of mass and the other to investigate the effect of height. Your teacher will lead you through the investigations.

B. Do your investigation using the format given in the section on **How to do an investigation** in the Resource Pages.

C. Record all your information and results in a table.

D. Use the results of your experiment to draw a graph of one of the following:
- mass versus distance
- height versus distance

E. Based on your results and the information that your graph gives you, draw a conclusion that relates the distance that a ball rolls to the mass of the ball or the height from which it was released.

On the basis of the investigation, you will have concluded that the **distance** travelled by the ball depends on both of the following:

- the **height** from which the ball was released
- the **mass** of the ball

In this activity you followed a **scientific process**:

- You thought about the **problem**.
- You developed a **hypothesis**.

- You **tested** the hypothesis in an experiment.
- You drew a **conclusion**.

When you follow a scientific process in an investigation, you are doing good science.

Calculate gravitational potential energy.

The gravitational potential energy of an object is dependent on two variables:

- the mass of the object – the greater the mass, the greater its gravitational potential energy
- the height to which the object is raised – the higher the object is raised, the greater its gravitational potential energy

These two statements are combined in the formula for gravitational potential energy:

gravitational potential energy = mass × acceleration of gravity × height

or

$E_p = m\,g\,h$ or $U = m\,g\,h$

where:

- E_p or U is the symbol for gravitational potential energy measured in Joules (J)
- m is the symbol for the mass of the object measured in kilograms (kg)
- g is 9,8 m/s^2
- h is the symbol for the height of the object above a reference position measured in metres (m)

Figure 7.4

$E_p = m\,g\,h$

Potential energy (J)
Mass (kg)
Acceleration of gravity (m/s^2)
Height (m)

NOTE: The Joule (J) is the standard unit for the measurement of energy in the SI system.

Worked examples: Calculate gravitational potential energy

1. An object that has a mass of 4 kg is held 2 m above the ground. Calculate its gravitational potential energy relative to the ground.

Solution

Given	mass is 4 kg; height above ground is 2 m
Unknown	gravitational potential energy relative to the ground
Formula	$E_p = m\,g\,h$
	$= 4 \times 9{,}8 \times 2$ (substitute)
	$= 78{,}4$ J

2. An object that has a mass of 0,5 kg is held at shoulder height (1,5 m) out of a third floor window. The height between each floor is 3,3 m. Calculate the object's gravitational potential energy relative to the ground.

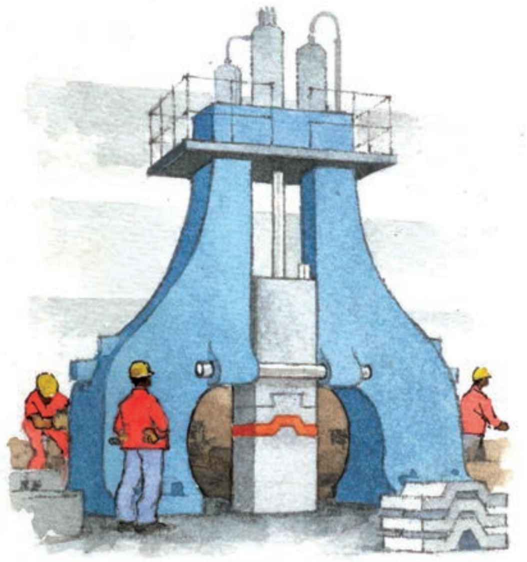
Solution

Given	mass is 0,5 kg; shoulder height is 1,5 m; 3 floors of 3,3 m
Unknown	gravitational potential energy relative to the ground
Formula	$E_p = m\,g\,h$
	$= 0{,}5 \times 9{,}8 \times (3 \times 3{,}3 + 1{,}5)$ (substitute)
	$= 55{,}9$ J

Activity 2 Calculate gravitational potential energy

1. An object that has a mass of 10 kg is held 0,5 m above a table. The table is 0,9 m high.
   - a) Calculate the object's gravitational potential energy relative to the table.
   - b) What is the object's gravitational potential energy relative to the floor?
   - c) Calculate the object's gravitational potential energy relative to the floor when it is on the table.
2. A ball is thrown up into the air. It reaches a height of 12 m. Its mass is 200 g.
   - a) Calculate the ball's gravitational potential energy as it reaches its highest point above the ground.
   - b) As the thrower leans back to throw the ball, his hand is 1 m above the ground. Calculate the ball's gravitational potential energy when it is 1 m above the ground.
   - c) Calculate the energy the thrower gives to the ball.
   - d) What is the ball's gravitational potential energy when it is on the ground?
3. One of the methods that a blacksmith uses to shape metal is drop-forging. You can see a drop forge in Figure 7.5. The red-hot metal in a mould is shaped when a heavy weight is dropped repeatedly onto the mould (also called a die).
   - a) What is the reasonable reference height (position of zero height) for the machine?
   - b) Calculate the potential energy of the 500 kg hammer when it is raised to its maximum of 2 m above the mould.
   - c) A delicate mould needs a maximum of 4 000 J per hammer blow to shape a small object. Calculate the maximum height to which the 500 kg hammer should be raised.

Figure 7.5 *A drop forge*



d) A certain machine operator prefers to use a smaller hammer raised to the top of the machine rather than a heavy hammer raised only part of the way. Calculate the mass of the hammer he would use in (c).

4. One hundred and twenty five 100 mm long nails need to be hammered into a long piece of pine to fix it to a pine rafter. There is little room to work, so all the carpenter will be able to do is lift the hammer and drop it. The hammer he will use weighs 4 kg and he will be able to raise it to a maximum of 300 mm above the head of the nail. On average a 100 mm nail requires 160 J of energy to drive it into pine.

a) Calculate the minimum number of times the carpenter must hit each nail.

b) Calculate the total energy he will expend doing the job.

c) The carpenter is a big guy, so he wants to use a hammer that is twice as heavy.

- Guess the number of hammer blows he will have to give each nail.
- Prove your guess by doing a calculation.

d) Criticise this question.

Zero height position

Definition: The zero height position is the reference position for a particular situation. It is the position at which the height is taken to be zero.

To be able to determine the gravitational potential energy of an object, a **zero height position** must be chosen.

- The ground surface is often taken as the position of zero height.
- In a classroom experiment involving gravitational potential energy, the desktop might be chosen as the zero height position.

Look at Figure 7.6a and Figure 7.6b. What zero height position would you choose for these two lifting devices?

Figure 7.6a *Mine headgear of an old mine*

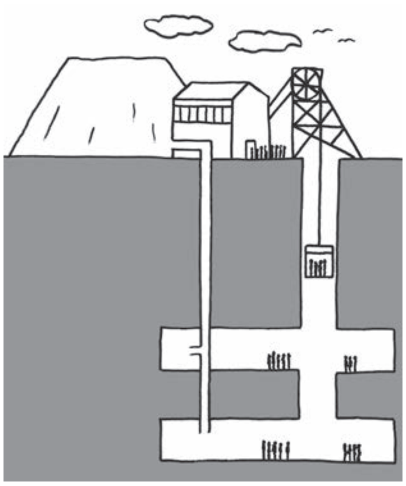


Figure 7.6b *An old-time builder with a crane on a tower*

Experiment 6: Determine the gravitational potential energy of an object at different heights

This is the fourth of ten experiments that will be assessed informally.

Work in groups of four to fulfill the aim of the experiment:

- Base your work on what you have done in this chapter.
- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Determine the gravitational potential energy of an object at different heights, by calculation and by investigation.

1. By calculation

Determine the gravitational potential energy of an object at different heights, by calculation. Use the formula: $E_p = m\,g\,h$

Calculate E_p for a mass of 1 kg for the heights in the table below:

Height (m)	Gravitational Potential Energy (J)
0,2	
0,4	
0,6	
0,8	

2. By investigation

You are required to determine the gravitational potential energy of an object at different heights, by investigation.

You will drop an object into sand from increasing heights. The impact of the object on the sand changes the shape of the surface of the sand.

The **aim** of this investigation is to measure the changed shape of the surface of the sand and relate it to the height from which the object is dropped.

- Do a few "trial" drops to observe the effect of the impact.
- Then plan and carry out the experiment.
- Draw a graph of the height (from which the object is dropped) versus the effect that you have measured.
- Test to see if your graph is useful.

Apparatus

- ❑ a wall and a level floor
- ❑ a large rigid bucket
- ❑ a bucketful of dry sifted sand
- ❑ an object to drop
- ❑ some flour to sprinkle onto the sand
- ❑ a 150 mm plastic ruler
- ❑ a metre rule
- ❑ masking tape to stick on the wall
- ❑ marker pen to make height markings on the tape
- ❑ graph paper

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 184 2016/01/05 3:18 PM

Figure 7.7a *The effect of a ball dropping into sand in laboratory conditions*

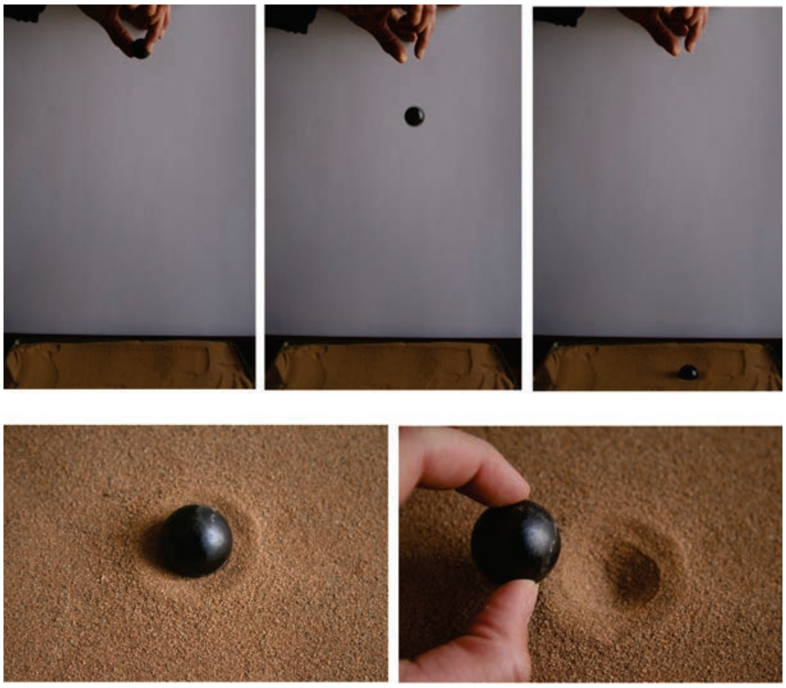
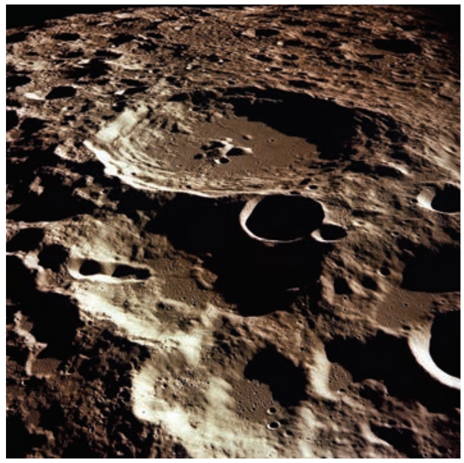


Figure 7.7b *The effect of asteroids crashing into the moon millions of years ago*



Describe the scientific problem

A. Write a focus question.

- The instructions will have raised a number of questions. Discuss and decide on the one question that your group is working together to answer.
- Write out the question using a full sentence.

B. Write your expected answer to the focus question. This is called your **hypothesis**.

- Do a few "trial" drops to observe the effect of the impact of the object on the sand.
- Describe in writing:
  - the effect that the impact has on the sand
  - how you expect the effect to change as the height increases
  - the measurement or measurements you will record after each drop

C. Plan an investigation.

- Write a list of the materials, equipment or other resources that you will need.
- Write down what you intend to do – the steps you need to take. This is called the **method**.
  - Write the steps in the order that you will do them, and number the steps.
  - Use short phrases to describe the steps.
- Draw up a table for the results.
- Decide what type of graph you will use to represent the data in the table.

D. Do the investigation.

- Do the investigation in the way you planned it.
- Record the results in the table.
- Draw the graph on graph paper.
- Test your graph:
  - Choose a height, somewhere in the middle of the range of your graph, and drop the object from that height.
  - Measure the effect and check whether your graph predicts a similar measurement.

E. Draw a conclusion.

Write one sentence or more that describes how the information that you have created (the information you can get off the graph) answers or does not answer the focus question.

F. Recommend improvements.

Think about the whole investigation and suggest, in writing, how to do it better.

Unit 7.2 Kinetic energy

Kinetic* energy is the energy of motion. An object that is in motion has kinetic energy.

> * **kinetic** (adj.) – this word comes from the Greek word *kinesis* which means motion or movement

Definition: Kinetic energy is the energy of an object due to its motion.

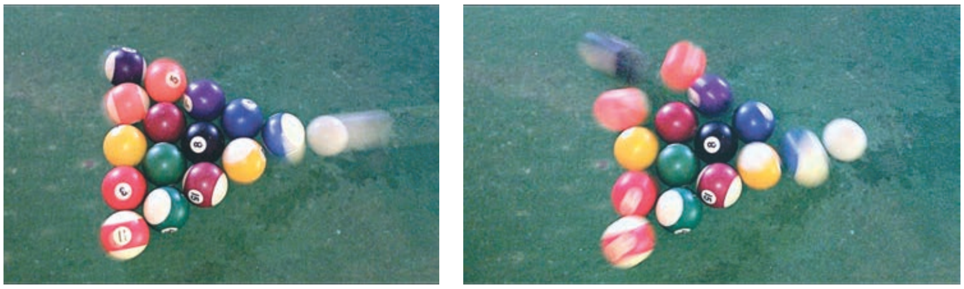
Examples of kinetic energy

Example 1

At the start of a game of snooker all the balls except the white ball are arranged in a triangle on the table, as seen in Figure 7.8a. The white ball is hit hard at the triangle of balls to break it up and spread the balls around. **It is the kinetic energy of the white ball that breaks the group up**: the kinetic energy of the white ball is shared amongst the others and they move to new positions.

Figure 7.8a *The kinetic energy of the white ball breaks up the triangle.*

Figure 7.8b *These pictures were taken a few milliseconds apart. Compare the movement of the balls at the corners of the triangles. Do the balls in the middle move?*



Example 2

The height that the skateboarder in Figure 7.9 reaches depends on his kinetic energy when he hits the bottom of the ramp. If he is going slowly, his kinetic energy will be low and he will not go high up the ramp. If he is going very fast, kinetic energy may carry him into the air above the ramp.

Figure 7.9 *The faster the skate-boarder approaches the ramp, the higher he will go.*

Forms of kinetic energy

There are different forms of kinetic energy, including:

- energy of translational motion (from one position to another)
- energy of vibrational motion (the atoms in a solid)
- energy of rotational motion (in engines, wheels, wind-generators, etc.)

Figure 7.10 *The soccer ball has translational energy.*

Figure 7.11 *The atoms of a solid have vibrational energy.*

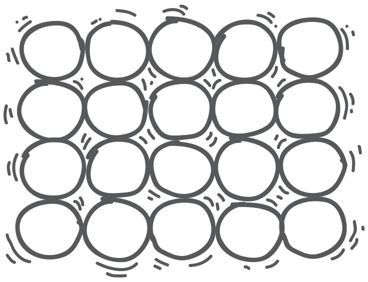


Figure 7.12 *The blades and rotor of a giant wind generator have rotational energy.*

Activity 3 The distance that a ball will roll is related to its initial speed

A. Raise one end of the runway about 4 cm off the floor. Release the ball from the top of the runway and let it roll down.

B. Observe (don't measure) how fast it goes at the bottom of the runway, and how far it rolls.

C. Repeat steps A and B for heights of 6 cm, 8 cm, 10 cm and 12 cm.

D. Discuss and describe in writing: the relationship of the speed of the ball at the bottom of the runway to the distance that the ball rolls.

Apparatus

- ❑ a smooth floor
- ❑ a ball
- ❑ a runway – a plank or piece of curtain railing
- ❑ a pile of thin books

On the basis of the observations you made, you probably realised that the distance rolled by the ball depends on its speed at the bottom of the board.

Calculate kinetic energy

If we look back at previous activities we can say:

- The greater the mass of a rolling ball, the further it will roll.
- The faster a ball is rolling at a certain point, the further it will roll beyond that point.

Scientists would express our rough ideas in terms of kinetic energy:

- The greater the mass of a moving object, the greater its kinetic energy.
- The greater the speed of a moving object, the greater its kinetic energy.

These two physical quantities of mass and speed are combined in the formula for the kinetic energy of an object:

$$E_k = \frac{1}{2} m v^2$$

Figure 7.13

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

Kinetic energy (J) Mass (kg) Speed (m/s)

where:

- E_k is the symbol for the kinetic energy of the object in joules (J)
- m is the symbol for the mass of the object in kilograms (kg)
- v is the symbol for the speed of the object in metres per second (m/s)

NOTE: The unit for kinetic energy is the same as the unit for potential energy: the Joule (J).

Worked examples: Calculate kinetic energy

1. An object with a mass of 12 kg is travelling at a speed of 3 m/s. What is its kinetic energy?

Solution

Given	m is 12 kg; v is 3 m/s
Unknown	E_k
Formula	$E_k = \frac{1}{2} m v^2$

$$= \frac{1}{2} \times 12 \times 3^2 \qquad \text{(substitute)}$$

$$= 54 \text{ J}$$

2. If an object with a mass of 1,5 kg has kinetic energy of 14,3 J what is its speed?

Solution

Given	m is 12 kg; E_k is 14,3 J
Unknown	v
Formula	$E_k = \frac{1}{2} m v^2$

$$v = \sqrt{\frac{2E_k}{m}} \qquad \text{(change the subject)}$$

$$= \sqrt{\frac{2 \times 14{,}3}{12}} \qquad \text{(substitute)}$$

$$= 1{,}54 \text{ m/s}$$

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 188 2016/01/05 3:18 PM

3. If an object with a speed of 23 cm/s has kinetic energy of 0,5 J what is its mass?

Solution

Given v is 23 cm/s; E_k is 0,5 J

Unknown m

Formula $E_k = \frac{1}{2} m v^2$

$m = \frac{2E_k}{v^2}$ (change the subject)

$= \frac{2 \times 0,5}{0,23^2}$ (substitute)

$= 18,9$ kg

Activity 4 Calculate kinetic energy

1. a) An object weighing 10 kg is travelling at 10 m/s. Calculate its kinetic energy.
   b) An object weighing 1 g is travelling at 100 m/s. Calculate its kinetic energy.
   c) An object weighing 100 g is travelling at 1 m/s. Calculate its kinetic energy.
   d) Compare your answers for 1b) and 1c).
2. In the workshop, an apprentice is able to hit a horizontal steel pin with a 4 kg mallet at a speed of 9,3 m/s. Calculate the kinetic energy of the mallet just before it hits the pin.
3. A Formula 1 racing car that has a mass of 700 kg reaches 300 km/h down the back straight. A mine truck weighs 70 000 kg (100 × greater) and travels at 30 km per hour (10 × slower). Which has the greater kinetic energy?
4. a) Your friend, who weighs 60 kg, walks into a door at 2 m/s. She gets hurt because her body has to absorb the kinetic energy. Calculate her kinetic energy as she hits the door.
   b) A small car, which weighs 1 000 kg, hits a brick wall at 60 km/h. Calculate the car's kinetic energy just before it hits the wall.
   c) Walking into a door is bad enough. What is the ratio of the numbers you have just calculated? Think about it and think about a possible result of driving too fast.
5. a) When Siphiwe Tshabala scored the opening goal for Bafana Bafana in the 2010 world cup, he was flying – it was a perfect strike. The 0,45 kg ball left his foot at 30 m/s. Calculate the ball's kinetic energy as it left his foot.
   b) A fifteen year old player set up an experiment to determine how fast he could kick the ball. He was disappointed to measure only 15 m/s with the same type of ball. Calculate the kinetic energy of the ball that came off the boy's foot.
   c) Explain why Tshabalala's strike, which gave the ball just twice the speed the boy gave it, gave it many times more kinetic energy.

6. **a)** When Protea cricketer JP Duminy hit a ball over the boundary in the 2015 World Cup, the ball left his bat at 22 m/s. The ball weighed 0,16 kg. Calculate the kinetic energy of the ball just after JP hit it.

b) In the same game, Protea cricketer Vernon Philander bowled a ball which left his hand with a kinetic energy of 122 Joules. Calculate the speed at which the ball left his hand.

c) The opposition batsman missed the ball Philander bowled, and by the time it reached the wicketkeeper its speed had reduced by 50%. Calculate the ball's kinetic energy when the wicketkeeper caught it.

Unit 7.3 Mechanical energy

We have studied gravitational potential energy and kinetic energy separately. We bring these two concepts together in the concept of mechanical energy.

Definition: Mechanical energy is the sum of the kinetic energy and gravitational potential energy of an object.

The formula for mechanical energy

Mechanical energy is the total energy of an object due to its motion and its position. If you add together the energy of motion and the energy of position of an object, you get its mechanical energy.

$$E_M = E_p + E_k$$

where:

- E_M is the symbol for mechanical energy measured in Joules (J)
- E_p is the symbol for gravitational potential energy measured in Joules (J)
- E_k is the symbol for kinetic energy measured in Joules (J)

Figure 7.14

$$E_M = E_p + E_k$$

Mechanical energy (J)

Gravitational potential energy (J)

Kinetic energy (J)

Worked examples: Calculate mechanical energy

1. If a moving object has gravitational potential energy of 20 J and kinetic energy of 30 J, what is its mechanical energy?

Solution

Given E_p is 20 J; E_k is 30 J

Unknown E_M

Formula $E_M = E_p + E_k$

$= 20 + 30$ (substitute)

$= 50$ J

2. If the mechanical energy of an object is 10,5 J and its gravitational potential energy is 3,2 J what is its kinetic energy?

Solution

Given E_p is 3,2 J; E_M is 10,5 J

Unknown E_k

Formula $E_M = E_p + E_k$

$E_k = E_M - E_p$ (change the subject)

$= 10{,}5 - 3{,}2$ (substitute)

$= 7{,}3$ J

3. A moving object has a mechanical energy of 100 J. Its mass is 1 kg and its height is 5 m. What is its speed?

Solution

Given E_M is 100 J; m is 1 kg; h is 5 m

Unknown E_p, E_k and v

Formula for E_p $E_p = m\,g\,h$

$= 1 \times 9{,}8 \times 5$

$= 49$ J (substitute)

Formula for E_k $E_k = E_M - E_p$

$= 100 - 49$

$= 51$ J (substitute)

Formula for v $v = \sqrt{\frac{2E_k}{m}}$

$= \sqrt{\frac{2 \times 51}{1}}$ (substitute)

$= 10{,}1$ m/s

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 191 2016/01/05 3:18 PM

4. A falling object that has a mass of 0,7 kg has kinetic energy of 0,6 J and mechanical energy of 1,1 J. What is its speed and height?

Solution

Given E_M is 1,1 J; m is 0,7 kg; E_k is 0,6 J

Unknown v, E_p and h

Formula for v

$$v = \sqrt{\frac{2E_k}{m}}$$

$$= \sqrt{\frac{2 \times 0{,}6}{0{,}7}} \quad \text{(substitute)}$$

$$= \sqrt{1{,}71}$$

$$= 1{,}31 \text{ m/s}$$

Formula for E_P

$$E_p = E_M - E_k$$

$$= 1{,}1 - 0{,}6 \quad \text{(substitute)}$$

$$= 0{,}5 \text{ J}$$

Formula for h

$$h = \frac{E_P}{mg}$$

$$= \frac{0{,}5}{0{,}7 \times 9{,}8} \quad \text{(substitute)}$$

$$= 0{,}07 \text{ m}$$

Activity 5 Calculate mechanical energy

Do this activity in pairs.

1. A moving object has gravitational potential energy of 30 J and kinetic energy of 40 J. Calculate its mechanical energy.
2. The mechanical energy of an object is 11,5 J and its gravitational potential energy is 4,2 J. Calculate its kinetic energy.
3. The mechanical energy of an object is 111,5 J and its kinetic energy is 44,2 J. Calculate its gravitational potential energy.
4. A moving object has a mechanical energy of 400 J. Its mass is 6 kg and its height is 4 m. Calculate its speed.
5. A moving object with a mass of 0,5 kg has kinetic energy of 0,8 J and mechanical energy of 1,5 J. Calculate its speed and height.
6. a) A dart has gravitational potential energy of 1,5 J and kinetic energy of 5 J just before it hits the dartboard . Calculate its mechanical energy.
   b) The mass of the dart is 0,1 kg. Calculate its height and speed.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 192 2016/01/05 3:18 PM

7. Theo Ngubane represented South Africa at the world downhill racing championship for the first time in 2013. At times his mountain bike reaches a speed of 60 km/h down a rough single track and on some jumps his wheels are 1,5 m off the ground. Theo has a mass of 62 kg and his bike weighs 12 kg.
   a) At a jump on a level section, Theo reached a height of 1,2 m above the ground. Calculate the gravitational potential energy of Theo and his bike at the highest point.
   b) Theo's horizontal speed at the top of the jump was 35 km/h. Calculate his kinetic energy at that point.

Figure 7.15 *A competitor in a cross-country mountain biking competition*

8. In a small town north of Merweville in the Karoo it is a tradition for the foreman on a building site to throw the last brick up to the bricklayer. A Merweville brick has a mass of 4 kg.

   The highest brick ever caught in the town left the foreman's hand 1,8 m above the ground at a speed of 12,2 m/s.
   a) Calculate the kinetic energy with which the brick left the foreman's hand.
   b) The bricklayer caught the brick at its highest point, so its velocity was 0 m/s as he caught it. Calculate the height at which the bricklayer caught the brick.

The conservation of energy (Extension)

Our understanding of mechanical energy is based on the law that energy cannot be created or destroyed, it can only be changed from one form to another.

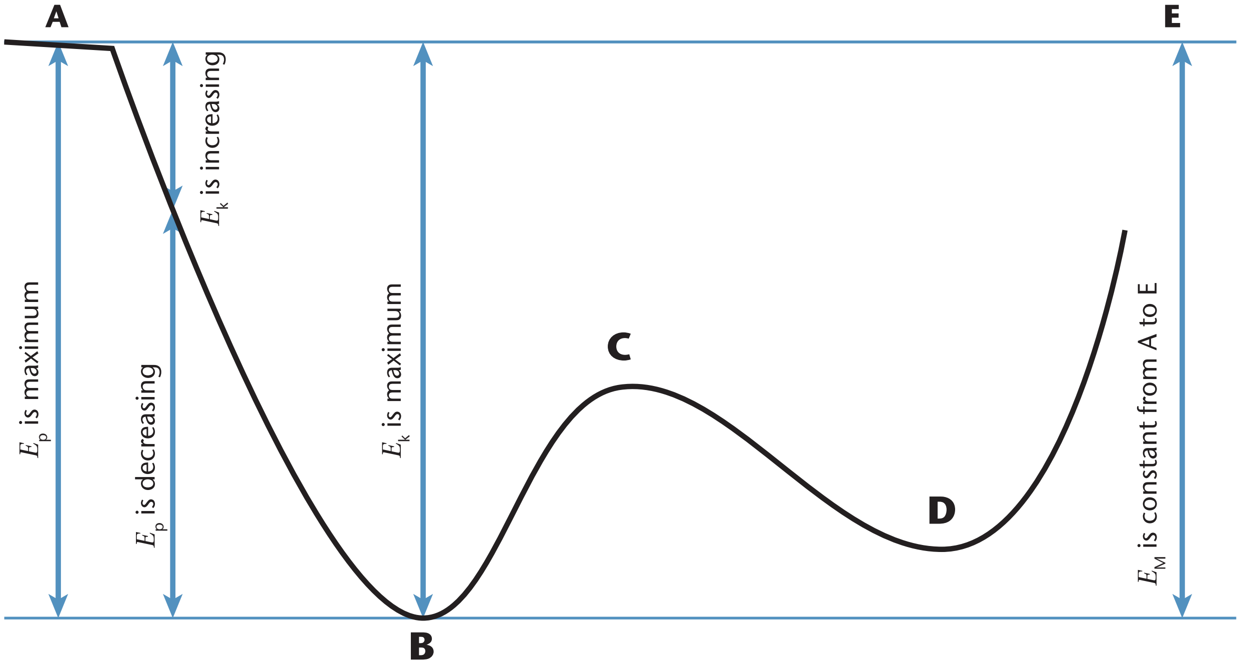
In this work we assume ideal conditions: there is no air resistance and no friction. So the mechanical energy in the system remains constant.

For example: Figure 7.16 on the next page represents a skateboarder who is doing an extreme skating course.

- When she stands at A, she has maximum gravitational potential energy and maximum mechanical energy.
- As she moves from A to B, her gravitational potential energy deceases and her kinetic energy increases but her mechanical energy stays the same.
- As she moves from B to C, her gravitational potential energy increases and her kinetic energy decreases but her mechanical energy stays the same.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 193 2016/01/05 3:18 PM

Figure 7.16 *Energy of the skateboarder*



Activity 6 Conservation of energy calculations

In Figure 7.16 above, the skateboarder has a mass of 62 kg and B is the height of zero potential.

Copy and complete the table below in your workbook.

Position	Height (m)	Gravitational potential energy (J)	Kinetic energy (J)	Mechanical energy (J)
A	8			
B	0			
C	3			
D	1			
E	8			

Mechanical energy does work (Extension)

Mechanical energy is also defined as the ability to do work.

Figure 7.17a *The ball has gained mechanical energy in the form of gravitational potential energy.*

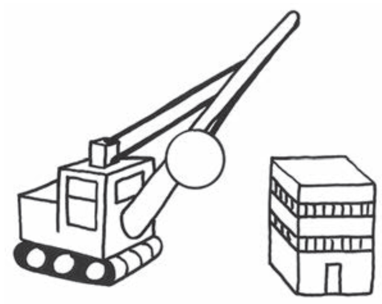


Figure 7.17b *The mechanical energy remains constant as the ball swings down: it is in the form of gravitational potential energy and kinetic energy.*

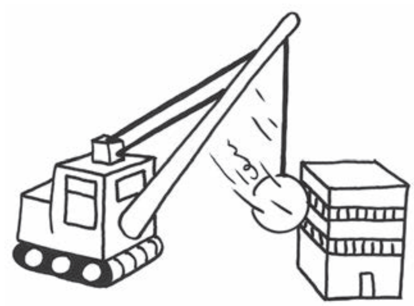


Figure 7.17c *With the same mechnical energy, now all in the form of kinetic energy, the ball smashes into the building.*

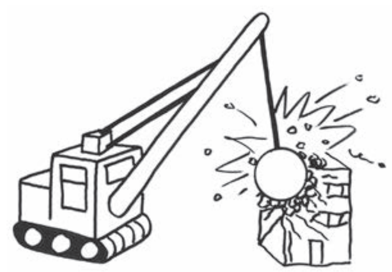
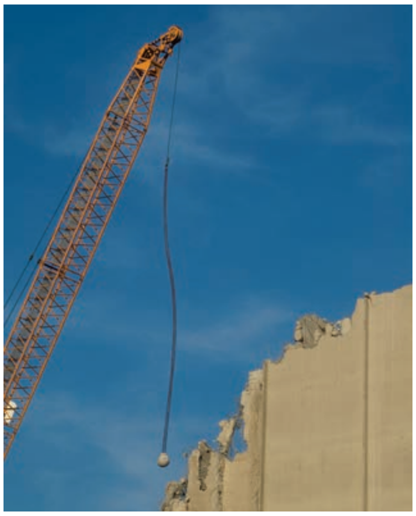


Figure 7.17d *The mechnical energy has been used to knock down the building.*

The steel ball of a demolition crane is able to knock a building down because of the mechanical energy (in the form of kinetic energy) of the ball.

- The ball is attached to two cables. It hangs from one cable and is pulled sideways and up by the other cable. As the ball is pulled it gets higher and higher, and its mechanical energy (in the form of gravitational potential energy) is increased.
- When the ball is as high as necessary, the cable is released and the ball swings down towards the building. As it swings down its mechanical energy stays constant, but its gravitational potential energy reduces and its kinetic energy increases. At the bottom of the swing, when the gravitational potential energy is the least and kinetic energy is at its greatest, the ball strikes the building.

Figure 7.18 *A demolition crane*

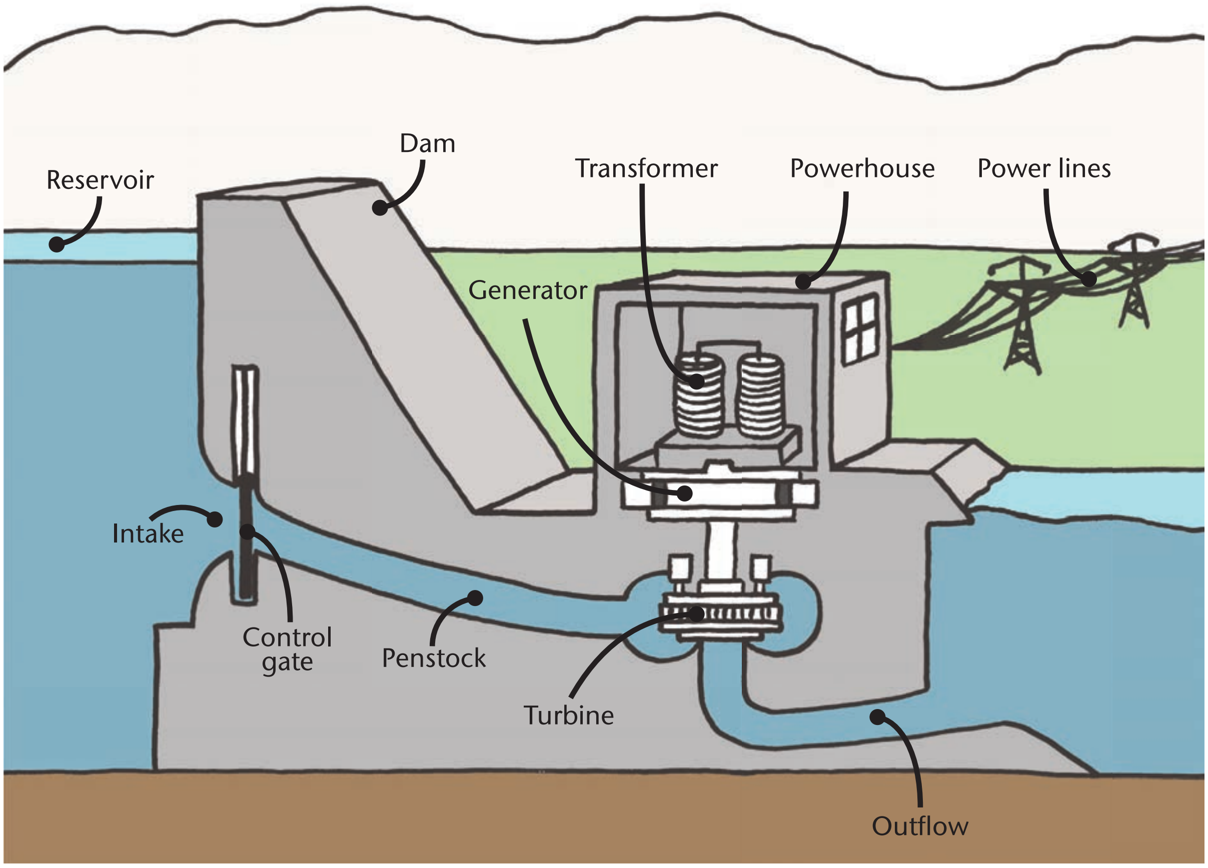


This is mechanical energy doing work. The mechanical energy that the ball had gained when it was lifted up is used to do the work of knocking down the building.

Activity 7 Mechanical energy is the ability to do work

Figure 7.19 shows a hydroelectric power station. The mechanical energy of the water is used to turn a turbine, which turns a generator, which produces electricity.

Figure 7.19 *Electricity is generated at a hydroelectric power station.*



Describe how the mechanical energy of water is used to do the work of turning the generators in a hydro-electric power station.

Chapter summary

- The energy an object gains as it is physically lifted up from one position to a higher position is gravitational potential energy. The gravitational potential energy of an object is the energy it has because of its position in the gravitational field.
- The gravitational potential energy of an object is dependent on:
  - the mass of the object: the greater the mass, the greater its gravitational potential energy
  - the height to which an object is raised: the higher it is raised, the greater its gravitational potential energy

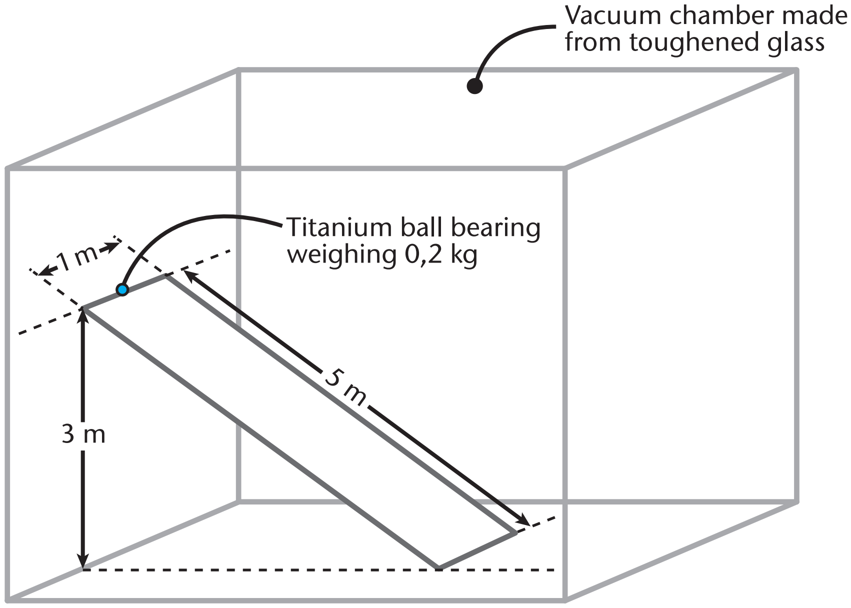
- The formula for gravitational potential energy: $E_p = m\,g\,h$ or $U = m\,g\,h$
  - E_p or U is the symbol for gravitational potential energy measured in Joules (J)
  - m is the symbol for the mass of the object measured in kilograms (kg)
  - g is 9,8 m/s^2
  - h is the symbol for the height of the object above a reference position measured in metres (m)
- The Joule (J) is the standard unit for energy in the SI system.
- The zero height position is the reference position for a particular situation. It is the position at which the height is zero.
- Kinetic energy is the energy of motion – an object that is in motion has kinetic energy. Kinetic energy is the energy of an object due to its motion.
- There are a few forms of kinetic energy:
  - energy of translational motion (from one position to another)
  - energy of vibrational motion (all atoms vibrate)
  - energy of rotational motion (in engines, motors, wheels, wind-generators, etc.)
- The physical quantities of mass and velocity are combined in the formula to determine the kinetic energy of an object: $E_k = \frac{1}{2} m\,v^2$
  - E_k is the symbol for the kinetic energy of the object in joules (J)
  - m is the symbol for the mass of the object in kilograms (kg)
  - v is the symbol for the speed of the object in metres per second (m/s)
- The concepts of potential energy and kinetic energy are brought together in the concept of mechanical energy.
- Mechanical energy is the sum of the kinetic energy and potential energy of an object: $E_M = E_p + E_k$
  - E_M is the symbol for mechanical energy measured in Joules (J)
  - E_p is the symbol for gravitational potential energy measured in Joules (J)
  - E_k is the symbol for kinetic energy measured in Joules (J)

Challenges and projects

Challenge 1: Roll balls from a height

An experiment is being done in a large glass vacuum chamber, so there is no air resistance. A titanium ball will roll down a sheet of titanium, so there will be **negligible** friction between the ball and the sheet to slow the ball down. Because there is no air resistance and no friction between the ball and the sheet, the mechanical energy will not change while the ball is in motion. A robot called Serena will perform the operation.

Figure 7.20 *The ideal physics laboratory*



Questions

1. What is the speed of the ball as it reaches the floor? To answer this you need to first answer the following questions:
   a) What is the gravitational potential energy of the ball when it is placed at the top of the slope?
   b) What is the mechanical energy when the ball is at the top of the slope?
   c) What will the gravitational potential energy of the ball be at the bottom of the slope, just before it hits the floor?
   d) What will the mechanical energy of the ball be at the bottom of the slope, just before it hits the floor?
   e) What will the kinetic energy of the ball be at the bottom of the slope, just before it hits the floor?
   f) What will the speed of the ball be at the bottom of the slope, just before it hits the floor?
2. If the problem in (1) was done again, with a ball that is exactly twice as heavy as the original ball, in what way would the answers to the above questions change?
3. In what way would the answers to the questions in (1) change if the titanium sheet was removed and the ball was allowed to fall freely to the floor?

Challenge 2: Draw graphs to illustrate the relationship between kinetic energy and mass, and kinetic energy and velocity

Investigate the statement: Kinetic energy is directly proportional to the mass of the object and is proportional to the square of the speed of the object.

CHAPTER 8 Properties of materials

In engineering and technology you are going to work with many different materials. You need two kinds of knowledge about materials.

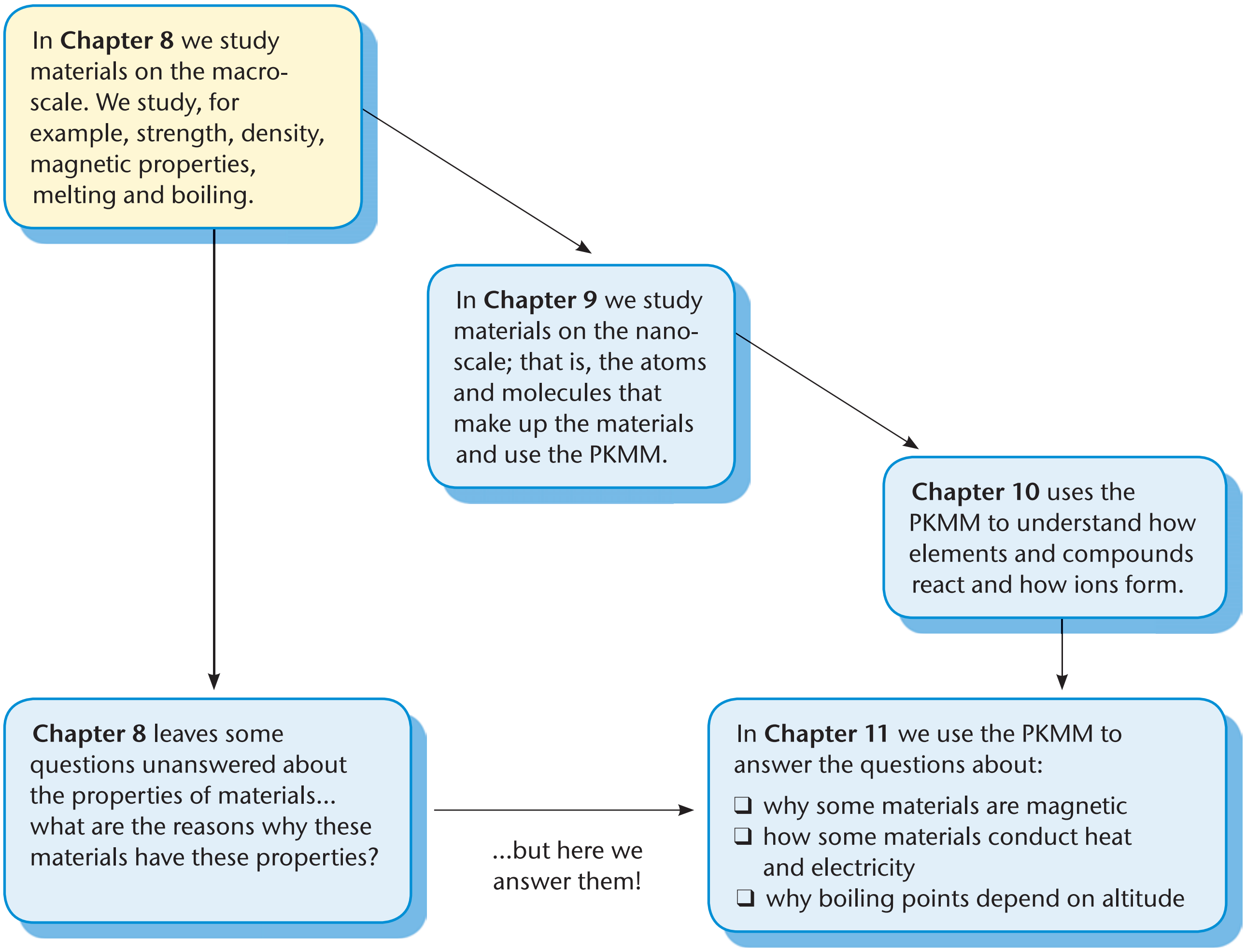
First, you have to know the **properties** of materials; that is to say, how you can choose them and use them, how you can change them, and how you can combine them.

Second, you have to know the **reasons** why materials have their properties. That is to say, you have to understand how their atoms behave.

The first kind of knowledge is about material on the **macro-scale**. “Macro” means big; you are going to study pieces of material that are big enough to hold in your hand or in a cup.

The second kind of knowledge is about the same materials but on the **nano-scale**. “Nano-scale” knowledge is knowledge about the atoms that make up materials. Atoms and most molecules are too small to see, even with a microscope. So we have to use a clever model that lets us work out how the particles behave – this model is called the Particle Kinetic Model of Matter (the PKMM).

Now here is a map to show where we are going in the next four chapters.



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 199 2016/01/05 3:18 PM

Unit 8.1 Strength of materials

Materials are the substances we choose for making things

Look at Figure 8.1. When you design something, you want to know about the properties of the materials you are going to use. For example, will the material be strong enough for the forces that will act on it? Will the material be a good heat insulator? Will the material break and shatter if you drop it? Will the materials be able to bend without breaking? What will happen to the material if it gets very hot? And if it gets very cold?

Figure 8.1 *Is it strong enough?*

Strength, **toughness**, **flexibility**, **insulation** – these are physical properties of materials.

There are some special words that we use for properties of materials:

Brittle means a material can be hard and strong, but it will break easily if it is hit or if you drop it on a hard surface. For example, glass is hard but *brittle*. A steel file is *brittle* and may crack if you drop it on the floor. On the other hand, some materials are not *brittle* at all: they are **tough**. For example, polyethylene tubing that is used for water-pipes is *tough*. You can hit it and bend it and it will not break.

Malleable means you can shape the material by hammering or pressing it, and it will not break. For example, sheet metal can be pressed into the shape of car body panels.

Ductile means that you can stretch the material into a wire. For example, copper and low-carbon steel are the materials from which wire is made. Aluminium strips that you see in window-frames are **extruded** from aluminium rods. To extrude means to squeeze the material through a die that gives it the shape you want.

How strong is a piece of material?

"Strong" has many meanings when we talk about materials. As you learned in Chapter 3, the strength of a piece of material is its ability to resist forces of compression, torsion, bending, shear and tension. Tension means stretching forces, and we are going to investigate strength in tension.

Engineering laboratories test the tensile strength of materials by slowly stretching a piece of the material, called a test **specimen***, in a big machine.

* **specimen –** a sample; a small piece of the material that is like all the rest of the material

Figure 8.2 shows you the machine that stretches the specimens. The jaws of the machine clamp the test specimen tightly and then they slowly move apart, stretching it. A force **gauge*** measures the stretching force on the specimen and distance gauges measure the length of the stretching.

In Figure 8.3 you see that, as the force increased, the specimen formed a neck at one point, the neck grew narrower, and then it fractured (broke) at that point.

Figure 8.2 *A machine that tests specimens of materials for tensile strength: the specimen gets clamped between the two sets of jaws.*

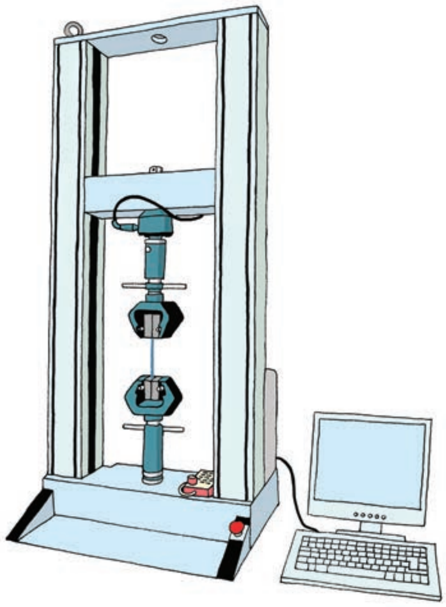


Figure 8.3 *This is a test specimen of steel. The bottom specimen is the specimen before the stretching test, and the top one is the specimen after the test. The narrow part is called a "neck", and that is where the steel broke. Notice the gauge marks on the specimen that show how much it stretched.*

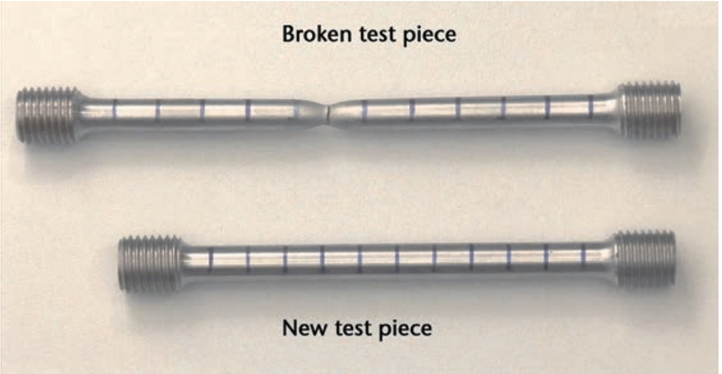


Photo by Rainer Schwab, University of Applied Sciences Karlsruhe, Germany, 2013.
This photo is part of a video on a tensile strength test:
https://www.youtube.com/watch?v=D8U4G5kcpcM

The video can help you to understand a tensile strength test better.
The video gives more detailed and advanced explanations and formulae than you need to know in this grade – you do not need to learn or understand all of that now.

The technologist plots a graph of the measurements on the test specimen; the graph compares the amount of stretch (this is called the strain) to the force on the specimen, per unit area of the cross-section (called the stress).

From such a graph, a trained person can tell you how this material will behave when forces act on it. The graph in Figure 8.4 on the next page tells a story – let's follow the story.

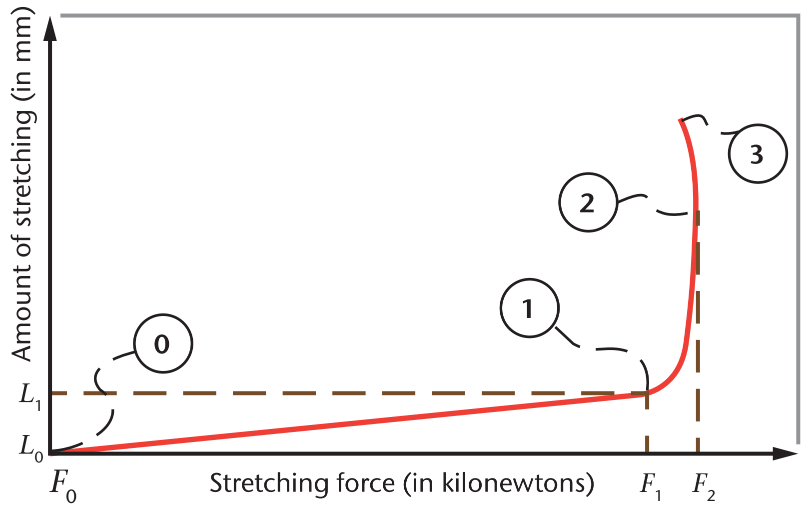
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 201 2016/01/05 3:18 PM

At point ⓪ there is no stretching force on the steel specimen and so it does not stretch – F is zero and the stretch is zero.

Now the force F increases to F_1 and the steel has stretched a little, from L_0 to L_1. We are at point ① on the graph. At this point, you could let the steel go, and it would jump back to its original length, like a very strong rubber band.

We say that the part of the graph between ⓪ and ① shows that this type of steel is **elastic**, up to force F_1.

Figure 8.4 *A graph of the stretching that is caused by the force*



Engineers draw the graph differently. Look at the stress-strain graph in the **Challenges and projects** section at the end of this chapter.

But if you continue to increase the stretching force from F_1 to F_2 (find F_2 on the graph) the steel begins to deform – it gets narrower and longer, and it carries on stretching.

Now you don't increase the force; you just keep holding the stretched steel with F_2 kilonewtons. We are at point F_2 on the graph. The steel keeps on stretching as its atoms begin to slide past each other.

Quick Activity:

How does the graph show you that the steel goes on stretching?

If you did not pull harder than F_2 , the steel would not break. A force just less than F_2 is the **maximum tensile strength** of this kind of steel.

Then at point ③ the steel fails, because the atoms of steel are sliding apart and can no longer hold together. It snaps with a loud bang and you see in Figure 8.3 what the specimen looks like now.

The fact that the steel began to change shape between points ① and ② on the graph tells us that the steel is **ductile*** – that is, it can change shape without breaking.

✻ **ductile** (adj.) – a ductile metal can be stretched out into a thin wire. You could not do this with a cylinder of concrete, because concrete is not *ductile*.

Activity 1 A tensile strength test of two materials

In this activity, you are going to model the kind of tensile strength test that is done in mechanical and civil engineering laboratories. Materials that technologists test include metals, plastics, wood, composites like kevlar and fibre-glass.

Look carefully at the test rig set-up in Figure 8.8 on the next page. That is what you are going to make.

Apparatus (per group)

- ❑ a small desk to act as a test rig. The desk must have broad rounded edges, not sharp edges.
- ❑ plastic sheet; the kind used for shopping bags
- ❑ copier paper or exercise book paper
- ❑ scissors for cutting the specimens
- ❑ packaging tape
- ❑ 2 nails or pencils
- ❑ string
- ❑ 2-litre milk bottle with a large opening cut near the top
- ❑ water; at least 2 litres
- ❑ a beaker to measure 100 ml

First, prepare the test specimens

A. From each of the paper and the plastic material, cut a strip about 30 cm long and 1 cm wide. Try to cut very straight strips, exactly 1 cm wide.

⚠ The edges of the strips must not have any tears or crooked cuts.

B. Choose one end of a strip to be the bottom, and lay it on parcel tape as you see in Figure 8.5. Put the pencil on the end of the plastic strip and bring the tape over and stick it down. Now your sample will look like Figure 8.6.

Figure 8.5 *Put the end of the specimen on the tape, and then put the dowel on top of the specimen.*

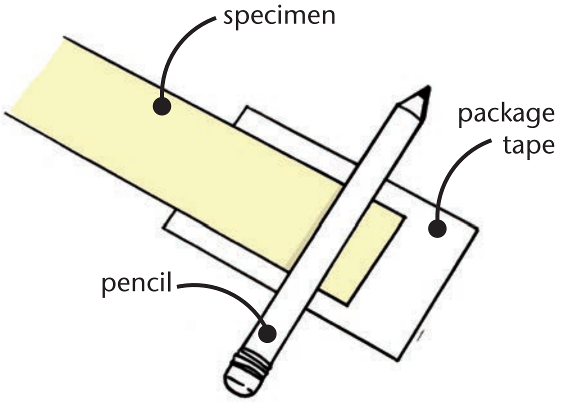
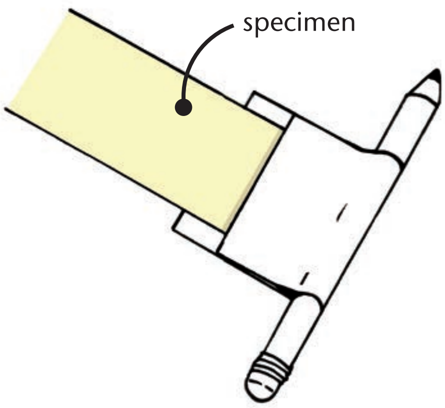


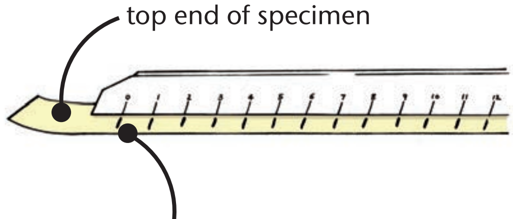
Figure 8.6 *Fold the tape over and stick it down. This gives you a strong part to hang the bucket on.*



Now you have to make some **gauge marks** to see where the specimen stretches the most.

C. Make a mark near the top of each specimen and then make 15 marks equal distances apart. To write on plastic, use a felt-tip pen.

Figure 8.7 *Make 15 gauge marks on the test specimen at equal distances.*



Prepare the table for recording the data

In your notebook, prepare a table that looks like this. Some of the values have been filled in for you already.

mass in grams	200 g	400 g	500 g	600 g	700 g	800 g	900 g	1 000 g	1 100 g	1 200 g
pulling force on the specimen	2 N	4 N	5 N	6 N						
starting position of the pencil	e.g. 155 mm	e.g. 157 mm								
amount of stretch in the plastic	0 mm	e.g. 2 mm								
starting position of the pencil	e.g. 140 mm	e.g. 140 mm	e.g. 140 mm							
amount of stretch in the paper	0 mm	0 mm								

Set up the test rig

D. Use parcel tape to fix the top end of the plastic specimen to the desk. The specimen must hang vertically (straight down).

⚠ The desk must not have a sharp edge under the specimen because it will break the specimen there.

E. Lift the small desk onto the teacher's table so that everyone can see it well.

F. Cut an opening in the front of the plastic milk bottle, so that you can easily pour water into it – see Figure 8.9.

Figure 8.8 *This is the test rig, with the paper specimen in position.*

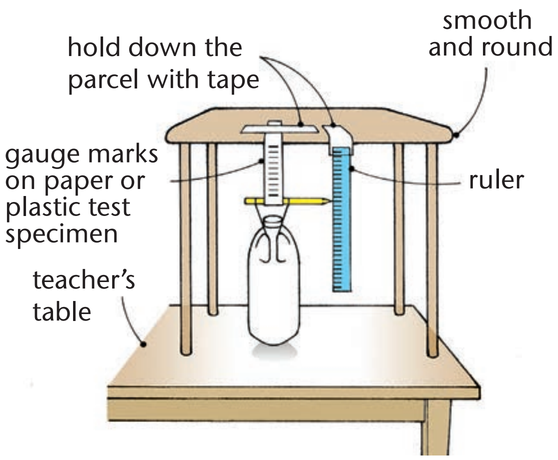
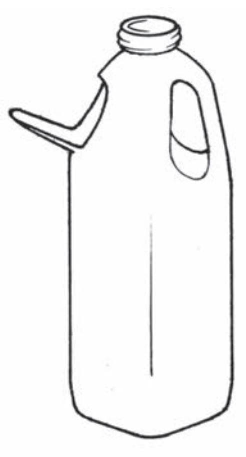


Figure 8.9 *Cut the milk bottle like this.*



G. Hang the plastic bottle on the pencil. The strings **must be equally spaced**, and next to the specimen. Make the strings long enough so that the bottle is close to the table and will not splash water when the specimen breaks.

H. Use tape to hang the ruler from the table. Record the starting position of the pencil against the ruler. For example, is the pencil point at 15,5 cm? If so, record 155 millimetres as the starting position.

I. Now add 200 millilitres of water to the bottle. The stretching force on the plastic sample is now 2 newtons. (The empty bottle weighs so little that we can ignore its weight.)

200 ml of water has a mass of 200 g.

J. Now go on adding water, 100 ml at a time. Each 100 ml adds a force of 1 newton to the force that is stretching the specimen. Keep count and record how many times 100 ml of water was added.

K. Observe the plastic specimen carefully – can you see anything changing?

L. Does the pencil point move down? In your table, record how much it has moved from the starting position.

M. When you reach 400 ml and 500 ml of water (4 N and 5 N force), lift the bottle and see whether the plastic strip goes back to its original length. If it does go back, you are still on the elastic part of the graph.

N. At a certain force, you will see the plastic stretching even though you are not adding weight. Look carefully at the place where it is stretching the most.

Then the plastic sample will break! If you made the bottle correctly, it will not spill the water.

O. Put the two pieces of plastic together so that the broken ends join. Are all the gauge marks still 1 cm apart?

P. Now take the paper specimen and repeat the procedure.

Q. After the paper fails, put the broken ends together and measure the total distance between the gauge marks.

Questions

1. Did you see the gauge marks moving further apart when you tested the plastic specimen?
2. After the plastic failed, what was the total distance between the top and the bottom gauge marks? (Was it still 150 mm?)
3. At the point where the plastic failed, is its width the same as before? Describe what you saw.
4. What was the maximum tensile strength of the plastic specimen? Your answer will be in newtons.
5. Did you see the gauge marks moving further apart when you tested the paper specimen?
6. After the paper failed, you measured the total distance between the gauge marks – was it still 150 mm?
7. What was the maximum tensile strength of the paper specimen? Your answer will be in newtons.
8. Draw a graph of the stretch amount as the pulling force increases, for the plastic specimen. On the same axes, draw a graph for the paper specimen. You should look at Figure 8.4 on page 202 to see what quantities to put on your axes.

What we have learned from Activity 1

You probably found that the paper hardly stretched at all, up to the point where it failed.

The plastic stretched at about 5 newtons but it could go back to its starting length if you lifted the bottle. So it was **elastic** when it was being stretched by forces of about 5 newtons or more. But when the force reached about 10 newtons, it began to stretch much more, and faster, and to get narrower in one part.

We say that the plastic is **ductile** – that is, it can stretch a certain amount without breaking. While it is stretching, it gives you some warning that it may break. On the other hand, paper is not ductile; that means it will break without warning.

All materials will fail (break) if the stress on them is great enough, and therefore engineers have to know about the stresses that materials can bear before they fail. In building and manufacturing, materials testing is an important industry. People's lives may depend on accurate knowledge about the strength of materials.

In Grade 12, you will learn much more about strain and stress on materials.

Unit 8.2 Density of materials

If you have done a painting job on a house, you will know how useful a ladder is. You need to move the ladder often, so if it were made of steel it would be strong but very heavy to move. Most ladders are made of aluminium and they are light enough to carry with one hand.

Figure 8.10 *A ladder made of aluminium is much easier to carry than a steel one.*

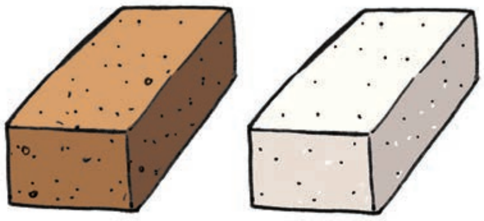
The size and structure of the steel ladder and the aluminium ladder could look the same, but the materials are different. They have different **densities**.

The density of a material is its heaviness-for-size. For example, think of a brick, **painted white**, and a block of polystyrene just the same size and shape as the brick. To look at the two objects, you could not tell which one is the brick. But if you picked them up, you would know at once.

Let's put heaviness-for-size into science language. We say that the density of the brick is its mass per unit volume; that is, the number of grams for every 1 cubic centimetre, or the number of g/cm^3.

The density of a common cement brick is about 2 g/cm^3 while the density of polystyrene foam is about 0,024 g/cm^3 – about 100 times less than the density of the brick!

Figure 8.11 *The brick and the polystyrene block have the same volume, but the brick has more mass than the polystyrene block. If the brick were painted white you could not tell them apart, unless you picked them up and felt their weight.*



Densities of some materials (all in grams per cm^3)	
❑ polystyrene	0,024
❑ petrol	0,72
❑ engine oil	0,88
❑ water at 4 °C	1,0
❑ aluminium	2,74
❑ steel	7,83
❑ lead	11,39
❑ gold	19,32
❑ platinum	21,30

Quick Activity:

How many polystyrene blocks would you need to make up the mass of one brick?

In the box next to Figure 8.11 you see the densities of some materials you might use or know. Notice that the box does not say how big each object is; the density is a property of the material and not of the object. So a big block of steel will have the same density as a small block of steel. (The big block will be heavier, of course!)

Calculate density

The density is the mass for every cm^3, so the density is the mass per cm^3.

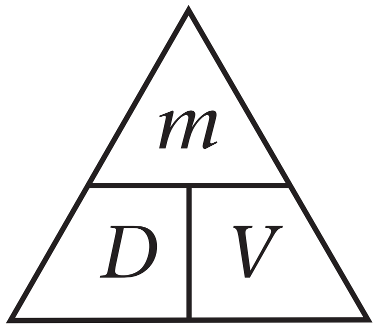
We can calculate density using the following formula:

$$D = \frac{m}{V}$$

where:

- D is density measured in grams per cubic centimeter (g/cm^3)
- m is mass measured in grams (g)
- V is volume measured in cubic centimetres (cm^3)

Figure 8.12 *Here is a way to remember the density ratios. To calculate density, cover the D with your finger and you will remember that $D = \frac{m}{V}$. Cover V, and you will remember that $V = \frac{m}{D}$.*



Worked examples: Calculate density

1. A block of aluminium has a volume of 300 cm³ and a mass of 822 g. Calculate its density.

Solution

Given volume = 300 cm³; mass = 822 g

Unknown density

Formula $D = \frac{m}{V}$

$= \frac{822}{300}$ (substitute)

$= 2{,}74\ \text{g/cm}^3$

2. What is the mass of 5 litres of petrol, not counting the container?

Solution

Given V = 5 litres = 5 000 millilitres = 5 000 cm³

density of petrol = 0,72 g/cm³ (from table on previous page)

Unknown m

Formula $D = \frac{m}{V}$

$m = D \times V$ (rearrange the formula)

$= 0{,}72 \times 5\ 000$

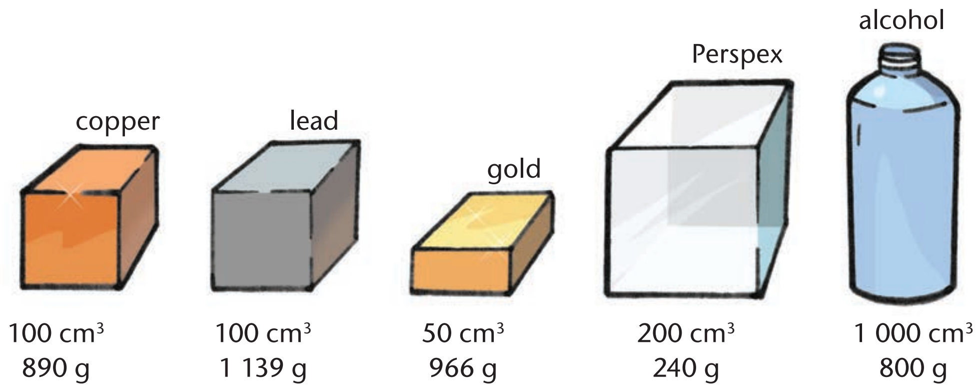
$= 3\ 600\ \text{g}$

Activity 2 Work with information about density

1. If you had a steel ladder and an aluminium ladder of exactly the same shape and size, about how many times heavier would the steel ladder be? Use the table of densities to answer this question.

2. Work out the density of the objects in Figure 8.13 and write them in order, from least dense to most dense.

Figure 8.13 *Put these materials in order, beginning with the least dense.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 208 2016/01/05 3:18 PM

3. If you take a block of aluminium and cut it into two pieces, exactly equal in volume, what will be the density of each half?
4. If you do the same with lead, what will be the density of each half?

Unit 8.3 Magnetic and non-magnetic materials

You have learned about magnets in Chapter 3, Forces.

Let's revise what you learned.

- Magnets can attract some objects, and we say those objects are made of magnetic material. A magnet causes a force between itself and a magnetic object, and this force acts even though the magnet is not touching the object.
- A magnet has a north-seeking pole (the N pole) and a south-seeking pole (the S pole). At the poles, the magnetic force is stronger than at other places on the magnet.
- The N pole of a magnet will attract the S pole of another magnet, but the N poles of two magnets will repel each other and the S poles of two magnets will also repel each other.

Figure 8.14 *A magnet can cause an attraction force that pulls objects like the ones you see here.*

Figure 8.15 *The magnetic force is strongest at the poles of the magnet.*

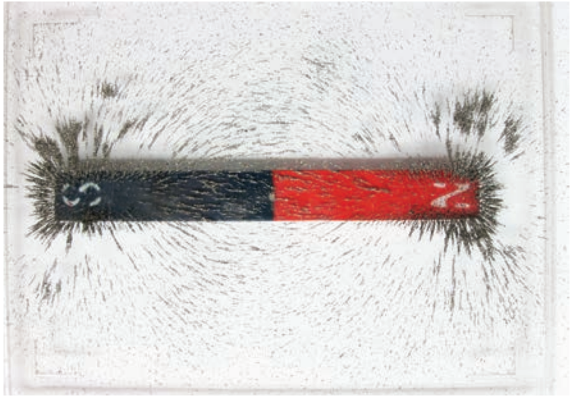
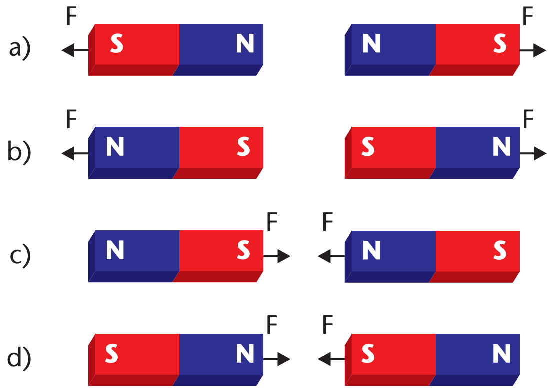


Figure 8.16 *Opposite poles attract each other, and like poles repel each other.*



You know that a magnet can lift up pins and nails, and these objects are made of a magnetic material. But not all materials are attracted to a magnet.

Experiment 9: Which materials are magnetic?

In this experiment you are going to classify materials into groups by finding out which materials are attracted by a magnet.

Procedure

A. You must collect a lot of small objects to test with a magnet.

NOTE: You will find that many objects are coated with plastic or with brass. Paper-clips are often painted bright colours, but the paper-clip underneath the paint is made of steel. Brass screws are usually made of steel but coated with brass. Coins might look like copper or brass, but they are made of an alloy (a mixture of metals) that contains a lot of iron.

Apparatus (per group)
- ❑ about 10 small items such as paper-clips, five-cent coins, one-rand coins, bottle-caps, pieces of a straw, drawing pins, safety pins, piece of eraser, piece of paper, ring-pulls from cold-drink cans, whole cold-drink cans, pieces of cooking-foil, knife blades
- ❑ a strong magnet

B. For each object you have to ask yourself: what material is this thing mostly made from?

C. Kitchen sinks are made of stainless steel, because stainless steel does not rust. If you can find a stainless steel sink, test it with a magnet also. Do they attract each other?

D. Prepare a table in your notebook, as you see in Question 1 below.

Questions

1. Complete the table below in your notebook, from your observations.

Objects that a magnet attracts	Material the object is made from
side of a cold-drink can	steel
stainless-steel sink?	
	The materials above are magnetic materials.

Objects that a magnet does not attract	Material the object is made from
stainless-steel sink?	
	The materials above are non-magnetic materials.

2. What kinds of materials are non-magnetic? Make a list.

3. How many non-magnetic materials in your list are metals?

4. Are all metals magnetic?

5. Think of an object that is made from a magnetic material and a non-magnetic material.

Magnets and magnetic materials

In **Experiment 9** you found that non-metal materials like plastic and glass and paper are not attracted by a magnet.

Of the **metals**, only steel (which is mostly iron), nickel and cobalt are attracted by a magnet. This can be a surprise to many people, who think that magnets attract all metals.

In fact most other substances, including metals, do respond to a magnet but the force is so extremely weak that we say they are non-magnetic.

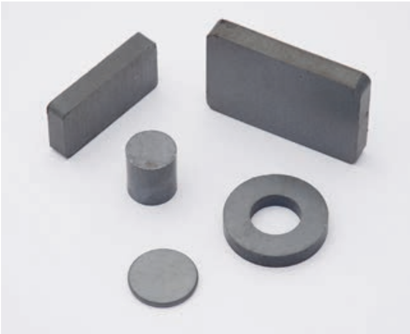
Uses of permanent magnets

You already know about the magnets that hold a fridge door closed; perhaps the doors of your kitchen cupboard have little magnets to keep them closed. Perhaps you have ear-rings that hold on your ears by the use of small neodymium magnets.

Magnets used to be made from hardened steel, but nowadays two new materials are used:

- **Ferrite ceramic**: this is a mixture of iron oxide and cobalt carbonate, and is like a piece of black pottery.
- **Neodymium ceramic**: this is a mixture of iron, boron and neodymium. These magnets are usually coated with nickel metal to protect the ceramic magnet inside.

Figure 8.17 *Ferrite magnets are hard and crack easily.*



To find out how to get magnets from old appliances, go to www.scienceteachingalive.com and open the video called How to get magnets out of old speakers and hard drives.

At the back of a loudspeaker there is a ferrite ring magnet like the ones in Figure 8.17. Microwave ovens use large powerful ring magnets to focus the microwave into the heating cavity. Many electric motors need permanent magnets and computer hard drives use neodymium magnets.

The new electric cars like the Prius use 1 kg of neodymium magnets in their motors.

The wind-powered generators, that you will see more and more of in South Africa, have as much as 600 kg of permanent magnets to help generate electricity.

Unit 8.4 Melting and boiling points

States of matter

In Grades 6 to 9 you often met the idea that matter can exist in three states: solid state, liquid state and gaseous state. Solids are hard and keep their shapes; liquids flow and take the shape of their container; while gases flow, fill their container and flow upwards and out of their container.

Matter might change its state as the temperature changes. For example, a hard block of margarine will change its state from solid in the fridge to runny liquid on a hot day. A rubber hose is flexible when it is warm, but on a very cold day the hose might crack if you try to bend it.

It may surprise you that rock can melt and that iron can boil, but we never usually experience temperatures that are so high. In Figure 8.18 you see a photo of molten rock coming out of a volcano, from many kilometres deep in the crust of the Earth.

Figure 8.18 *Lava is molten rock.*

In technology and engineering we deal with matter in all three states, solid, liquid and gaseous, and in Chapter 11 you will see how the particle kinetic model of matter helps us to explain how matter changes its state.

In the Resource Pages you can find information and exercises on reading thermometers. At the end of the year you will learn about heat and temperature.

Ice and water are common substances used when we talk about melting and boiling, but in fact most substances can solidify and melt, boil and cool down, evaporate and condense. The learners in the class who are doing Electrical Technology know that the metal alloy called solder melts at quite a low temperature.

Activity 3 Melt some solids

Apparatus

- ❑ a piece of solder wire, about 20 mm long
- ❑ a zinc-coated washer
- ❑ a piece of wax candle, about as long as your thumb
- ❑ 3 test-tubes
- ❑ a pair of pliers
- ❑ a Bunsen burner

A. Put a piece of solder wire in the test-tube; you need a piece about 20 mm long. Heat the bottom of the test-tube with the biggest flame you can achieve. Observe the solder when it melts, and describe the melted solder. Can you pour it out? What is it like when you pour it out?

NOTE: You may see smoke come out of the test-tube, but that is just the flux inside the solder, burning.

B. Hold a zinc-coated washer in the flame of the burner. Hold it with a pair of pliers. Observe what happens to the zinc coating on the steel washer.

C. Put a piece of wax candle, about as long as your thumb, into another test-tube. Use a small flame and heat the test-tube with the burner. Observe what happens to the piece of candle and describe the melted wax. Can you pour it out?

What we have learned from Activity 3

The solid wax melts at quite a low temperature; you can drop molten wax on your hand without suffering injury. Molten solder on your hand would be much more painful, because it is at a higher temperature. (Do not try this!)

Solder is an alloy of tin and **lead***, carefully chosen to give a certain melting point. For example, the solder that is often used for electronics work melts at 183 °C, while other kinds of solder melt at lower or higher temperatures.

✻ **lead metal** (noun; say LED, not leed) – a soft metal that is very dense

✻ **lead** (noun; say leed) – a wire that conducts current in a circuit

✻ **lead** (verb; say leed) – to go in front, or to show the way

Activity 4 Work with tables of data

1. Find the table of melting points of pure metals and alloys in the Resource Pages. Use the table to find the melting points of the following metals and alloys:

a) lead **b)** tin **c)** solder for electronics circuits

d) zinc **e)** silver

2. Compare the melting points of the pure metals lead, tin and silver, with the melting points of their alloys. If you make an alloy of two metals, how does the melting point of the alloy compare with the melting points of the two pure metals?

The alloys to look at are:

a) solder for electronics

b) solder for metals that touch food

3. You melted solder, and it became a liquid. If you heated it more, could you get boiling solder? Could you get boiling iron? Well, why not? Find the melting and boiling temperature of iron.

4. Tungsten is the metal that is used for making the glowing filaments of light-bulbs. Find the melting and boiling temperature of tungsten.

The boiling point of water

You already know about melting ice and boiling water. Ice melts at 0 °C and water... well, some people say it boils at 100 °C. We will look more carefully at that idea in Activity 5.

Activity 5 Graph the heating and cooling of water

In this activity you practice the skill of reading a thermometer and drawing a graph.

In Figure 8.20 on the next page, you see what you are going to do. You will record how the temperature of the water changes as time passes. The temperature will depend on the time, so temperature will be the **dependent variable**.

Apparatus (per group)

- ❑ large test-tube or small flask to hold water
- ❑ a support for the flask; e.g. a tripod
- ❑ 50 ml of water
- ❑ spirit burner and matches
- ❑ thermometer that reads to 110 °C
- ❑ clock with seconds hand; big enough for everyone to see

Procedure

Everyone in the class will need a table to record measurements, as you see in Question 1, and a sheet of graph paper.

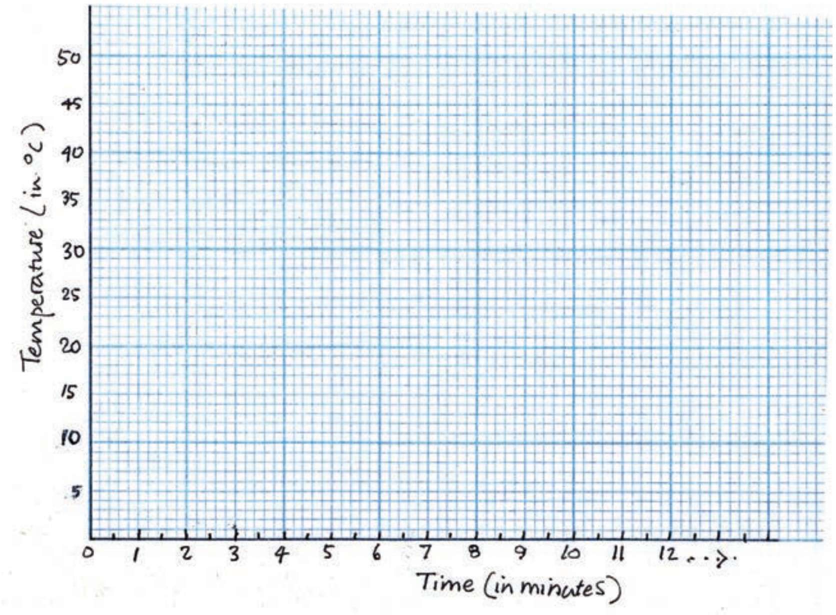
A. First prepare the table in Question 1 to record your measurements. Look at that table now.

B. Then prepare the axes for your graph.

The most difficult part of drawing a graph is to get the right spacing for the units on each axis. You want the equal spaces between units to be as big as you can make them.

Turn your graph paper sideways. We'll measure and record the time along the horizontal axis, and measure and record the temperature up the vertical axis.

Figure 8.19 *Your graph axes might look like this.*



Divide the horizontal time axis into about 24 minutes, and the vertical axis into 100 degrees Celsius.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 214 2016/01/05 3:18 PM

C. Pour 40 ml of cold water into the test-tube and set it up as you see in Figure 8.20. If you use a stopper, leave it a little loose so that steam can escape.

D. Light the burner and check the clock.

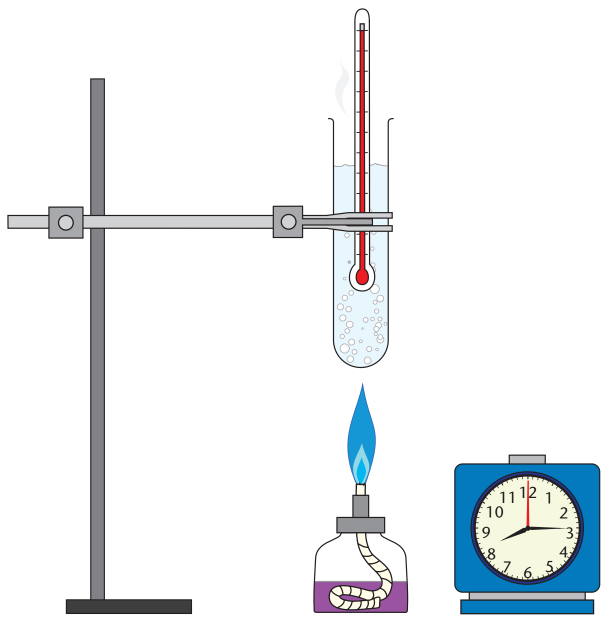
E. Wait until the minute hand is on a whole number and the seconds hand crosses the 12 at the top. Then put the burner under the flask. The time is zero minutes. Read the thermometer and record the first temperature, for minute zero.

F. Every 30 seconds, read the temperature of the water, and record it next to the time. Make a prediction: at what temperature will the water begin to boil?

G. When the water starts to boil, let it go on boiling for five minutes while you record the temperature. Then take away the flame and let the water cool. Go on recording the temperature every half minute.

H. Now change the form of your data from a table to a graph. Plot the data points on the graph paper. You will find some help in Question 3.

Figure 8.20 *Set up the apparatus like this. Don't let the thermometer rest on the glass next to the flame!*



Questions

1. Prepare a table like this in your notebook:

Time (min)	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	3½	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$
Temp (°C)																
Time (min)	8	$8\frac{1}{2}$	9	$9\frac{1}{2}$	10	$10\frac{1}{2}$	11	$11\frac{1}{2}$	12	$12\frac{1}{2}$	13	$13\frac{1}{2}$	14	$14\frac{1}{2}$		
Temp (°C)																
Time (min)	15	$15\frac{1}{2}$	16	$16\frac{1}{2}$	17	$17\frac{1}{2}$	18	$18\frac{1}{2}$	19	$19\frac{1}{2}$	20	$20\frac{1}{2}$	21	$21\frac{1}{2}$		
Temp (°C)																

2. Have you prepared your graph paper?

3. Point A on the graph in Figure 8.19 is a data point; it represents a certain temperature at a certain time. What time and temperature does point A represent?

4. What does your graph tell you about the boiling temperature of water in the place where your school is?

5. Describe the graph going up to the boiling temperature: is it more or less straight, does it dip down in the middle, or what shape does it have?

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 215 2016/01/05 3:18 PM

6. When the water begins to cool, the graph has another shape. Describe that shape.
7. The water is cooling down, but what is the lowest temperature the graph will reach?
8. Compare the starting temperature and the lowest temperature that the graph will reach. Explain your answer.
9. There are two variables that you recorded and showed on your graph. What were the two variables? Which one was the independent variable and which was the dependent variable?

Some "why" questions that arise from Activity 5

The temperature of the water rises steadily because the flame is transferring energy to the water. That is why you see the graph going up in a more or less straight line. But at a temperature near 100 °C, the temperature stops rising.

As the minutes pass, the water goes on boiling but the temperature stays the same. So what is really happening in the water as the temperature rises? And why does it stop rising when the water begins to boil?

People say that water boils at 100 °C, but in most places it boils at a lower temperature. Why?

The answers are in Chapter 11. We're coming to that.

Chapter summary

- Materials are strong or weak, measured by how much they can resist forces of bending, shear, torsion, compression and tension.
- Each material has a density, measured in g/cm^3 or kg/m^3. Lead has greater density than aluminium.
- A few materials are strongly attracted by a magnet. All of these are metals: iron, nickel and cobalt. We call them magnetic materials. All other materials are attracted so weakly that we call them non-magnetic.
- Some solids have quite low melting temperatures while other solids melt at very high temperatures. Very pure substances melt at an exact temperature, but most mixtures of different substances melt over a range of temperatures. Engineers use data tables that show the melting points of many different substances.
- Solids become liquid when they have melted, and the liquids can boil if the temperature goes high enough.

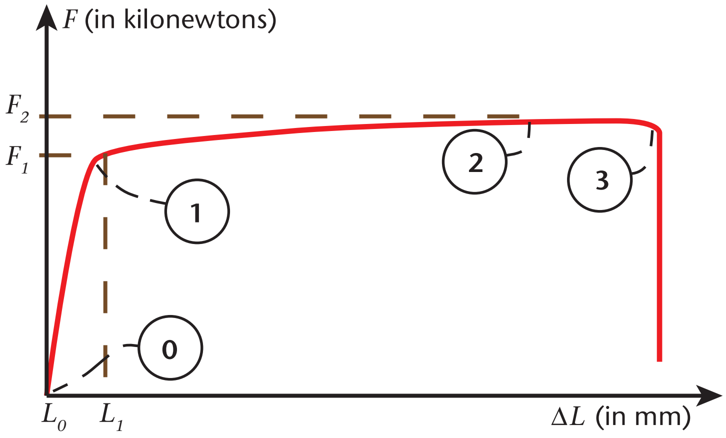
Challenges and projects

Challenges

1. Is a short rope stronger than a long rope of the same diameter and material? Explain your reasoning.

2. An engineer would draw the graph of tensile test data as shown in Figure 8.21. Look at this graph. Now go back to page 202 and follow the story of the tensile test. Try to link this story with Figure 8.21.

Figure 8.21 *This graph tells the same story as the one in Figure 8.4.*



Engineers plot the force on the vertical axis and the extension ΔL (the amount of stretching) on the horizontal axis. They plot the data like this because the slope of the graph is the change in force divided by the change in length between points ⓪ and ①.

3. Lead metal is dense, at 11,39 g/cm^3, but it is not the most dense metal. What are the two most dense metals? You will need to go on the internet or find a book that tells you – this is not in the Resource Pages.
4. You can get strong ferrite magnets out of old loudspeakers and microwave ovens. If you can get onto the internet, find out how to get magnets from old appliances at www.scienceteachingalive.com and open the video called **How to get magnets out of old speakers and hard drives**.
5. Does boiling water get hotter if you let it boil for longer?

Projects

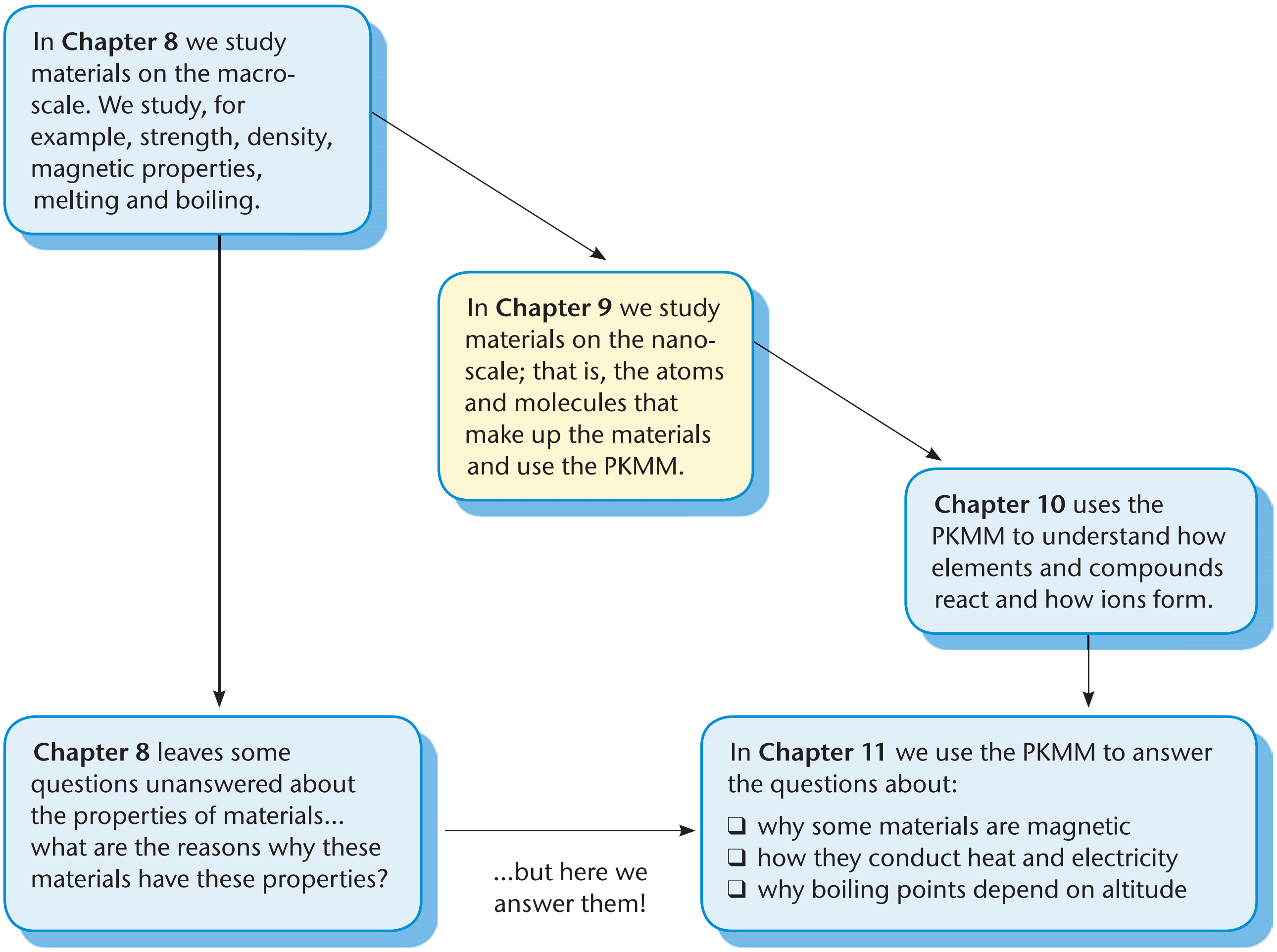
Project 1: Find out what happens to the freezing point and boiling point of water if you add salt to the water.

Project 2: Design a fair test to compare three types of paper for their maximum tensile strength.

Project 3: Think of 5 clever, unusual uses for magnets. The magnets can be any shape you choose. Draw pictures of how you would use the magnets.

CHAPTER 9 Elements and compounds

In Chapter 8 you learned about the properties of materials. In this chapter you learn about the atoms that make up those materials. Here is a map to show where we are going in Chapters 8 to 11.



In this chapter you learn about the atoms that make up materials. Briefly:

- Pure substances can be compounds or elements.
- Compounds are made from two or more elements, and compounds can be broken down into their elements.
- Each element has its own kind of atom and its own symbol in the periodic table.
- Each kind of atom has a structure made of protons, neutrons and electrons that occupy different energy levels.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 219 2016/01/05 3:18 PM

Unit 9.1 The classification of matter

The physical world is made up of a huge number of different substances. Scientists have discovered or made over 10 million different substances. But all those substances are made from only about 100 simpler substances called **elements**.

Ten million substances is far too many to study and even to put in one list. We need a method to group the substances and make it easier to study them. The method is called **classification**.

To understand classification, think of a big supermarket – you go in there to buy some soap but you see a great number of different products on the shelves. There's rice and tea and washing powder and oil and milk and nailbrushes and mugs and eggs and face cream.

If these products were all mixed up you'd need hours to find the soap. But the supermarket sorts the products and so you find the soap on the shelf marked "Personal care products". Soap is there with deodorant, toothpaste and face-cream; these are personal care products and they are on the same shelf.

The supermarket manager has sorted the products into groups or classes, using some rule of what things belong together. We say that the manager has **classified** them.

"Personal care products" is a broad classification, and within that group we may find soap (four different kinds of soap), shampoo (three kinds of shampoo), and so on.

Figure 9.1 *A supermarket sorts its products and it groups similar kinds of products together.*

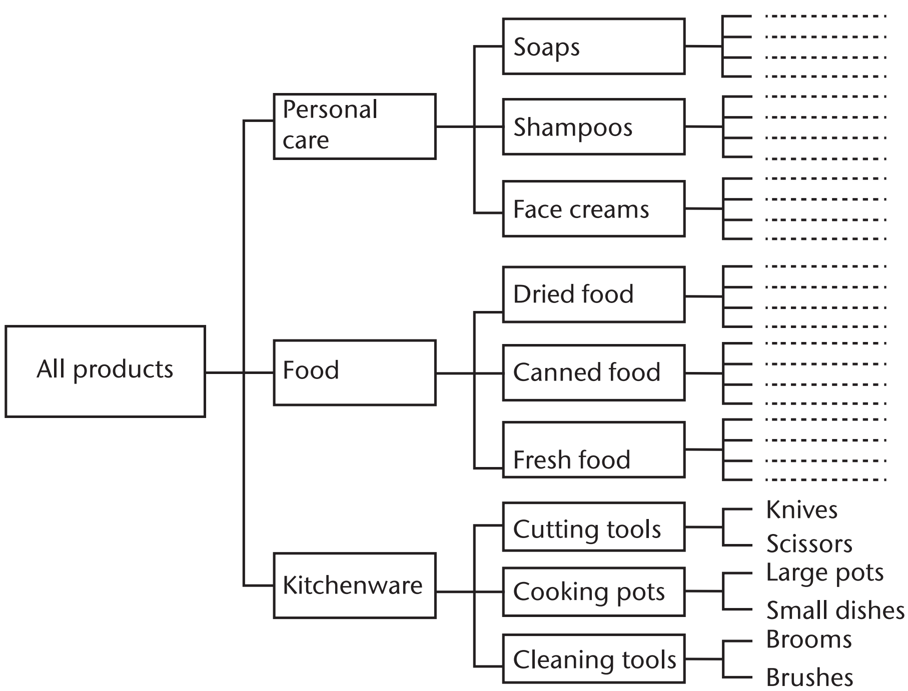
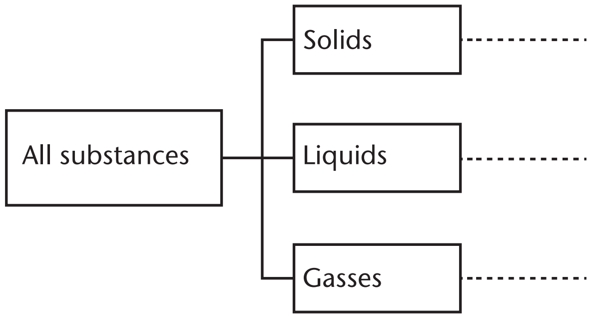


Figure 9.2 *This is a classification diagram for items in a supermarket.*

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 220 2016/01/05 3:18 PM

In Science we can also do sorting and classifying. In the diagram below, you see how all substances can be sorted into three classes.

Figure 9.3 *A classification diagram for all substances. The groups are based on the state of the substance; that is, whether it's a solid, a liquid or a gas.*



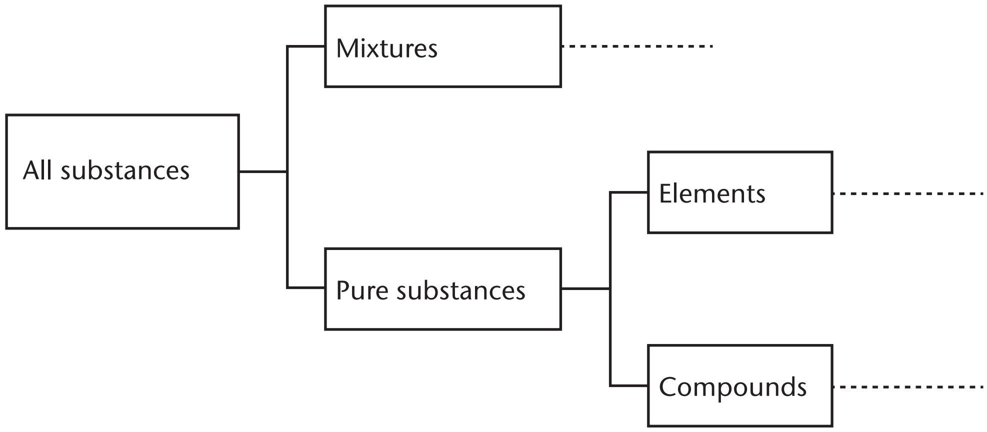
Quick Activity:

1. Use Figure 9.3 and name four solids, four liquids and two gases you can find in a supermarket.
2. Thinking of the supermarket, name two solids that are metals and two solids that are non-metals.

Now we are going to classify substances in another way. We will classify all substances into the two classes **mixtures** and **pure substances**.

Look at the classification diagram in Figure 9.4. You see that some substances are mixtures but other substances are **pure substances**. Of the pure substances, some are **elements** and some are **compounds**.

Figure 9.4 *This is another way to classify all substances. The groups are based on what the substances are made from.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 221 2016/01/05 3:18 PM

Mixtures

A mixture is two or more substances mixed together so that if you take a sample (a small piece) you will always find all the substances together in it. For example, if you poured salt and sugar into a bag and shook it, you would have a salt-and-sugar mixture. If you tasted the mixture, you would get both tastes together. But it would still be a salt-and-sugar mixture, not some **new** substance.

Homogeneous mixtures

If you mixed sugar and water in a cup and stirred the mixture well, you would have an even mixture. That is to say, the mixture from the bottom of the cup would taste the same as the mixture from the top of the cup – the mixture is the same all the way through. In science, an even mixture is called a homogeneous mixture.

In Chapter 8 you learned about alloys. An alloy is a solid that is a mixture of elements that has the properties of metals. An example of an alloy is solder. Solder that you use for electronics is 37% lead and 63% tin, and we can say that the lead is dissolved in the tin.

This may sound strange, to talk about a solid solution. But look at Figure 9.5 and Figure 9.6. You could do this activity. Dissolve a crayon in hot, molten candle-wax and stir it. When the solution cools you have an even, solid solution of **coloured** wax in **white** wax.

Most of the substances that you know are mixtures

Most kinds of food and drink are mixtures, and the air that you breathe is a mixture of gases. Air has about 21% oxygen, 78% nitrogen, and small amounts of argon and carbon dioxide and other gases, including water vapour.

The gas that people use for cooking is a mixture of two gases, and the exhaust gas from a car is carbon monoxide mixed with a number of other gases.

Quick Activity:

Why must a car engine have an oil filter? What does the filter do?

Figure 9.5 *The coloured crayon dissolves in the hot, molten candle wax.*

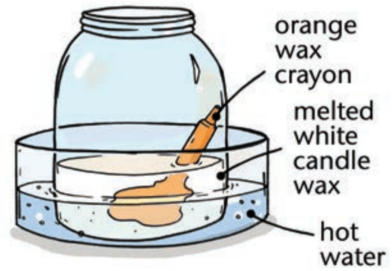


Figure 9.6 *When the wax cools, we have a solid solution of coloured wax in white wax.*

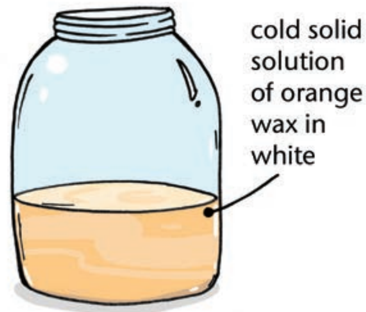


Figure 9.7 *You might test exhaust gas to measure the percentage of carbon monoxide in the gas.*

Pure substances

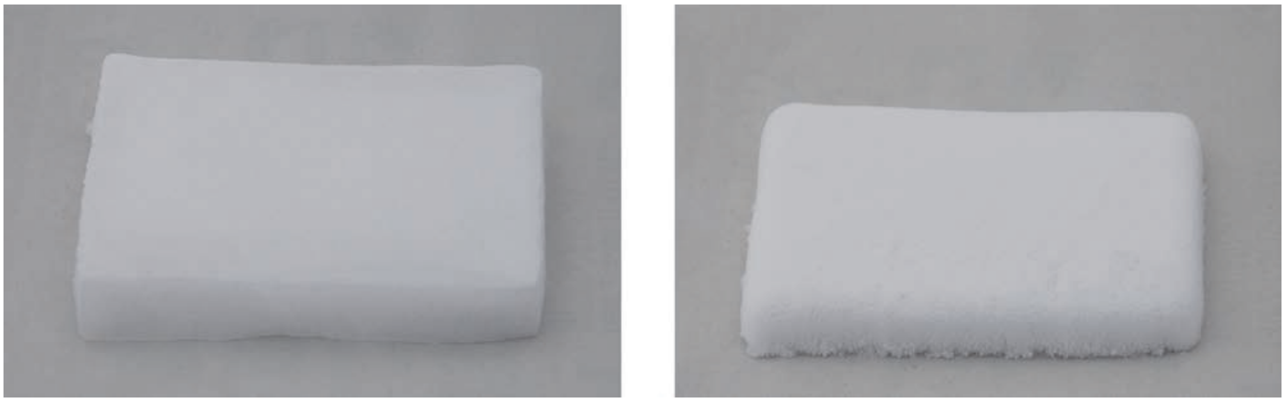
Pure substances are not mixtures. Pure substances are a single type of material.

There are two kinds of pure substances: **compounds** and **elements**.

Compounds

You probably know many compounds from your Natural Sciences in Grade 9. You may know names that end in "-ide", such as sodium chloride (called table salt), iron oxide (called rust), mercuric oxide, potassium chloride and of course carbon dioxide.

Figure 9.8 *"Dry ice" or "steam ice" is really carbon dioxide in the solid state.*



Dry ice

Dry ice 45 minutes later

Perhaps you know names that end with "-ate", like sodium carbonate (called washing soda), sodium bicarbonate (called baking soda), potassium permanganate (called *amanyazin*, *makganatsohle* and Condy's crystals) and magnesium sulfate (called Epsom Salts).

Many other substances have common names that hide the fact they are compounds: water, ammonia, and *igali* (tartaric acid).

In nature, most substances are compounds and there are millions of different compounds.

Pure carbon dioxide is a compound, but you can guess from the name "carbon dioxide" that it is made from two elements, carbon and oxygen.

Figure 9.9 *Some common compounds*

Elements

Definition: An element is the simplest type of pure substance. It cannot be broken down into any other substances.

Chemists have broken down compounds to obtain elements, but a few elements occur naturally. The element **sulfur** collects around holes in the Earth where a volcano blows out gases, steam and lava. In a very few places on the Earth people have found pure **gold**, or pure **copper**.

Mostly, ancient metalworkers obtained metals from special types of rock that contained the right compounds. They obtained **mercury** by heating a rock called cinnabar. The cinnabar rock contains the compound, mercuric sulfide, along with lots of waste rock that has to be thrown away. They got lead from the compound lead sulfide, by heating a type of rock called galena.

At a place called Loolekop near Phalaborwa, in the 1500s, African metal-workers extracted the element **copper** from a rock called chalcopyrite. This rock contains compounds of copper, iron and sulfur.

We know that Tswana metal-workers on the highveld in the 1500s extracted iron from iron oxide; the oxide was in red-brown rock called haematite. South African archaeologists have found the ovens where they **smelted** the ore.

The ancient metal-workers had knowledge of how to extract metals from certain rocks. Mostly, they kept the knowledge secret, because their metals were rare and could be sold at a high price.

Figure 9.12 *The method that Tswana metal-workers used for extracting iron from iron oxide*

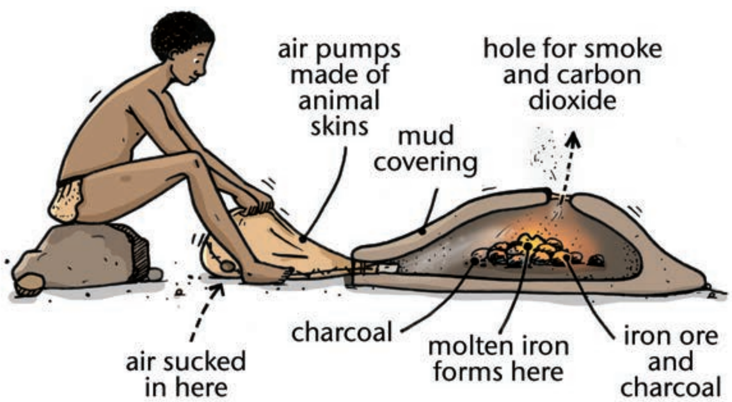


Figure 9.10 *Volcanoes produce sulfur from vents near the bottom.*

Figure 9.11 *In a few places on Earth one can find lumps of fairly pure copper or gold.*

Quick Activity:

Name the elements from which these compounds are made:

a) sodium chloride
b) iron oxide
c) mercuric oxide
d) potassium chloride

Alloys of metals with other elements

You remember that when you dissolved sugar in water you got a sugar-in-water solution. Alloys are mixtures of elements in which the atoms of the elements are so finely separated and mixed with each other that we can say one element has dissolved in the other element.

So we can have atoms of the element tin dissolved in between atoms of the element copper. This hot, molten solution cools and becomes a solid, not a liquid. We call the solid solution an **alloy**.

About 5 000 years ago, metal-workers on the island of Cyprus combined copper with tin, and they obtained an alloy called **bronze** that was harder than copper.

Alloys you might work with in the workshop

- ❑ brass
- ❑ bronze
- ❑ phosphor bronze
- ❑ duralumin
- ❑ solder
- ❑ white metal
- ❑ low, medium and high
- ❑ carbon steel
- ❑ stainless steel

In ancient Iraq, metal-workers could not find tin so they combined zinc with copper, to make **brass**.

In Japan, sword-smiths about 1 300 years ago found that they could make an alloy, **steel**, by combining iron with carbon from charcoal. Steel was harder than iron, brass or bronze.

Steel nowadays is made from iron (80–98%), carbon (0,2–2%), plus other metals such as chromium, manganese, and vanadium. Different grades of steel come from changing the quantity of the carbon and other elements.

If you do Mechanical Technology as a subject, you will hear about "ferrous" and "non-ferrous" metals. These names come from the Latin name for iron, *ferrum*. The chemists gave iron the symbol Fe.

As another example, the Latin name for lead was *plumbum* and so lead was given the symbol Pb. Copper came from the island of Cyprus and so copper was called *cuprum* and the chemical symbol is Cu.

In the periodic table on page 227 you can find the names and symbols of some of the substances you already know.

Quick Activity:

1. In technical jobs, you need to know about iron, manganese, chromium, vanadium, titanium, tungsten, molybdenum and cobalt, and non-ferrous elements copper, tin, lead, zinc, aluminium and nickel. Go to the periodic table on page 227 and find the symbols for these 14 metals.
2. Find the names of the elements with these symbols: C, Cl, O, N, S.

Let's revise what you may know from Grade 9 about metals, non-metals and metalloids (also called semi-metals).

Figure 9.13 *Metals are shiny, ductile and malleable.*

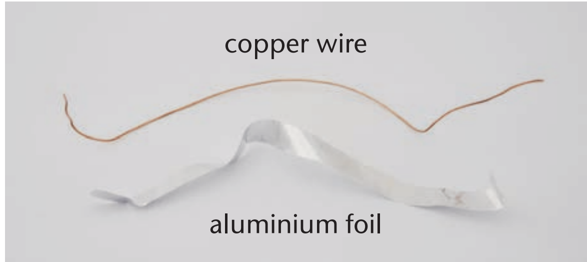


Figure 9.14 *Non-metals are mostly not shiny, and do not conduct electricity.*

Figure 9.15 *These are metalloids.*

Properties of metals

From Grade 8 and 9 you should know some physical properties of metals – metals are shiny if they are polished; they can bend without breaking; they conduct electricity and they conduct heat.

Properties of non-metals

Non-metals are usually dull, not shiny. Some of them are gases; most of the others are solids but they are **brittle** (in other words, they crack and break if you bend them). Most of them don't conduct electricity and they don't conduct heat very well.

Properties of metalloids

Metalloids are elements that have some properties of metals and some properties of non-metals. Silicon is a good example of a metalloid. Carbon has a form called graphite that conducts electricity, and another form called diamond that does not conduct electricity at all.

The periodic table of the elements

The periodic table is a powerful and useful classification of the elements. Scientists in the 1800s began to organise their knowledge of the elements by grouping together elements that had similar properties. This was the start of the periodic table of the elements we have today.

Find the periodic table on page 227.

The elements all have numbers called their **atomic number**. Hydrogen is 1, helium is 2, lithium is 3, and so on.

Why is the table called the **periodic** table? If you look down the rows in the table, you see that they are numbered as "Period 1", "Period 2", and so on. We'll soon come to the reason why they are called periods.

Look across the table from left to right, and notice that there are 18 **groups** of elements.

Figure 9.16 *Periodic table of the elements*

Metals | Nonmetals

PERIODIC TABLE OF THE ELEMENTS

29 Cu Copper 63,546 — Atomic number: 29; Symbol: Cu; Atomic weight: 63,546

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
Period 1	1 **H** Hydrogen 1,00794																	2 **He** Helium 4,0026
Period 2	3 **Li** Lithium 6,941	4 **Be** Beryllium 9,0122											5 **B** Boron 10,811	6 **C** Carbon 12,011	7 **N** Nitrogen 14,0057	8 **O** Oxygen 15,9994	9 **F** Fluorine 18,9984	10 **Ne** Neon 20,183
Period 3	11 **Na** Sodium 22,9898	12 **Mg** Magnesium 24,305											13 **Al** Aluminum 26,9815	14 **Si** Silicon 24,305	15 **P** Phosphorus 30,9738	16 **S** Sulfur 32,066	17 **Cl** Chlorine 35,453	18 **Ar** Argon 39,948
Period 4	19 **K** Potassium 39,098	20 **Ca** Calcium 40,08	21 **Sc** Scandium 44,956	22 **Ti** Titanium 47,87	23 **V** Vanadium 50,942	24 **Cr** Chromium 51,996	25 **Mn** Manganese 54,9380	26 **Fe** Iron 55,845	27 **Co** Cobalt 58,9332	28 **Ni** Nickel 58,69	29 **Cu** Copper 63,546	30 **Zn** Zinc 65,39	31 **Ga** Gallium 69,72	32 **Ge** Germanium 72,61	33 **As** Arsenic 74,9216	34 **Se** Selenium 78,96	35 **Br** Bromine 79,904	36 **Kr** Krypton 83,80
Period 5	37 **Rb** Rubidium 85,47	38 **Sr** Strontium 87,62	39 **Y** Yttrium 88,906	40 **Zr** Zirconium 91,22	41 **Nb** Niobium 92,906	42 **Mo** Molybdenum 95,94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101,07	45 **Rh** Rhodium 102,905	46 **Pd** Palladium 106,4	47 **Ag** Silver 107,868	48 **Cd** Cadmium 112,41	49 **In** Indium 114,82	50 **Sn** Tin 118,71	51 **Sb** Antimony 121,76	52 **Te** Tellurium 127,60	53 **I** Iodine 126,9045	54 **Xe** Xenon 131,29
Period 6	55 **Cs** Cesium 132,905	56 **Ba** Barium 137,33	49 - 71* Lanthanides	72 **Hf** Hafnium 178,49	73 **Ta** Tantaium 180,948	74 **W** Tungsten 183,84	75 **Re** Rhenium 186,2	76 **Os** Osmium 190,2	77 **Ir** Iridium 192,2	78 **Pt** Platinum 195,08	79 **Au** Gold 196,967	80 **Hg** Mercury 200,59	81 **Tl** Thallium 204,38	82 **Pb** Lead 207,2	83 **Bi** Bismuth 208,98	84 **Po** Polonium (210)	85 **At** Astatine (210)	86 **Rn** Radon (222)
Period 7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 - 103** Actinides	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (268)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112+ (277)						

*LANTHANIDES	57 **La** Lathanium 138,91	58 **Ce** Cerium 140,12	59 **Pr** Praseodynium 140,908	60 **Nd** Neodynium 144,24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150,36	63 **Eu** Europium 151,96	64 **Gd** Gadolinium 157,25	65 **Tb** Terbium 158,925	66 **Dy** Dysprosium 162,50	67 **Ho** Holmium 164,930	68 **Er** Erbium 167,26	69 **Tm** Thulium 168,934	70 **Yb** Ytterbium 173,04	71 **Lu** Lutetium 174,97
**ACTINIDES	89 **Ac** Actinium (227)	90 **Th** Thorium 232,038	91 **Pa** Protactinium 231,036	92 **U** Uranium 238,03	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

The elements in a group have similar properties

Let's take Group 1. Apart from hydrogen, all the elements going down the group are metals. They are soft enough to cut with a knife, they react easily with oxygen and they react very fast with water.

In Group 2, we also have metals, but they are a little harder and are less reactive with water.

In Groups 3 to 12, we also have metals like scandium, titanium and so on. These are harder than the metals in Group 1 and 2. These metals are called the **transition metals**.

Now we get to Groups 13, 14, 15, 16, and 17.

Group 13 has the metalloid boron (B) at the top and then the metals aluminium (Al) and gallium (Ga) lower down. Look at the stair-step line that zig-zags between aluminium and silicon. On the left of that zig-zag are metal elements, and on the right are non-metal elements.

Metalloids

The elements nearest to the zig-zag line are called metalloids because they have some properties of metals and some properties of non-metals. Examples are silicon ($_{14}Si$) and germanium ($_{32}Ge$). To simplify things, metalloids to the right of the zig-zag line are grouped with non-metals and metalloids to the left of the zig-zag line are grouped with metals.

So **Groups 13, 14, 15 and 16** have some metals and some non-metals in them.

Group 17 is all non-metals; it has the elements fluorine ($_{9}F$), chlorine ($_{17}Cl$), bromine ($_{35}Br$), iodine ($_{53}I$) and astatine ($_{85}At$). These elements are together called the halogens and they are reactive, with fluorine at the top of the group being the most reactive.

Group 18 has only gases; these gases react with almost nothing else. That's interesting, because they come right next to the reactive halogens. Helium ($_{2}He$) you might know from party balloons. Neon ($_{10}Ne$) is a gas that is used in electric signs and in strip lighting. Argon ($_{18}Ar$) is used inside light-bulbs – it does not react with other substances and so the hot filament does not burn even though it is very hot. Argon is the gas you will use if you do TIG welding (Tungsten Inert Gas welding) in Mechanical Technology. The word "inert" means "does not react with other substances." These gases in Group 18 are called the **noble gases**.

Quick Activity:

1. Are most of the elements metal or non-metals?

2. The metalloids have some of the properties of metals and some of the properties of non-metals. Find the 6 metalloids on the periodic table. What do you notice about their positions?

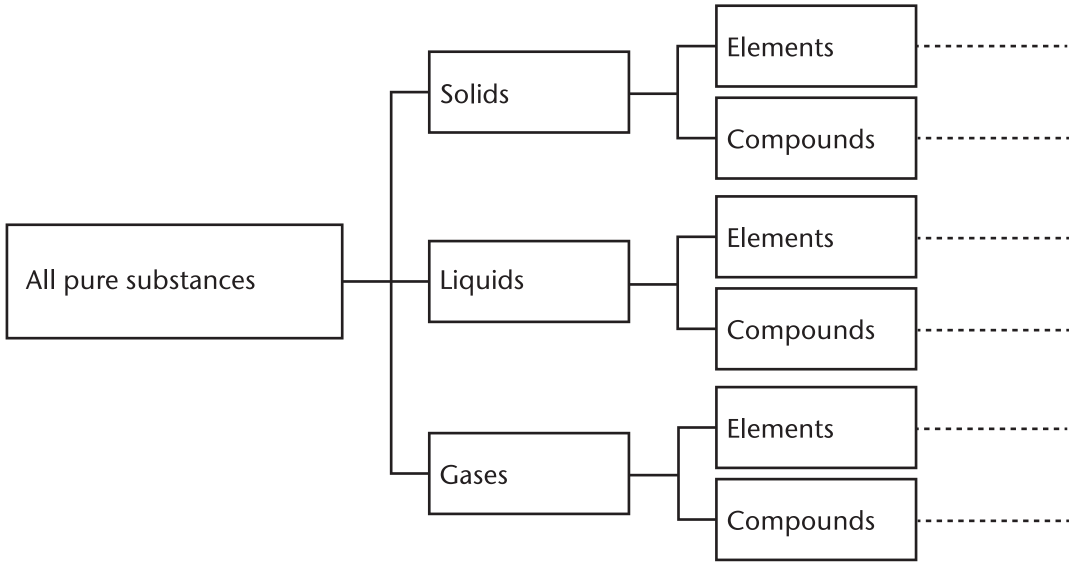
3. Which of the elements below are non-metals?
carbon (C), gallium (Ga), silicon (Si)

Unit 9.1 Summary activity

Answer these questions in your notebook.

1. People talk about "pure air"; a scientist would not agree that air is pure. Why not?
2. What do we call a mixture that is the same in every part?
3. You can have pure oxygen and pure carbon. Can you have pure carbon dioxide? Explain your answer.
4. How can you work out from the periodic table which elements will have similar properties?
5. Copy Figure 9.17 below and add examples where you see the dotted lines.

Figure 9.17



Unit 9.2 The particles that make up elements and compounds

Macro-scale versus nano-scale

> **macro-scale** (adj.) – largescale; thinking of a whole system together
>
> **nano-scale** (adj.) – very, very small; thinking about the particles that are too small to see

Up to this point we have been talking about elements and compounds as quantities of substances that you can put in a bottle or hold in your hand. When we think about large quantities of a substance in that way, we are thinking on the **macro-scale***. Here are 4 examples of macro-scale observations:

- We can see substances expand when they get hot, and contract when they get cold.
- We can see water get hotter until bubbles form in the water and rise to the top as the water boils.
- We can see substances like salt dissolve in other substances, such as water.
- We can see that carbon is black and chalk is white.

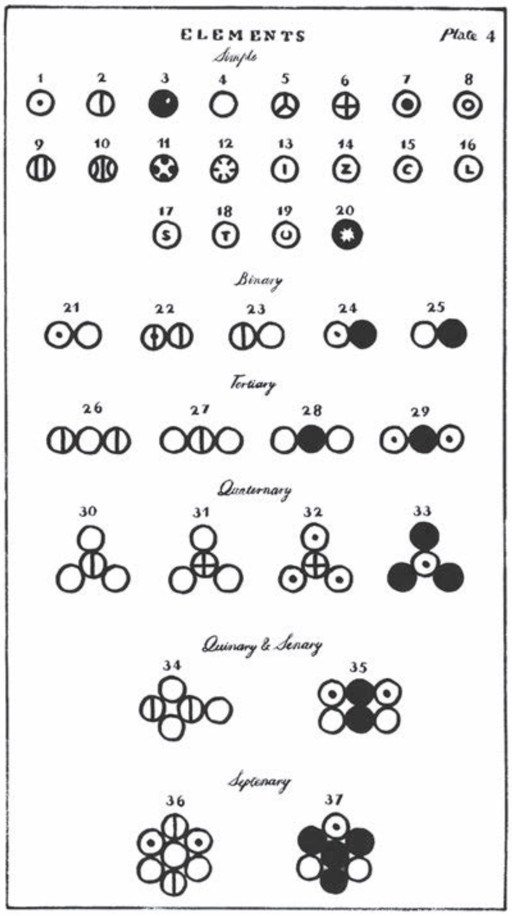
When we want to understand why substances expand when they get hot, or why bubbles form at the bottom of boiling water, we have to think on the **nano-scale***. A nanometer is 10^{-9} metres. That is one millionth of a millimetre. That is the kind of measurement we are talking about in nano-scale. It is the sort of measurement we use for atoms.

Atoms are not all the same size, but average-sized atoms are so small that about 1 000 000 atoms could line up across the width of a human hair. This means they are just too small to see, even with the most powerful microscope. But let's imagine we have some magic spectacles that allow us to see atoms and molecules. We can certainly think about atoms and imagine what they are like and how they behave.

A very long time ago, in Greece, a thinker called Demokritos imagined atoms. He said that matter could be divided into smaller and smaller pieces until you reached a piece that can no longer be divided. The Greek word for this piece was "a-tomos" meaning "cannot be cut". From that word we got our English word "atom".

The experimenters in the 1700s and 1800s found the idea of atoms useful, even though they could not prove that atoms were real things.

Figure 9.18 *John Dalton drew these pictures to represent his ideas about elements, and how atoms join to form the molecules of compounds.*



John Dalton, who lived at that time (1766–1844), was a school teacher and scientist. He was very interested in gases, and did a great number of experiments on gases. He explained his ideas to other people by using drawings like the one you see in Figure 9.18 on the previous page.

John Dalton drew those little balls to represent atoms of elements. He drew little balls joined together to represent the new thing that they could form, called a molecule.

John Dalton's ideas about matter

- Each kind of element is made up of just one kind of atom, and atoms of different elements have different masses.
- When billions of atoms, all of one kind, join together they make a little piece of the element. Billions of iron atoms form a little piece of iron, billions of carbon atoms form a tiny piece of carbon, and so on.
- A molecule is made up of atoms joined together. The atoms may be different kinds or they may be the same kind.
- When atoms combine they combine in simple whole numbers.
- Therefore atoms join together in fixed ratios. For example, two hydrogen atoms will join with one oxygen atom, and form one molecule of water.

Most elements exist as molecules

Almost all the matter you can think of is made up of molecules. The air is made mostly of nitrogen and oxygen; nitrogen atoms (N) join together in pairs as nitrogen molecules (N_2); oxygen atoms (O) join together as oxygen molecules (O_2).

Sulfur atoms (S) join together in sets of eight as sulfur molecules (S_8), and then millions of these sets of eight atoms stick together so that we have a piece of sulfur.

A tiny piece of carbon is made up of millions of carbon atoms (C) joined together. There are too many to count, so we just write C, instead of $C_{\text{(huge number)}}$.

A tiny piece of copper (Cu) is also made of a huge number of copper atoms joined together, but we just write Cu instead of $Cu_{\text{(huge number)}}$.

Figure 9.19 *Oxygen is an element, so it has only one kind of atom. The atoms join together in pairs. (Oxygen atoms are not really red.)*

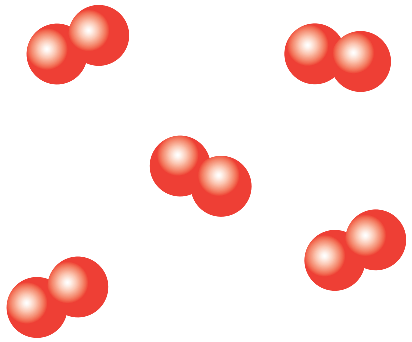
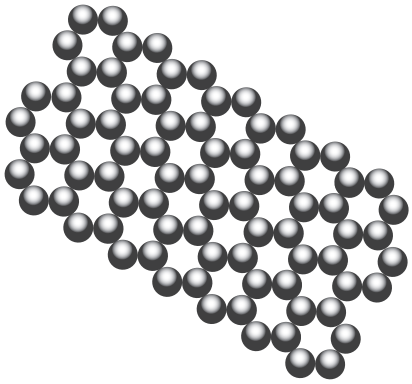


Figure 9.20 *Sulfur is an element. Sulfur atoms join together in eights, and then make pieces of sulfur. The forces between the eights are weak, so sulfur melts easily.*

Figure 9.21 *Carbon is an element. Carbon atoms join together to form a piece of carbon. Carbon is a giant molecule.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indd 231 2016/01/05 3:18 PM

Compounds are made of molecules

We have been talking about elements, but what about compounds? You can also have molecules that are made of different kinds of atoms joined together, and when billions of these molecules stick together, you can see a compound. For example, two hydrogen atoms (H and H) may join to an oxygen atom (O); then we have a water molecule. We write H_2O to represent a water molecule.

H_2O is called a **formula** for the compound water. The small "2" means that there are two hydrogen atoms for every oxygen atom.

Ammonia gas molecules form when three hydrogen atoms (H) join with one nitrogen atom (N), and form an ammonia molecule (NH_3). The H and N atoms join in the exact ratio three H to one N. That ratio is fixed and has only whole numbers – it does not happen that one H joins with two N; nor does $1\frac{1}{2}$ H join with an N.

Figure 9.22 *Water molecules. When they are close together, they form liquid water.*

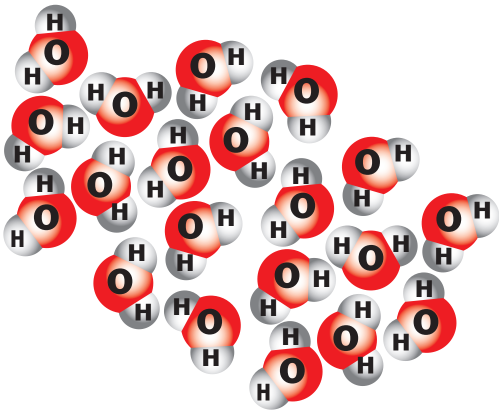
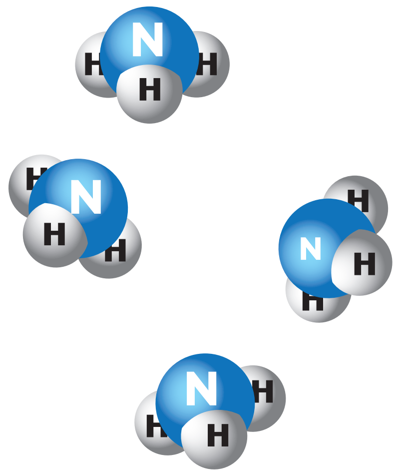


Figure 9.23 *Ammonia gas molecules.*



> **Definition:** **A compound is a substance made from two or more elements, with the elements' atoms in a set ratio of whole numbers.**

Dalton's ideas clarified the thinking of many other scientists, and the knowledge of chemistry began to grow.

Remember that scientists could still not prove that atoms exist, but their theory of atoms kept on leading them to further ideas, ideas that they could test. And many of their ideas turned out to be correct.

In the 1800s more and more machines were powered by steam – machines inside factories and engines on the railways. Railways were being built in most countries of the world. So engineers had to understand steam, heat and pressure in gases in order to make the engines work better and waste less energy. They said, "let's **think** of atoms as little marbles that move fast and bounce off each other and off the walls of the pistons inside the engine". So they thought of atoms as little bouncing marbles and did some calculations on how to make the engines work better. Their calculations were very useful and steam engines did work better.

Dalton's ideas about atoms were taken further, and scientists now talk of the **particle kinetic model of matter.**

In Chapter 16 you will learn more about thermodynamics. This is the study of heat and movement.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 232 2016/01/05 3:18 PM

The particle kinetic model of matter (the PKMM)

The words in this name need explaining. We use the word "particle" in everyday talk but it has a special meaning in science. It does not mean a small piece of something, like a speck of dust. It means an **atom** or a **molecule** or a smaller **part of an atom**.

"Kinetic" is a word that you use to tell about something that moves. For example, kinetic energy is the energy of moving objects.

"Matter" means all solids, liquids and gases.

Here is the particle kinetic model of matter:

1. Solids, liquids and gases are made of particles that are too small to see.
2. Between the particles is empty space; there is nothing between them; not air nor anything else.
3. The particles attract each other but if they come too close together they **repel** each other.
4. The particles move and vibrate all the time, even if no object pushes them.
5. The particles move and vibrate faster if they receive energy.

What is a model in science?

How did the scientists and engineers reach agreement on this kind of model?

For scientists a **model** is a description in words, pictures and mathematics that predicts how some **system*** will behave.

If scientists can make a prediction about how a change in one part of the **system** will cause a change in another part of the system, and the change happens as they predicted, then they feel that their model is good and accurate.

Let's see if we can make some predictions about matter from the model.

* **system** (noun) – a set of parts that work together. A change in one part of the system causes changes in other parts of the system. Examples are your nervous system, an ecosystem, and an electric circuit.

Activity 1 Make a prediction about air molecules

Focus question: Can you use the particle model to predict how much you will compress air in a syringe?

Apparatus (per group)
❑ a large, empty syringe

A. Look at Figure 9.24. This is what you are going to do. Predict how far you will be able to press the piston down in the syringe. Half-way? Three-quarters of the way? All the way to the bottom?

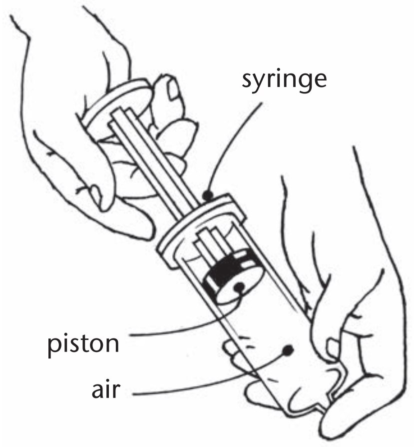
B. Pull back the piston of the syringe to fill the syringe with air. Then close the end of the syringe with your thumb.

C. Now press the piston in as far as you can and hold it there.

D. Look closely at the space below the piston; what do you think is happening in that space?

E. Keep your finger over the end of the syringe, but take away your other hand from the piston. What happens?

Figure 9.24 *Try to compress the air until the piston reaches the bottom of the syringe.*



Questions

1. What do you think is happening to the air in the space below the piston?

2. Can you see air molecules there? What are they doing, do you think?

3. What do you think is holding the piston back so that you cannot compress the air to the bottom of the syringe?

4. When you stop pressing down on the piston, it moves back to its starting position. What is the force that pushes it?

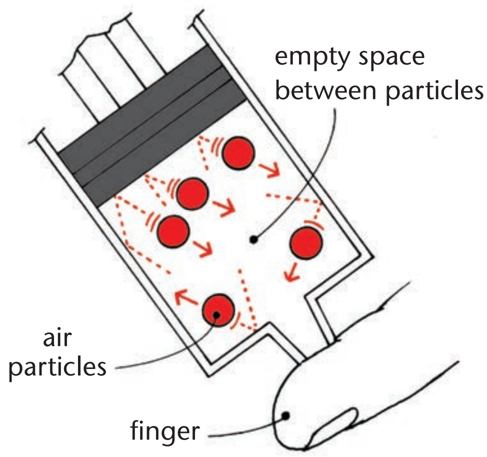
What we have learned about models from Activity 1

The PKMM (the Particle Kinetic Model of Matter) tells us that the molecules of a gas are moving all the time, and when they bump into each other they repel each other.

We can then **predict** that if we push the air particles closer together they will bump into each other and the piston more often. As they bump the piston and walls of the syringe they will press harder against the piston.

This is what we predict, and it actually happens, and so the model seems to be correct.

Figure 9.25 *The model says that when you press the piston in, the particles hit the piston more often and push back against it.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 234 2016/01/05 3:18 PM

Activity 2 Make a prediction about hot and cold water

Apparatus (per group)

- ❑ two saucers or flat bowls
- ❑ two sheets of paper
- ❑ two crystals of potassium
- ❑ permanganate
- ❑ cup of cold water
- ❑ boiling water

Focus question: Use the particle model to make a prediction: will the crystals dissolve the same way in hot water and cold water?

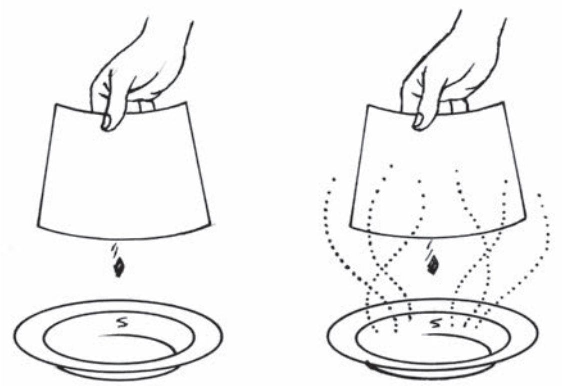
A. Look at Figure 9.26; this is what you are going to do. When the coloured crystals fall into the water, they will dissolve. But **before** you drop them into the water, you must make a prediction about what you will see. Go to **Questions 1 and 2**.

B. Fold the two sheets of paper as you see in Figure 9.26, and put a large crystal of potassium permanganate in the fold in each paper.

C. Pour cold water into one saucer and very hot water into the other saucer.

D. Now drop the two crystals into the cold and the hot water **at the same moment**. Do not stir the water or move the saucers – just watch what happens. Answer **Questions 3 and 4**.

Figure 9.26 *You are going to drop the crystals into the saucers at the same moment.*



Questions

1. Will there be any difference in the way in which each crystal dissolves in the water? If so, what will the difference be?
2. What is the reason you make that prediction?
3. What was the difference in the way the coloured solution spread in the two saucers?
4. Was your prediction correct?
5. How does the particle kinetic model help to explain this difference?

TechSci_G10-LB-Eng-DBE3_9781431522842.indd 235 2016/01/05 3:18 PM

What we have learned about models from Activity 2

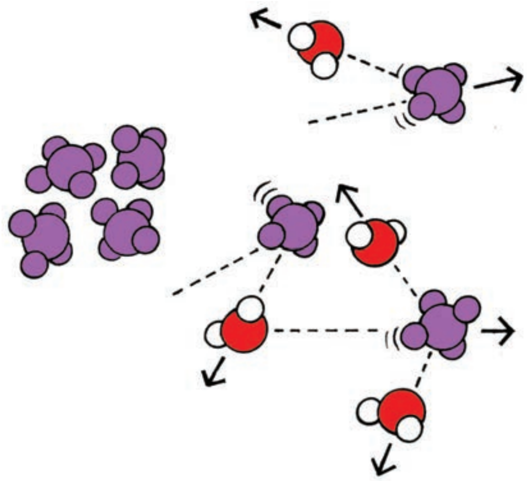
The PKMM tells us that the particles of cold water move all the time, and so the water molecules bump the purple particles of potassium permanganate and spread them out.

But the model also says that the water molecules move and vibrate faster when the water temperature increases. We can then **predict** that the water molecules of hot water will bump the coloured particles harder than molecules of cold water. Then we can predict that the coloured particles will spread out faster among the molecules of hot water. This is what actually happens, and so the model seems to be correct.

It is because of correct predictions like this that scientists trust the PKMM – it leads them to correct predictions, even though they cannot see the particles.

In Chapter 10 you will use these ideas about particles to understand reactions between elements, and the reactions of compounds.

Figure 9.27 *The model says that the water molecules move faster if the temperature is higher. So the water molecules bump the purple particles harder and spread them out faster.*



Unit 9.2 Summary activity

Complete answers to these questions in your notebook.

1. A piece of iron is shiny if you polish it. Iron atoms join together in a giant iron molecule. Which of these two statements is a macro-scale statement and which is a nano-scale statement?
2. What is the main difference between elements and compounds? Use the ideas of atoms and molecules in your answer.
3. The particle kinetic model of matter has five statements about particles. What are they?

Unit 9.3 The structure of the atom

You remember that the engineers had used the idea of atoms that behave like little bouncing marbles to improve steam engines.

But still some scientists in the early 1900s doubted that atoms were real things. The main problem was that nobody could see an atom. An atom is so small that about 1 000 000 atoms can line up across the width of a human hair. So what can we really know about it?

Well, scientists look carefully at any signs of what atoms do, and they try to make a description of what an atom is like. The description is called a **model** of an atom. If scientists have a good model of an atom, they can predict how atoms will behave when they do experiments on them, and the predictions turn out to be correct.

The scientists in the late 1800s knew there was something electrical about atoms; they knew this from many experiments with static electricity. They also found that they could dissolve a compound in water and use electric current to break up the compound into its elements. One element formed at the positive electrode and the other element formed at the negative electrode.

At the end of the 1800s and the beginning of the 1900s, scientists made a number of discoveries.

They found electrons; the electrons were particles in the atom, and were very much smaller than the atom! Electrons carried the negative electric charge that people knew about from static electricity.

So if the atom had negative electrons, the rest of the atom must be positive, so that the negative and the positive charges balanced each other.

In 1909, Ernest Rutherford's team in England presented the results of new experiments: they said that atoms had a very, very tiny nucleus with electrons whirling around it. The atom is almost all empty space, with a tiny positive nucleus and negative electrons moving around it, giving the atom its size and shape.

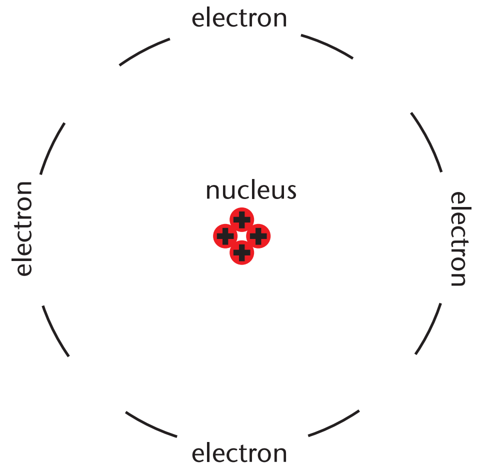
Look at Figure 9.28. This diagram shows Rutherford's first model of a beryllium atom. Beryllium is a metal element.

The very tiny nucleus, said Rutherford, is made up of even smaller particles he called **protons**. The beryllium atom has four positive protons and four negative electrons. That means the numbers of protons and electrons are equal, and so the atom is neutral (neither negative nor positive overall).

Check whether Figure 9.28 agrees with this paragraph above.

So each element has its own kind of atoms; each kind of atom has a specific number of protons in the nucleus, and the number of protons is the same as the **atomic number** in the periodic table!

Figure 9.28 *Rutherford's first model of the atom. The nucleus has almost all the mass but is very much smaller than the atom as a whole.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 237 2016/01/05 3:18 PM

Then scientists found another particle called the **neutron** in the nucleus, which added to the mass of an atom but did not have positive or negative electric charge.

Quick Activity:

1. Find beryllium on the periodic table on page 227. What is **the atomic number** of a beryllium atom? What is the mass number of a beryllium atom?
2. Now look at Figure 9.29. In what way does this Figure give you the same information as the periodic table?

The particles that make up an atom

Each element has its own kind of atom.

Each kind of atom has its own number of **protons** that carry positive charge, and **electrons** that carry negative charge.

The number of positive protons and the number of negative electrons are equal.

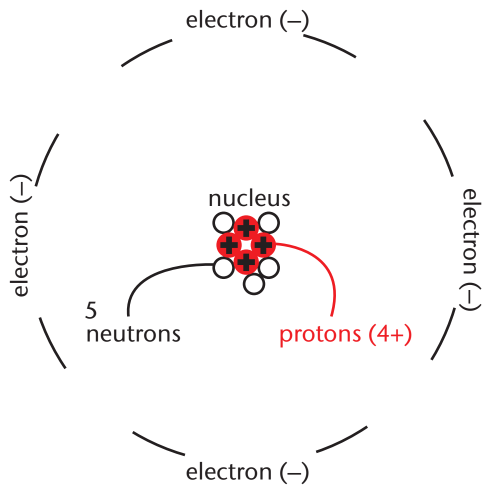
The protons are in the nucleus and the electrons move around the nucleus.

The nucleus also contains neutrons. A neutron has about the same mass as a proton but it has no charge.

Each kind of atom has its own **atomic number** in the periodic table, and the atomic number is the number of **protons**.

Each kind of atom has a mass number, which is the total of the number of protons plus neutrons.

Figure 9.29 *This represents a better model of a beryllium atom, but it was not yet the final model.*



Isotopes

Most carbon atoms have 6 protons and 6 neutrons, but among a hundred carbon atoms you might find 1 that has 6 protons and 8 neutrons. The common carbon atom is written $^{12}_{6}C$ but these odd-one-out atoms are written as $^{14}_{6}C$ or “carbon-14”. They are called **isotopes** of carbon.

Definition: **Isotopes of an element are atoms with the same atomic number but differing mass numbers. So carbon-12 and carbon-14 are both isotopes of carbon.**

The atoms have the same number of electrons because they have the same numbers of protons, and so they will take part in chemical reactions in the same way. But their masses are different.

Quick Activity:

1. What is the atomic number of a lithium atom?
2. The mass number for most lithium atoms is 7. But eight out of every hundred lithium atoms have a mass number 6. Do these atoms have a different atomic number to the majority of the lithium atoms?

Activity 3 Work out the basic structure of some atoms

A. Go to the periodic table on page 227 and find the metal elements beryllium ($_4$Be), sodium ($_{11}$Na) and magnesium ($_{12}$Mg).

B. Compare the drawing of the beryllium atom in Figure 9.28 on page 237 with the information about beryllium in the periodic table.

Questions

1. How many electrons does a beryllium atom have? How can you work it out from the periodic table?
2. Go to sodium ($_{11}$Na) in the periodic table. How many protons in a sodium atom's nucleus? And how many electrons does a sodium atom have?
3. Now look at magnesium ($_{12}$Mg). How many protons in a magnesium atom's nucleus? How many electrons?
4. What is the nett electric charge on a magnesium atom? Explain your answer.

Electronic structure: Rules for electrons in atoms

The model of the atom was still incomplete; it still did not help scientists to predict what the electrons will do if they are given energy. For example, why does hot matter give out light?

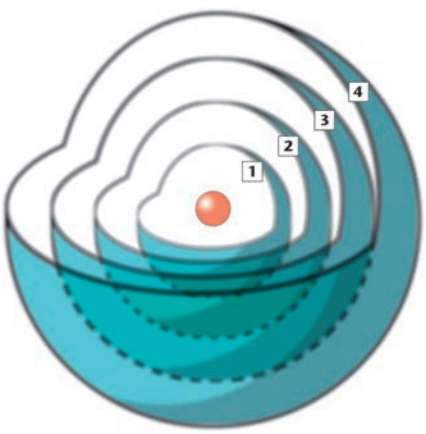
Another problem was this: Positive charges (the protons) attract negative charges (the electrons), so the electrons should all fall into the nucleus, and every atom should collapse like a leaking balloon. Then we would all be dead. But atoms don't collapse, and so we are alive.

So, the atom model needed to be improved.

A Danish scientist called Niels Bohr worked with Rutherford for a time. Electrons are so very small, he said, that completely new rules apply to them.

Niels Bohr wrote the new model of the atom; he said the electrons obey rules that nobody expected, but later experiments showed that the new rules for electrons were correct.

Figure 9.30 *Think of the energy levels as shells around a nucleus. This picture shows the shells cut open; they are actually like complete balls, one inside the other.*



Rule 1: Electrons are in **different energy levels**; the higher the energy, the further the electron moves from the nucleus. And each energy level can hold only a certain number of electrons.

Rule 2: The lowest energy level is closest to the nucleus. It can hold only 2 electrons. This energy level always fills up first.

Rule 3: The next energy level is further away from the nucleus and can hold up to 8 electrons.

Rule 4: The next energy level can hold up to 18 electrons.

Think of these levels as shells around the nucleus. Look at Figure 9.30 on the previous page. The nucleus is down in the middle of all those shells. Each shell represents all the places that an electron with a certain energy could be, all around the nucleus.

Core electrons and valence electrons

The positive nucleus holds the negative inner electrons quite strongly, and these are called the **core** electrons.

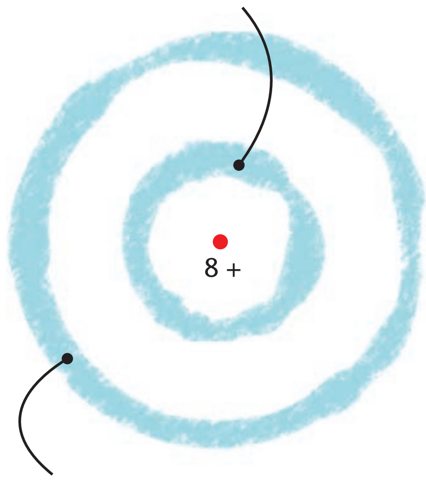
Of course, you know that atoms bond (join) together to form molecules, so they must touch on the outsides and so it must be their outer electrons that take part in making the bonds. These outer electrons that form bonds are called the **valence** electrons. Let's find out why they are called by that name.

Long before chemists understood the atom, they knew that atoms did join together in ratios of simple whole numbers. For example, they knew that when hydrogen and sulfur combined, it was always two hydrogen atoms for every sulfur atom, and so they wrote H_2S.

One nitrogen atom combined with three hydrogen atoms, and so they wrote NH_3.

One oxygen atom combined with two hydrogen atoms, and produced water, and so they wrote H_2O.

Figure 9.31 *The core and valence electron shells in an oxygen atom*



From these patterns they developed the idea of "combining power" or "valency". For example, they reasoned that every oxygen atom combines with two hydrogen atoms, and so oxygen has a **valency of two**, but hydrogen has a **valency of one**.

Unit 9.3 Summary activity

Answer these questions in your notebook.

1. Each kind of atom has its atomic number. What does that number mean?
2. What is the atom's mass number?
3. Why is the mass number different to the atomic number (except for hydrogen)?
4. Atoms contain positively charged protons, so why do atoms normally have no overall electric charge?
5. What is the difference between an electron shell near the nucleus and the shell on the outside of the atom?
6. What are the differences between the core electrons and the valence electrons?

Unit 9.4 Electron configuration

In Figure 9.32 on the next page, you see the first 36 elements in Periods 1 to 4. Each element has its own kind of atom, but some atoms have their valence electrons in the same energy level. All these kinds of atoms are placed in the same period.

In the first period we find the elements hydrogen and helium. A hydrogen atom ($_1H$) has only one electron and a helium atom ($_2He$) has only two electrons so we can't talk about a core. All their electrons are their valence electrons.

But now go to Period 2 (electron energy level L2). A lithium atom ($_3Li$) has an electron core that is like the helium atom, plus it has a valence electron in the second energy level, L2.

A beryllium atom ($_4Be$) also has an electron core like helium, but it has two valence electrons in the second energy level, L2.

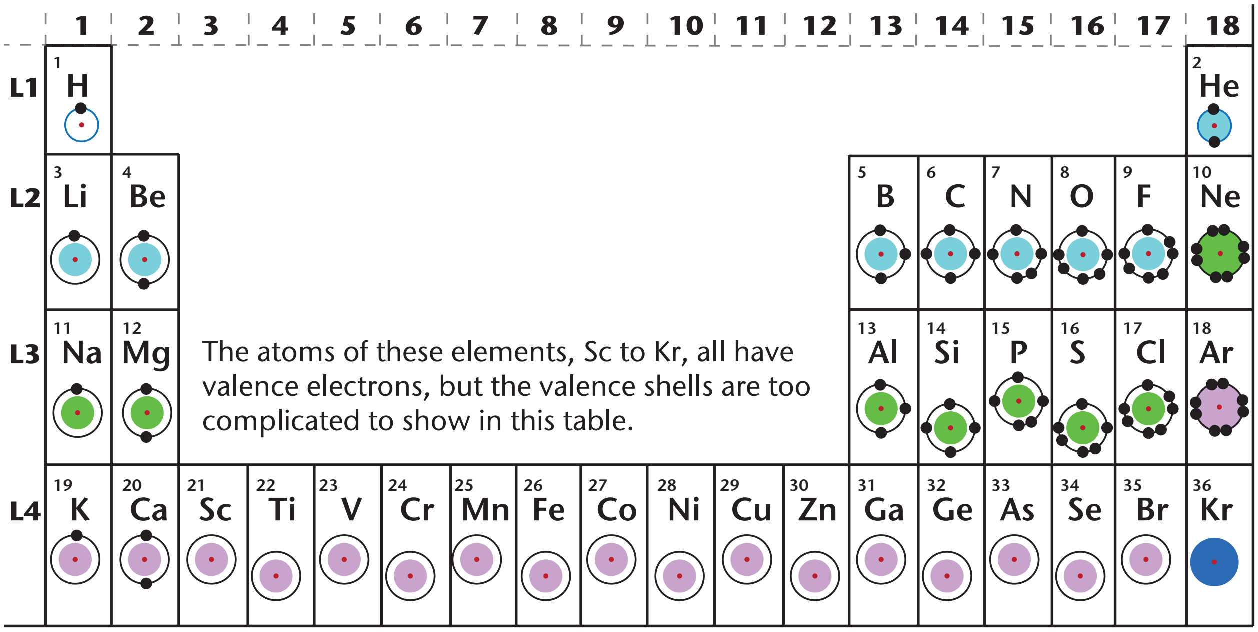
Of course, the nucleus of a beryllium atom is different to the nucleus of a helium atom – it has four protons, not two. A beryllium atom must have 4 protons, otherwise it could not hold onto 4 electrons! It also has more neutrons than a helium atom.

Go on to boron ($_5B$). It also has a core of electrons like helium but 3 valence electrons in the second energy level, L2.

Activity 4 Work out the number of electrons

1. How many valence electrons does a carbon atom ($_6C$) have? How many electrons does it have in its core?
2. In Figure 9.32 the atoms of nitrogen ($_7N$) and oxygen ($_8O$) seem to have the same kind of nucleus, but in fact they don't. What is the difference between the nuclei of nitrogen and oxygen atoms?
3. What is the total number of electrons in a fluorine atom?
4. How many valence electrons does fluorine atom ($_9F$) have?
5. Why is the number of fluorine valence electrons not the same as the atomic number of a fluorine atom?

Figure 9.32 *The periodic table of the elements, showing core and valence electrons. The nucleus of each kind of atom is shown as a small red dot, but in fact each nucleus is different and it has the number of protons equal to the atomic number for that kind of atom.*



Now let's look at a neon atom ($_{10}$Ne). In Figure 9.32, the whole neon atom is coloured green. It has eight valence electrons and, by Rule 3 on page 239, eight is the maximum number you can put into electron energy level L2.

The atoms of the next element, sodium ($_{11}$Na), must have their valence electrons in electron energy level L3, because Level L2 is full. The 10 **core** electrons of a sodium atom (Na) are like the electrons of neon (Ne, the green core), but then it has an eleventh electron with higher energy in the valence shell.

By now you can see the pattern. An atom in Period 3 (electron energy level L3) has an electron core like a neon atom plus extra electrons at the higher energy level.

Activity 5 What is similar among atoms in a group?

1. The metals lithium ($_3$Li), sodium ($_{11}$Na) and potassium ($_{19}$K) have similar properties, and that is why they are in the same group (Group 1). In what way are the properties similar? (If you don't know, get some help on page 228.)
2. What is similar about their valence shells?
3. Why are the metals beryllium ($_4$Be), magnesium ($_{12}$Mg) and calcium ($_{20}$Ca) in the same group (Group 2), do you think?
4. Neon ($_{10}$Ne) ends the second period, and sodium ($_{11}$Na) begins the third period. Why does the second period not carry on further with sodium?
5. Why do all the atoms in the third period, up to argon ($_{18}$Ar), have electron cores shown in green?

More details about electronic structure in atoms

Scientists had agreed on Niels Bohr's model of the atom; the model said that electrons are allowed to be in only certain energy levels. The higher the energy level, the greater the distance from the nucleus. We can think of them as shells around the nucleus.

The energy levels split into sub-levels

Scientists made more careful observations of how atoms behave and found that the Bohr model needed some extra rules to make it match the new observations. You saw Rules 1 to 4 on page 239. The added set of rules came from a theory called quantum mechanics.

These are the extra rules for electron structure:

Rule 5: Energy levels split into sub-levels called "s" and "p" orbitals. Look at Figure 9.33. Energy Level 1 (red) has only a 1s orbital, but Energy Level 2 (orange) splits into 2s and 2p orbitals. You see two sets of boxes in the orange level. Energy Level 3 (yellow) splits into 3s, and 3p orbitals. Energy Level 4 (green) splits into 4s and 4p orbitals. (There are more energy levels in Level 4 but we are not going to learn about those levels.)

Rule 6: Electrons occupy orbitals, but they first occupy the orbital with lowest energy, before they occupy one with higher energy.

Rule 7: The electrons prefer an empty orbital if they can find one. If there are no empty orbitals, they form an electron pair with another electron.

Figure 9.33 *The energy levels of the orbitals*

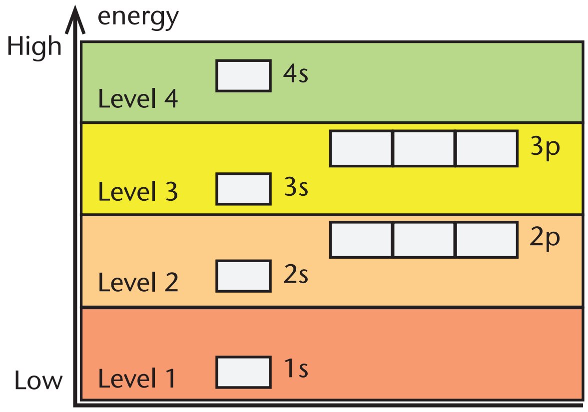
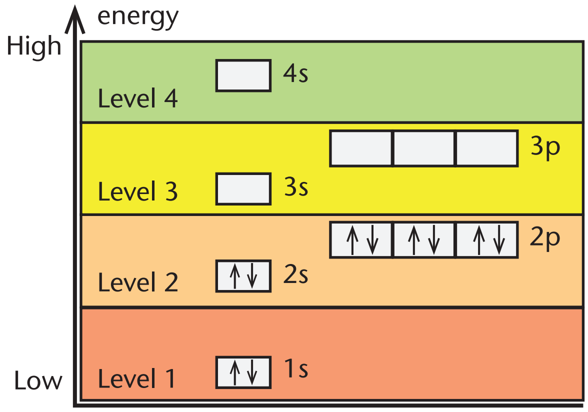


Figure 9.34 *Electrons in the orbitals of neon.*



The electrons are both negative particles, so they repel each other, but if they have opposite "spin numbers" they can share the same orbital. We show electrons with opposite spin numbers like this: ↑ and ↓. (Electrons don't actually spin, but the scientists had some reasons to choose this term, "spin number".)

Now if we use the rules to show the electronic structure of a neon atom (Ne), and we fill in ↑ and ↓ spins in Figure 9.33, then we get Figure 9.34. Each little box can have only 2 "spin" arrows – spin up and spin down.

We write the electron structure as $1s^2\ 2s^2\ 2p^6$. You say "one ess two, two ess two, two pea six". The $1s^2$ does **not** mean s-squared.

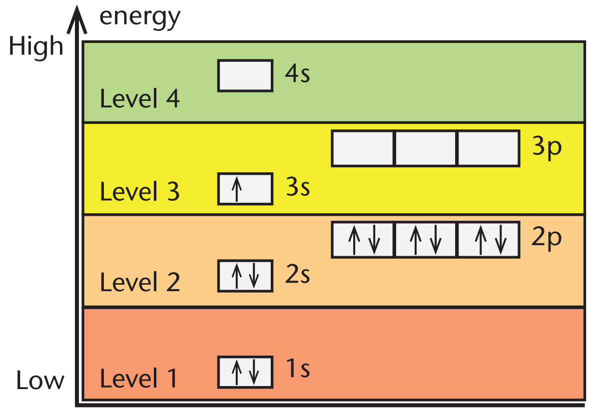
Now compare the electronic structure $1s^2\ 2s^2\ 2p^6$ with the structure for **neon** in Figure 9.32 on page 242. There you see eight dots for the eight electrons in the valence shell. Neon's valence electrons are in Energy Level 2, which can hold only eight electrons. Well, here the electrons are again; count the little arrows in the orange Energy Level 2 in Figure 9.34. How many do you find?

Now add up the electrons numbers in Energy Level 2, in $1s^2\ 2s^2\ 2p^6$ – you should get eight electrons.

Let's move on to sodium (Na). Find sodium in Figure 9.32 on page 242.

A sodium atom's electrons have the same structure as the neon atom ($1s^2\ 2s^2\ 2p^6$, in the red and orange levels in Figure 9.35), but with one electron in a higher energy level (yellow, Level 3). So the electronic structure for sodium is $1s^2\ 2s^2\ 2p^6\ 3s^1$.

Figure 9.35 *Electrons in the orbitals of sodium. Levels 1 and 2 are the same as for neon.*



The electrons in the red and orange levels are called the **core electrons** and that outer electron in the yellow energy level is called a **valence electron**. The valence electron can take part in reactions with other atoms.

Activity 6 Work out the electronic structure of magnesium

We are going to find the element magnesium (Mg) in the periodic table and write out its electron structure.

A First find Mg on the periodic table.

B. What is the atomic number of an Mg atom? From that, work out how many protons the nucleus has.

C. From that information, how many electrons does the atom have?

D. In what period (row) is magnesium, in the periodic table? Use that information to work out the highest energy level of its electrons.

Questions

1. Copy Figure 9.33 on page 243 and fill in a magnesium atom's electrons in the "s" and "p" orbitals.
2. Write out the electronic structure of magnesium atoms in the form of $1s^2$ $2s^2$, etc.
3. Write out the electron structure of aluminium (Al). Use the same method as for magnesium, above.
4. What are the energy levels of the core electrons of an aluminium atom?
5. Draw the shells of an aluminium atom and show how many valence electrons it has.

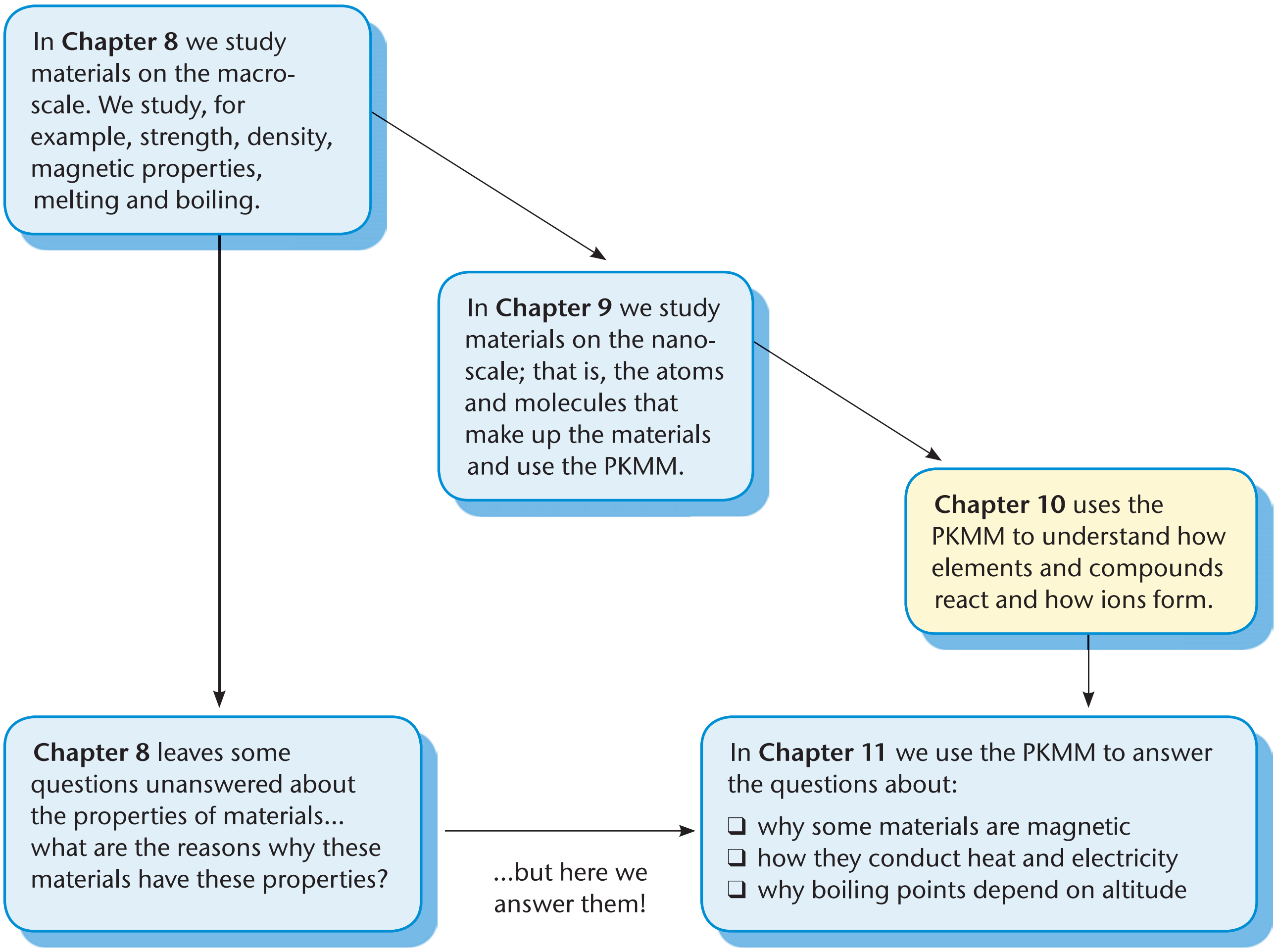
Chapter summary

- Pure substances are made of only one kind of matter. Pure substances can be classified as compounds or elements.
- Compounds are made from two or more elements, and compounds can be broken down into their elements.
- Atoms that form the molecules of a compound join together in a fixed ratio; for example, H_2O but never O_2H.
- The periodic table shows groups of elements that have similar properties.
- The elements are metals, non-metals or metalloids. Each of these three types of element appears in a particular part of the periodic table.
- Each element has its own kind of atom and its own symbol in the periodic table.
- In the periodic table, an element's atomic number shows the number of positive protons in each atom.
- Going down a group, the different atoms in a group have the same number of valence electrons. This is the main reason why these elements in the group have similar properties.
- Going across a period of the periodic table, the atoms all have the same electron cores, but each new kind of atom has one more valence electron.
- Each atom's electrons move around the nucleus but the electrons can have only certain energies, not all energies.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 246 2016/01/05 3:18 PM

CHAPTER 10 Reactions and equations

In Chapter 8 you learned about the properties of materials, and in Chapter 9 you learned about the particles and substances that make up those materials. In Chapter 10 you learn how the atoms join with each other in exact ratios. Look at the map below to see where the chapters are going.



Unit 10.1 Compounds can decompose to elements

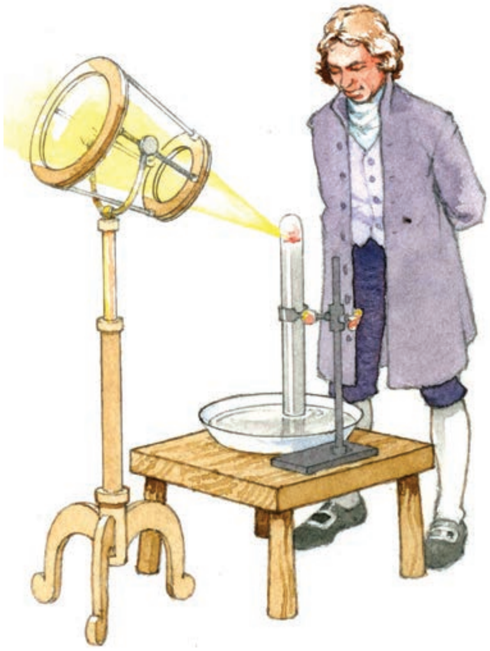
In Chapter 9 you learned how people, long ago, obtained elements from special kinds of rock. The rock contained compounds, and the compounds broke down into elements.

In 1774, Joseph Priestley in England was investigating an orange powder called "calx of mercury". The powder was in a small dish, floating on mercury in a narrow tube. You see the apparatus in Figure 10.1. He used two big magnifying glasses to focus the energy from the Sun onto the powder.

The Sun heated the orange powder inside the glass tube. It turned a dark colour and it gave off a gas. Priestly did not know what this gas was, but he used larger apparatus to collect enough of the gas to breathe some himself. He wrote in his notebook that it made him feel very good.

Nobody knew what the gas was and it did not yet have a name. But Priestley's discovery became a key idea in understanding chemistry. You can find the story in the Resource Pages.

Figure 10.1 *Joseph Priestley found that the heat of the Sun made the orange substance give off a gas.*



Activity 1 Read about Joseph Priestley's discovery

Find the story about Joseph Priestley in the Resource Pages. Read it and answer the questions below in your notebook.

Questions

1. What was the gas that Priestley discovered? Write two paragraphs to describe Priestley's experiment.
2. After he heated the orange powder, the mercury liquid in the tube was pushed down. Why did the liquid get pushed down?
3. He wrote in his notebook that breathing the gas made him feel good and the mice seemed to like it also. Why did the gas have that effect?
4. He also put a burning candle in a jar full of the gas. What happened to the candle flame?

Joseph Priestley had actually discovered oxygen. He was able to show that oxygen is one of the gases in air, and that all animals and humans need oxygen to live. He also showed that plants produce oxygen, and so plants replace the oxygen that humans, animals and fires remove from the atmosphere.

Mercury is an element and so is oxygen. Priestley had broken the compound mercuric oxide down into its two elements! In the periodic table you can find the elements oxygen ($_{8}O$) and mercury ($_{80}Hg$).

The orange compound, mercuric oxide (HgO), is a powder. Each grain of the powder is made up of billions of mercury atoms joined to billions of oxygen atoms in a regular pattern. This structure is called a **lattice**.

The energy from the sun, which came through Priestley's burning-glasses in Figure 10.1, gave the atoms enough energy to break apart. The atoms of oxygen formed oxygen molecules. The mercury atoms joined together in giant molecules that grew so big that he could see them as little drops of mercury.

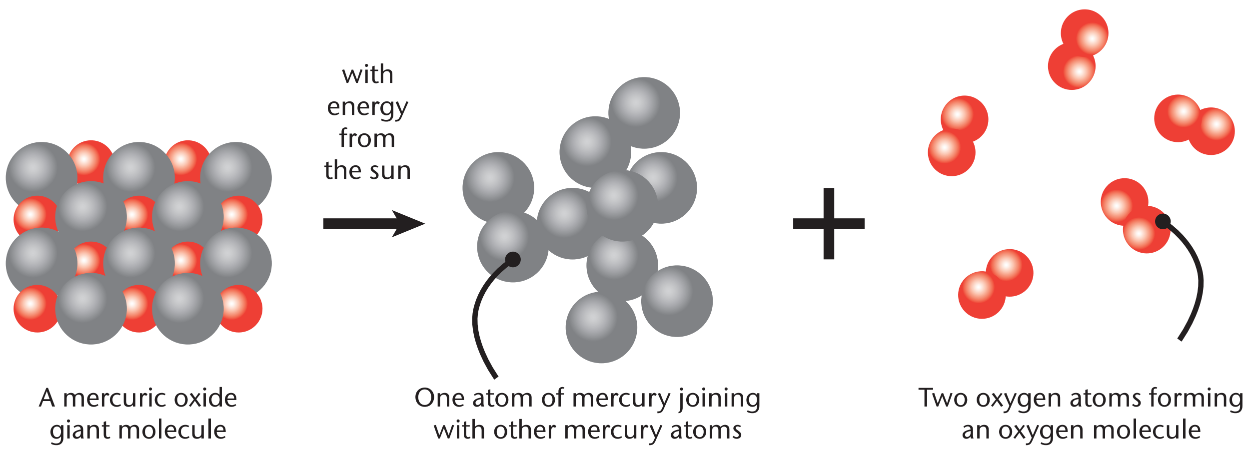
When atoms that were joined together break apart, and join with other atoms, we say that a reaction has happened.

Chemists have ways to summarise changes like this. Let's begin with a statement in words:

Mercuric oxide breaks up to form mercury and oxygen.

Then we do a drawing to show what happened. We call this a **picture model**.

Figure 10.2 *The giant molecule of mercuric oxide broke up to form ten mercury atoms and five oxygen molecules. The arrow tells us that the change was from mercuric oxide to mercury and oxygen.*



We can count 10 mercury atoms in the mercuric oxide giant molecule on the left of the arrow; there must be the same number of mercury atoms on the right. We count 10 oxygen atoms (coloured red) in the mercuric oxide on the left, and there must be the same number of oxygen atoms on the right. Oxygen atoms join together in pairs that we call O_2 molecules, but there are still 10 oxygen atoms.

In a chemical reaction, matter is conserved. That means no atoms are destroyed and no new atoms are created. That is why we can talk about a chemical equation: the number of each kind of atom is equal on the left and the right sides.

Balancing a chemical equation

Hg is the symbol for mercury, and **O** is the symbol for oxygen. So we can write an equation, counting up the atoms on each side of the arrow:

$10\ HgO \rightarrow 10\ Hg + 5\ O_2$

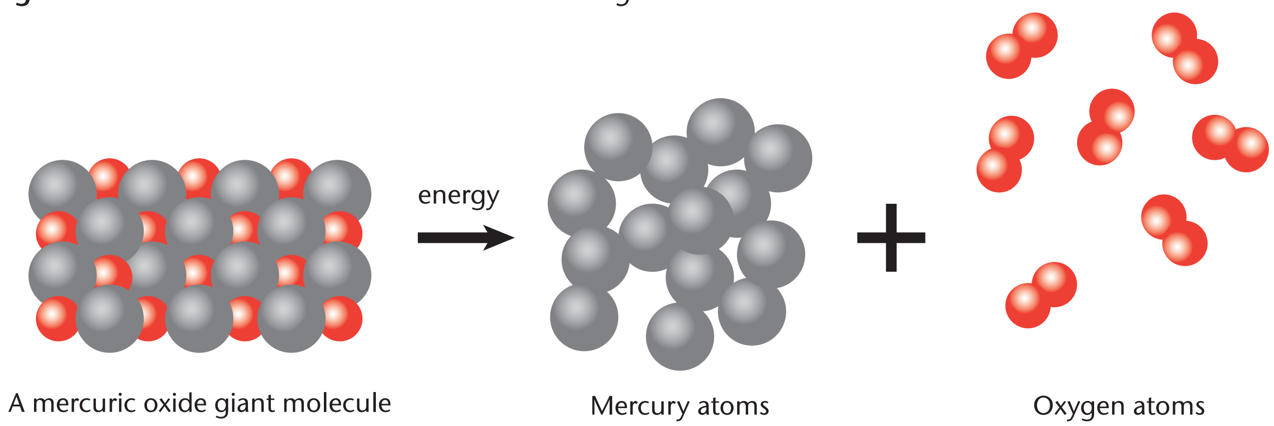
In symbols, we are saying the same as the picture model in Figure 10.2 on the previous page.

If we wrote:

$14\ HgO \rightarrow 14\ Hg + 7\ O_2$

the ratio of HgO molecules to O_2 molecules will remain the same, at two HgO to one O_2 molecule.

Figure 10.3 *Count the atoms on the left side and the right side of the arrow.*



Now the simplest way we can write the ratio is to write:

$2HgO \rightarrow 2\ Hg + O_2$

This equation tells us that for every two HgO molecules, we get two Hg atoms and one O_2 molecule.

The equation is **balanced** because the number of Hg atoms is the same before and after the reaction, and the number of O atoms is also the same, before and after.

We have been looking at Joseph Priestley's experiment that broke down mercuric oxide into elements; now let's look at another famous experiment that broke down water.

How scientists proved that water is a compound

The alchemists long ago believed that water was an element. But scientists after Priestley suspected that water was *not* an element.

In 1799, Alessandro Volta invented a kind of battery and wrote about it. Two scientists in England read what Volta wrote, and made a similar battery. They began experimenting with it immediately, to see whether they could break water into its elements.

You could actually do this yourself, using the apparatus you see in Figure 10.4.

You see a 9 volt battery connected to 2 stainless steel electrodes. Each electrode is inside a clear plastic tube, closed at the top but open at the bottom.

Each electrode is in contact with the water. When you connect the battery, bubbles begin to form at each electrode and fill the plastic tubes with gas.

But you get twice the volume of gas at the negative electrode compared to the positive electrode. When you test the gases, you find that the gas that collected at the negative electrode is hydrogen, and the gas at the positive electrode is oxygen.

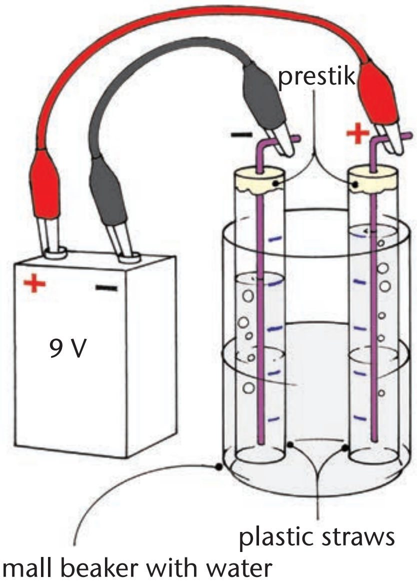
So water is not an element – it is made of two elements, oxygen and hydrogen. Like the scientists in 1800, we make an **inference*** – we infer that there were twice as many hydrogen molecules as oxygen molecules. If we collected two billion hydrogen molecules, then we collected one billion oxygen molecules.

In words, the reaction is:

water (by energy from the battery) breaks down into **hydrogen** and **oxygen**

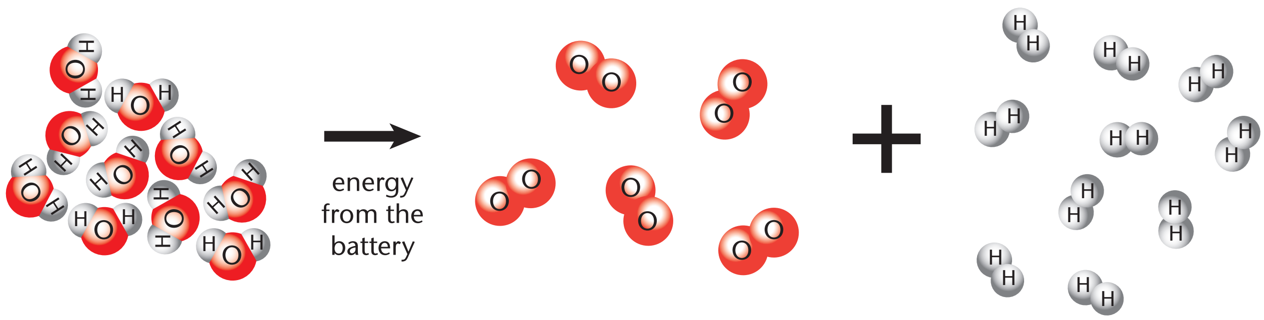
We can model this with beads, or we can draw this:

Figure 10.4 *The apparatus you need for decomposing water into its elements*



* **inference** – a conclusion you make after thinking about the observation

Figure 10.5 *A picture model of water decomposing into hydrogen and oxygen*



The picture model must show a balanced equation. Count the number of oxygen atoms and hydrogen atoms on each side of the arrow. Are they equal?

In symbols, we can summarise that picture with this equation:

$$2H_2O \rightarrow 2H_2 + O_2$$

Think: What is the ratio of hydrogen atoms to oxygen atoms in water? Is the hydrogen:oxygen ratio 2:1 or 1:1 or 1:2?

We can make elements react to form a compound

In Activity 2 we will react two elements and get the compound that forms.

Activity 2 Make a compound of magnesium and oxygen

This should be done as a demonstration.

Wrap a strip of magnesium around a pencil and heat it as you see in Figure 10.6. Don't look directly at the flame because it is very bright. The **oxygen** in the air reacts with the **magnesium**, giving off a lot of energy.

Magnesium and oxygen are called the **reactants** and the white powder is called the **product** of the reaction.

Figure 10.6 *Wrap the magnesium around a pencil and heat the end of the magnesium.*

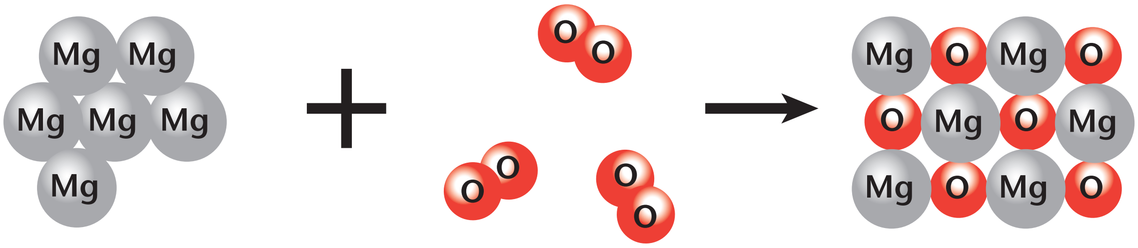
Figure 10.7 *The magnesium reacts with oxygen in the air.*

Figure 10.8 *The product of the reaction is a white powder.*

Questions

1. Look closely at the white powder: it has very small white crystals. Is the powder an element or a compound?
2. Complete this as a word equation: ______ and ______ react to form magnesium oxide
3. We can use a model or drawing to show the numbers of atoms in the reaction. If you use beads to represent atoms, use at least 6 beads stuck together to represent magnesium.

   Figure 10.9 *Use at least 6 beads to represent a magnesium giant molecule*

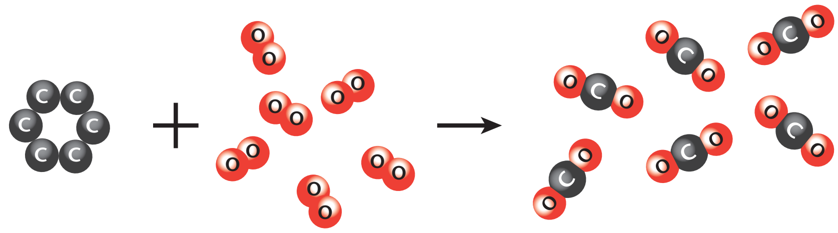


4. Complete the chemical equation below and balance it.
   $Mg + O_2 \rightarrow$ ________
5. Name the **reactants** and the **product** in the above reaction.

Activity 3 Practise balancing some more chemical equations

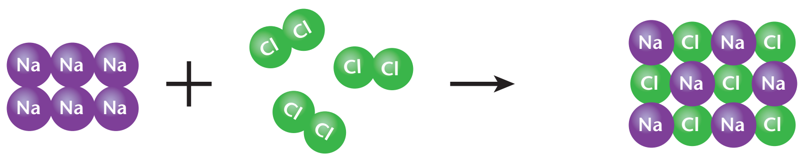
1. Copy or complete each picture model in your notebook and **balance the equations.**

carbon	+	oxygen	–(heat)→	carbon dioxide	(a colourless gas)
C	+	O_2	–(heat)→	________________	



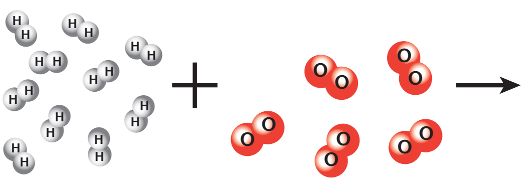
Draw the carbon dioxide molecules far apart because carbon dioxide is a gas.

sodium	+	chlorine	→	sodium chloride	(a white powder)
Na	+	Cl_2	→	________________	



Draw the Na and Cl atoms packed together, because they form a giant molecule.

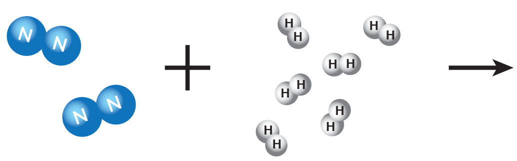
hydrogen	+	oxygen	–(heat)→	water	(a colourless liquid)
H_2	+	______	–(heat)→	________________	



?

This model is not complete. Draw enough molecules to let atoms balance in the equation.

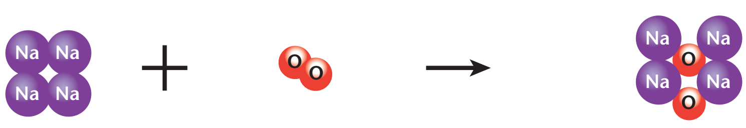
nitrogen	+	hydrogen	–(heat)→	ammonia gas	(a strong-smelling colourless gas)
N_2	+	H_2	–(heat)→	NH_3	This equation is not balanced.



?

This picture model is not complete. Copy it and draw the right number of NH_3 molecules.

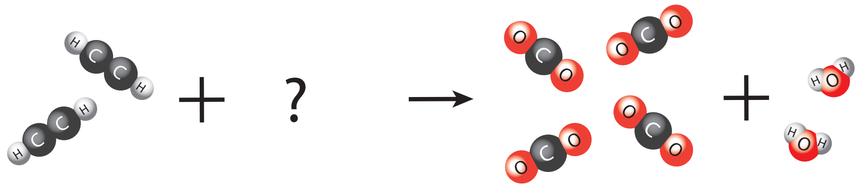
sodium	+	______	–(heat)→	sodium oxide	(a white powder)
Na	+	______	–(heat)→	Na_2O	



Draw the sodium and oxygen atoms packed together like this, because the white powder is a solid.

Acetylene and oxygen are two gases that are used in flame-cutting steel.

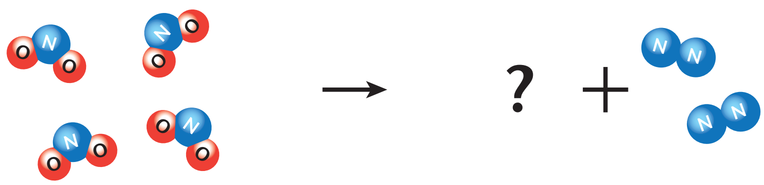
acetylene	+	oxygen	–(heat)→	carbon dioxide + water	(colourless gases)
C_2H_2	+	O_2	–(heat)→	CO_2 + H_20	This equation is not balanced.



This picture model is not complete. Copy it and draw the right number of O_2 molecules.

Catalytic converters reduce air pollution caused by nitrogen dioxide from car exhausts

nitrogen dioxide (a brown gas)	–(heat)→	oxygen + nitrogen	(colourless gases)
NO_2	–(heat)→	O_2 + N_2	This equation is not balanced.



This picture model is not complete. Copy it and draw the right number of molecules to make the equation balanced.

Indigenous iron-workers in South Africa used this reaction when smelting iron from iron oxide

iron oxide	+	carbon	–(heat)→	iron + carbon dioxide	
Fe_2O_3	+	C	–(heat)→	Fe + CO_2	This equation is not balanced.

2. In the reaction between carbon and oxygen (on the previous page):
   - **a)** Why does the picture model show carbon atoms packed together, but O_2 oxygen molecules far apart?
   - **b)** Why are the CO_2 molecules far apart?
3. What are the valencies of sodium and of oxygen in the compound Na_2O?

Unit 10.1 Summary Activity

Answer these questions in your notebook.

1. How do you know when a chemical equation is not balanced?
2. What are the reactants and products in a chemical reaction?
3. Draw a picture model of four water molecules decomposing into the molecules of the elements of water.

Unit 10.2 Some substances form ions in water, but others do not

Ions are atoms or molecules that have lost electrons, or atoms or molecules that have gained electrons. But how can we have atoms that behave like that? In this unit we are going to find out how ions form and how they behave.

We have to begin by understanding what water is made of.

Looking at water on the macro-scale

People, plants and animals can live on Earth because water has some amazing properties. In our bodies, water carries dissolved substances to all our organs.

In plants, water clings to the inside of tiny tubes inside the plants and so it can rise to the leaves at the top of the highest trees. Water dissolves substances in the soil and carries the solutions though the roots to all parts of the plant.

Water seems to have a skin on the surface. You can float a steel needle on its surface. Some insects, called pond-skaters, run on the skin that water forms: look at Figure 10.10. The reason for the skin is a force acting all over the surface, called **surface tension**.

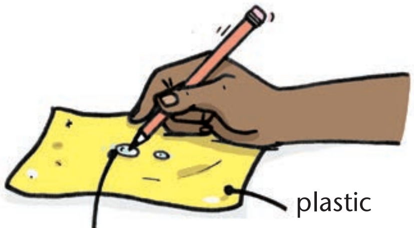
Figure 10.10 *This insect is a pond-skater. It can run on the surface of the water.*

Quick Activity:

Put two small drops of water on a smooth plastic or glass surface. Notice how they pull in their edges and form a little hill.

Now use a pencil and move them together until their edges just touch. They seem to reach out and grab each other, and form one round drop.

Figure 10.11 *Move the drops of water closer together, until they just touch.*



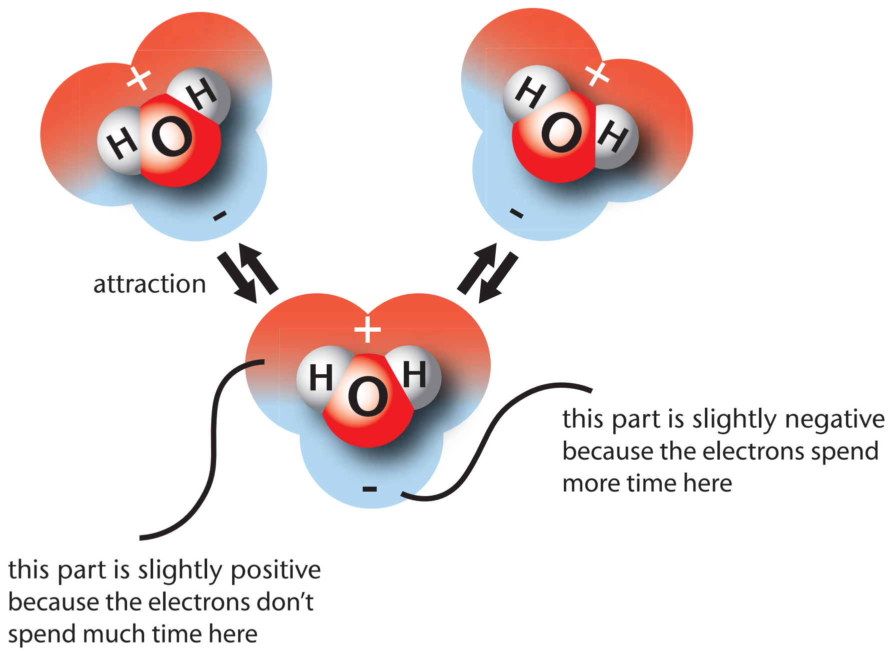
Looking at water on the nano-scale

Water molecules are made up of two hydrogen atoms and one oxygen atom bonded together. The three atoms have valence electrons and each valence electron spends some time moving near each atom. We say that the valence electrons are “shared” between the atoms.

If you look at the periodic table (on page 227) you see that hydrogen is on the left of the table, and oxygen is on the right. Atoms that lie towards the *right-hand side* of the periodic table tend to pull electrons towards themselves, and they do this more than atoms that lie towards the *left-hand side*.

The electrons in the water molecule spend most time in the space between the O and the H atoms and they are called shared electrons. The oxygen atom pulls the shared electrons over to its side, and so they spend more time near the oxygen atom. This makes the molecule slightly negative on the oxygen's end (remember that electrons are negative) and leaves it slightly positive on the hydrogens' end. You can see this in Figure 10.12.

Figure 10.12 *Each water molecule has a positive or a negative end. The positive end of one attracts the negative end of another.*



As you can see in Figure 10.12, the negative oxygen end will attract the *positive* part of another water molecule while the hydrogen end will attract the *negative* end of another water molecule. On the surface of the water, the water molecules pull sideways on each other and so they form the elastic "skin" on water.

The attraction between the water molecules is called **hydrogen bonding**.

Hydrogen bonding does not happen only between water molecules, of course – many substances dissolve in water. The water molecules pull on any parts of a molecule that are slightly positive or slightly negative.

Let's see how sugar and salt dissolve in water

You remember that we did mixtures in Chapter 9. A mixture is made of two or more substances mingled together.

Dissolving sugar in water

Let's imagine you mix some sugar in a cup of water, and stir the mixture well, until you get an even mixture. An even mixture is called a **solution***.

The sugar seems to disappear but of course it is still there.

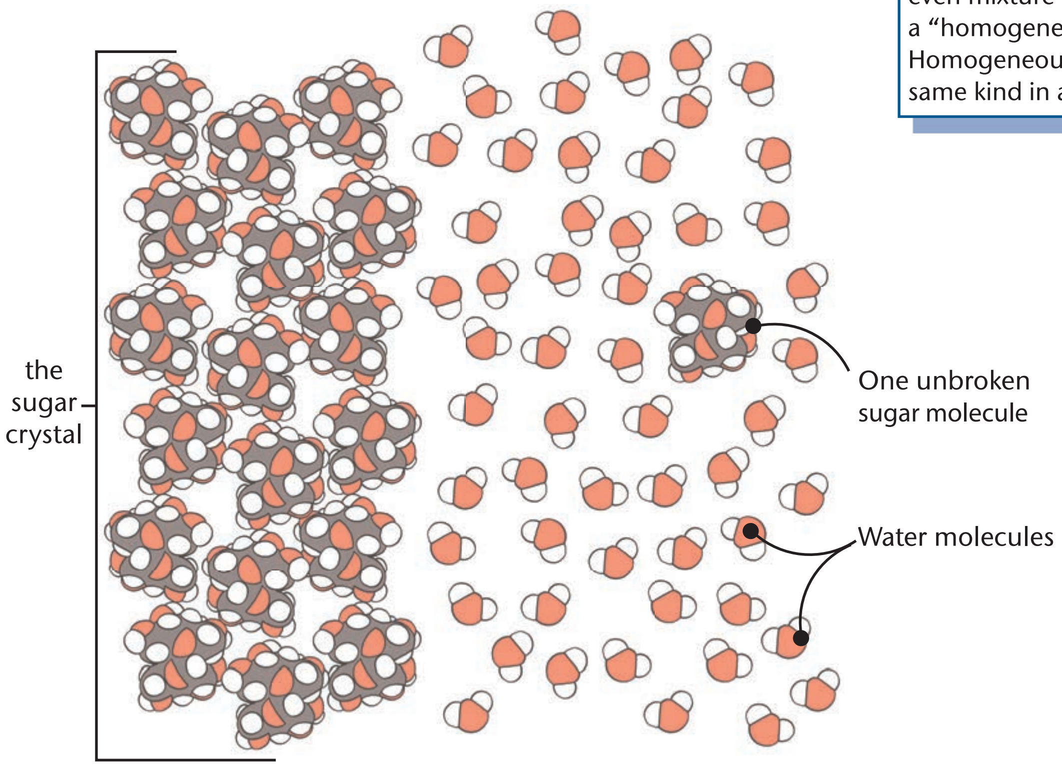
That was a macro-scale description of the sugar dissolving. Now let's think on the nano-scale.

Look at Figure 10.14. The water molecules pull at some slightly positive hydrogen atoms in the sugar molecules and this pulls the molecules out of the sugar crystal. Then the water molecules bump the sugar molecules around and spread them out among other water molecules. **But the sugar molecules themselves do not break up.**

Figure 10.13 *Sugar dissolves in water.*

> * **solution** (noun) – an even mixture of substances. An even mixture is also called a "homogeneous mixture". Homogeneous means "of the same kind in all parts".

Figure 10.12 *Each water molecule has a positive and a negative end. The positive end of one attracts the negative end of another.*



Dissolving salt in water

Does the same sort of dissolving happen with salt (NaCl) in water? No, something different happens on the nano-scale.

Remember what we said on page 256: atoms on the right-hand side of the periodic table have greater electron pulling-power than atoms on the left-hand side. That means the chlorine atom in a salt molecule has a bigger pull on the electron than the sodium atom; so much so, that the chlorine atom pulls the electron over to its side most of the time. If the atoms were pulled apart, the chlorine atom would try to keep the electron.

Now think of a salt crystal, NaCl, surrounded by water molecules. You remember from Figure 10.12 that a water molecule, H_2O, is a little positive on the side where the H atoms are, and a little negative on the side where the oxygen atom is. The positive ends of the H_2O molecules tug at the chlorine atoms in the salt crystal and the negative ends tug on the sodium atoms in the salt crystal. When the water molecules pull a sodium atom away from the crystal, the chlorine atom holds onto the electron they shared, leaving the sodium atom short of one electron and therefore positive. We call the positively charged sodium atom a positive **ion** (say EYE-on).

The chlorine atom gets pulled out of the crystal by the water molecules too. It still has that extra electron it held onto and so it has a negative charge. It, too, is an ion, but a **negative ion**.

Compounds like table salt (NaCl) and copper sulfate ($CuSO_4$) are made of a metal element and non-metal elements. Compounds like these tend to break up into positive and negative ions among water molecules.

The positive ions are called **cations** and the negative ions are called **anions**. On page 263 you can find a table of cations and anions.

Figure 10.15 *A salt crystal: green balls represent chlorine atoms.*

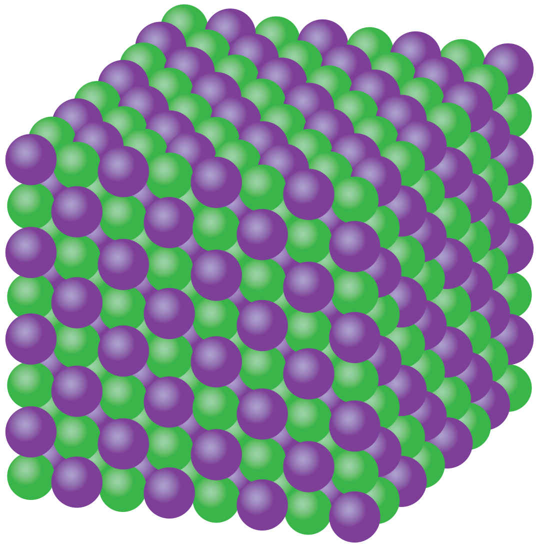
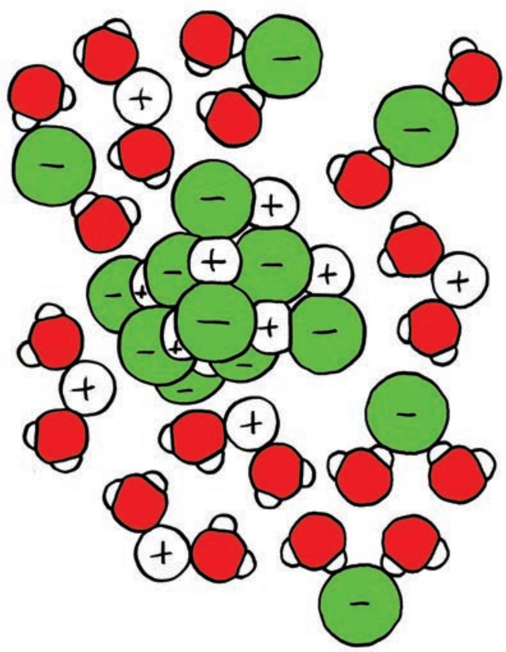


Figure 10.16 *The positive and negative ends of the water molecules tug at the negative chlorine and positive sodium atoms.*



Solutions can conduct electricity if they have ions. Scientists have a simple and very useful way to find out whether substances form ions in water.

Activity 4 Find out whether a substance forms ions in water

A solution will conduct an electric current if it has positive and negative ions in the solution.

Focus question: Do all solutions conduct current equally well?

Apparatus (per group)
- ❑ a micro-well plate, or alternatives described in the Teacher's Guide
- ❑ conductivity tester (described in the Teacher's Guide)
- ❑ 9 volt battery
- ❑ droppers, with labels, containing tap water and six different water solutions

Procedure

A. In Figure 10.17 you see a conductivity tester you can make; the school might have other kinds of conductivity testers. If a current flows from one electrode to the other, the LED lights up.

B. In your notebook, make a sketch of the micro-well plate in Figure 10.18. When you revise for a test, it will help you remember what solution you put in each well. These are the solutions in the droppers:

- tap water – don't add anything to it
- sugar A solution – 1 g of sugar dissolved in 1 litre of water
- sugar B solution – 10 g of sugar dissolved in 1 litre of water
- salt A solution – 1 g of salt dissolved in 1 litre of water
- salt B solution – 10 g of salt dissolved in 1 litre of water
- copper sulfate A solution – 1 g of copper sulfate dissolved in 1 litre of water
- copper sulfate B solution – 10 g of copper sulfate dissolved in 1 litre of water

Figure 10.17 *You can make this conductivity tester.*

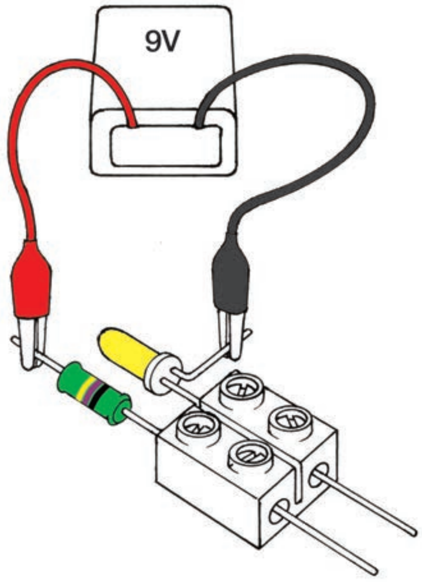
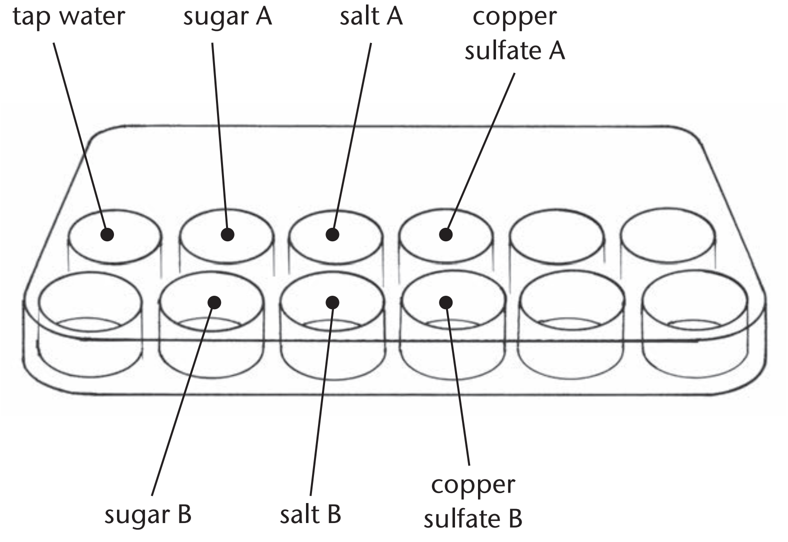


Figure 10.18 *The micro-well plate for testing the conductivity of solutions*



NOTE: Sugar B solution has more sugar in a litre of water than sugar A solution; we say that sugar B solution is more **concentrated** than sugar A solution.

C. Answer Question 1.

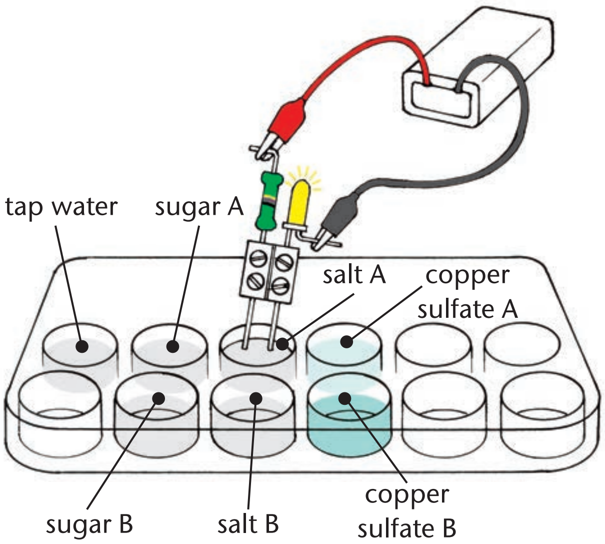
D. Use the droppers or squeeze-bottles your teacher has given you. Put tap water in the first well on the left. Half-fill each of the other wells with its correct solution.

E. Dip the conductivity tester into the tap water and see whether the LED glows. Record your observation in the table for Question 3.

F. Test all the other solutions and record how brightly the LED glows.

Figure 10.19 *Use the correct dropper to half-fill each well.*

Figure 10.20 *Notice how brightly the LED glows and record it.*



Questions

1. Which solution is more concentrated, salt A or salt B? Explain your answer.

2. Which solution is more concentrated, copper sulfate A or copper sulfate B? Explain your answer.

3. Copy and complete the table below, in your notebook. Next to each solution, write how bright the LED was. You can write "no light", "dim", "bright", or "very bright".

Brightness of the LED			
Tap water:	Sugar A:	Salt A:	Copper sulfate A:
	Sugar B:	Salt B:	Copper sulfate B:

4. Look at your records and try to find a pattern in them. In which solutions was the LED bright, dim, or not glowing at all?

5. Put the solutions in order of conductivity from least conductive to most conductive:

Least Most

6. Which solutions have the most ions per litre, which have the least ions per litre, and which seem to have no ions per litre?

What we have learned from Activity 4

Some compounds, such as sugar, dissolve in water as their molecules separate and mix with the water molecules. The molecules are not ions.

Other compounds, such as salt and copper sulfate, react with water and the molecules break up into ions. The ions mix with water molecules, and there are equal numbers of positive and negative ions. The ions move, so that there is a flow of charges through the solution. We say the solution conducts electricity.

If the solution has lots of ions among the water molecules to carry electric charge, the conductivity is high. If there are fewer ions among the water molecules, there are fewer ions to carry the electric charge, and the conductivity is low.

How we measure conductivity

Conductivity of solutions is measured in the unit Siemens per metre (S/m) or Siemens per centimetre (S/cm). The points of a conductivity tester are set exactly 1 cm apart.

Ions in water: Conductivity testing in industry

The water that is used in industrial boilers and power stations must have very low quantities of dissolved substances per litre. Dissolved substances could form deposits that block the pipes of a boiler. An industrial chemist will use a conductivity tester to test the water for dissolved substances.

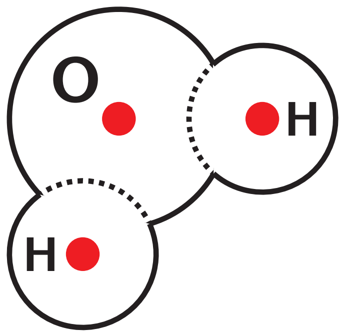
Very pure water will not conduct because it has almost no ions in it. Tap or borehole water always has some substances dissolved in it and so it will conduct a very small current. However, if the water conducts a larger current, that is a warning to the chemist that the water contains too much of some dissolved compound.

Unit 10.2 Summary Activity

1. Water, H_2O, has a polar molecule. "Polar" means that it has a positive and a negative pole. Scientists think that the molecule looks like Figure 10.21 on the right. Copy the diagram and complete it. Show the parts of the molecule that are a little positive and a little negative.

2. How do we know whether or not a compound breaks into ions in water?

Figure 10.21



Unit 10.3 Naming compounds

As you learned in Chapter 9, there are millions of different substances that chemists use and study. They need to have ways to name all the substances, so that they can talk and write to each other about them. That means they must agree on some rules for naming substances.

The table of cations and anions

In water solution, compounds that ionise form positive cations and negative anions. The cations are ions of metal atoms, and the anions are ions of non-metal atoms or groups of atoms called radicals.

The cation **NH**$^{4+}$ behaves like a metal ion in reactions.

You find the table of anions and cations in Figure 10.22 on page 263. You see that groups of cations and anions have headings such as 1+ or 2–. The cations that are grouped together under the heading 1+, for example, have a valency of 1 in reaction with anions.

The rules for naming compounds are drawn up by the International Union of Pure and Applied Chemistry (IUPAC).

Some elements have a valency that may be different in different reactions, and then we write a Roman numeral right next to the name of the cation to show which valency it has. So we write copper(II) chloride, which is $CuCl_2$, and copper(I) chloride, which is CuCl. This is called **Stock notation**.

Naming compounds

In times past, chemists gave whatever name they liked to substances, and so we have names like Epsom salts (magnesium sulfate) and Condy's crystals (potassium permanganate). Later on, chemists became more methodical and followed rules for naming compounds. The rule they followed was that **the name of the element towards the left side of the periodic table comes first.**

Stop reading for a moment and find the elements sodium ($_{11}$Na), potassium (^{19}K), chlorine ($_{17}$Cl) and iodine ($_{53}$I) on the periodic table on page 227.

Following the rule that the left-most element name in the periodic table comes first, we have **sodium chloride**, not "chlorine sodium", and **potassium iodide,** not "iodine potassium". We also have **hydrogen** sulfide and **hydrogen** chloride. And we have **carbon** dioxide, because carbon lies to the left of oxygen.

Quick Activity:

Use the Periodic Table to help you match the names and the formulae below. Note that there is one formula that does not have a match.

Names: copper sulfide; potassium bromide; hydrogen chloride; hydrogen sulfide

Formulae: CuS; HCl; KBr; NaCl; H_2S

Also, on the table of anions, you see groups of atoms with electric charge, like hydrogen carbonate (HCO_3^-), carbonate (CO_3^{2-}) and sulfate (SO_4^{2-}). These groups of atoms are called **radicals** and they usually behave like a single anion.

The prefixes **di-** and **tri-** are used to name compounds that have two atoms or three atoms of the same element in the molecule. Examples are carbon **di**oxide, sulfur **di**oxide and sulfur **tri**oxide.

However, chemists got lazy about naming compounds in a methodical way and so they agreed to talk about calcium chloride ($CaCl_2$) when they should really say calcium **di**-chloride. You may also know that $FeCl_3$ is called ferric chloride, even though it should really be called iron **tri**-chloride. (Ferric chloride is used for etching printed circuit boards.)

Figure 10.22 *Table of cations and anions*

Cations

1+		2+		3+	
cesium	Cs^+	barium	Ba^{2+}	aluminium	Al^{3+}
gold (I)	Au^+	beryllium	Be^{2+}	chromium (III)	Cr^{3+}
hydrogen	H^+	cadmium	Cd^{2+}	cobalt (III)	Co^{3+}
lead (I)	Pb^+	calcium (II)	Ca^{2+}	gold (III)	Au^{3+}
lithium	Li^+	cobalt (II)	Co^{2+}	iron (III)	Fe^{3+}
potassium	K^+	copper (II)	Cu^{2+}	manganese (III)	Mn^{3+}
silver	Ag^+	iron (II)	Fe^{2+}		
sodium	Na^+	lead (II)	Pb^{2+}		
copper (I)	Cu^+	magnesium	Mg^{2+}	**4+**	
ammonium	NH_4^+	manganese (II)	Mn^{2+}	tin (IV)	Sn^{4+}
		mercury (II)	Hg^{2+}	nickel (IV)	Ni^{4+}
		nickel (II)	Ni^{2+}	lead (IV)	Pb^{4+}
		strontium	Sr^{2+}		
		zinc	Zn^{2+}		
		tin (II)	Sn^{2+}		

Roman numeral notation indicates charge of ion when element commonly forms more than one ion. For example, iron (II) has a 2+ charge; iron (III) has a 3+ charge.

Anions

1-				2-		3-	
acetate	$C_2H_3O_2^-$	cyanide	CN^-	carbonate	CO_3^{2-}	arsenate	AsO_4^{3-}
amide	NH_2^-	cyanate	OCN^-	chromate	CrO_4^{2-}	arsenite	AsO_3^{3-}
hydrogen carbonate (bicarbonate)	HCO_3^-	fluoride	F^-	dichromate	$Cr_2O_7^{2-}$	citrate	$C_6H_5O_7^{3-}$
hydrogen sulfate (bisulfate)	HSO_4^-	hydride	H^-	oxide	O^-	ferricyanide	$Fe(CN)_6^{3-}$
bisulfide	HS^-	hydroxide	OH^-	oxalate	$C_2O_4^{2-}$	nitride	N^{3-}
bisulfite	HSO_3^-	hypochlorite	ClO^-	silicate	SiO_4^{2-}	phosphate	PO_4^{3-}
bromate	BrO_3^-	iodate	IO_3^-	sulfate	SO_4^{2-}	phosphite	PO_3^{3-}
bromide	Br^-	iodide	I^-	sulfide	S^{2-}	phosphide	P^{3-}
chlorate	ClO_3^-	nitrate	NO_3^-	sulfite	SO_3^{2-}		
chlorite	ClO_2^-	nitrite	NO_2^-	tartrate	$C_4H_4O_6^{2-}$		
chloride	Cl^-	perchlorate	ClO_4^-	tetraborate	$B_4O_7^{2-}$		
		permanganate	MnO_4^-	thiosulfate	$S_2O_3^{2-}$		
		thiocyanate	SCN^-				

Activity 5 Work out names and formulae of compounds

For each of the compounds in this activity, look back in the chapter to see whether you have drawn a picture model of it.

Part A. Given the names, work out the formulae for the compounds below.

magnesium oxide	sulfur tri-oxide	potassium nitrate
carbon monoxide	sodium chloride	aluminium tri-chloride
carbon dioxide	potassium chloride	copper(II) sulfate
sodium oxide	copper(II) chloride	potassium permanganate
sulfur dioxide	iron(III) oxide	sodium hypochlorite

Part B. Given the formulae, work out the names of the compounds below.

MgO	Fe_2O_3	$CaCO_3$	$KMnO_4$
CO	$CuCl_2$	$NaHCO_3$	$CuSO_4$
CO_2	$FeCl_3$	$NaCl$	HgS
Na_2O	$CaCl_2$	HgO	$Mg(OH)_2$

Chapter summary

- Compounds can decompose into the elements that they are made from. This decomposition is a chemical reaction.
- Elements can react with each other to form a compound.
- A chemical equation represents a chemical reaction. No atoms are destroyed or created in a reaction, and so the equation must have the same number of atoms for each element before and after the reaction.
- To understand chemical reactions, we need to know how elements and compounds are made up of atoms, and how they combine.
- Some compounds break up into positive and negative ions when they dissolve in water. The ions may have 1, 2, 3, or more electric charges, and the charges can be positive or negative.
- Water molecules are polar and they pull on positive and negative parts of the compound's crystals.
- Solutions containing ions conduct electric current. The size of the current gives an indication of the number of ions per litre of water.
- In water, ions may react with each other and form new compounds.
- Compounds are named using rules; for example, the element which lies more to the left of the periodic table is placed first in the name.

CHAPTER 11 Thermal and electrical properties

In Chapter 8 we learned about properties of materials on the macro-scale: we saw solids melt and liquids boil, for example. We know that water boils at a lower temperature if you are up a mountain than if you are at sea level. We know that metals conduct heat better than non-metals. But why do these things happen?

In this chapter we will try to answer those questions. If we look at materials on the nano-scale, and look at how their particles behave, we can explain why these events happen.

In **Chapter 8** we study materials on the macro-scale. We study, for example, strength, density, magnetic properties, melting and boiling.

In **Chapter 9** we study materials on the nano-scale; that is, the atoms and molecules that make up the materials and use the PKMM.

Chapter 10 uses the PKMM to understand how elements and compounds react and how ions form.

Chapter 8 leaves some questions unanswered about the properties of materials... what are the reasons why these materials have these properties?

...but here we answer them!

In **Chapter 11** we use the PKMM to answer the questions about:

- ❑ why some materials are magnetic
- ❑ how they conduct heat and electricity
- ❑ why boiling points depend on altitude

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 265 2016/01/05 3:19 PM

Unit 11.1 Melting points and boiling points of materials

In Chapter 8 you melted wax and solder and zinc, and you looked up the melting and boiling temperatures of different metals in the Resource Pages.

Why do materials melt and boil? Why do some materials melt at quite low temperatures and others melt at high temperatures? To understand that, we have to go into the nano-scale world. We may also call this the subatomic-scale world.

We'll have to think about the invisibly tiny particles that make up matter. Remember the Particle Kinetic Model of Matter – the PKMM. Read it again in the box on the right. The particles can be atoms, electrons, ions or molecules – these are all particles.

We have to talk "nano language" when we talk about particles, but we talk "macro language" when we talk about bulk matter; that is to say, the pieces of matter we can see or hold.

The Particle Kinetic Model of Matter (PKMM)

1. Solids, liquids and gases are made of particles that are invisible (too small to see).
2. Between the particles is empty space; there is nothing between them, neither air nor anything else.
3. The particles attract each other, but if they come too close together they **repel** each other.
4. The particles move and vibrate all the time, even if no object pushes them.
5. The particles move and vibrate faster if they receive energy.

How materials melt

In Chapter 8 you saw solder and wax being heated; you saw them get soft and then suddenly flow as liquids. How does this happen?

To "flow as a liquid" is **macro language**, because we can see it happen. To explain how it happens, we have to talk **nano language** about the particles we cannot see.

When the solid materials are at room temperature, their particles are in ordered patterns. Forces of attraction hold the particles in fixed positions, and the particles form a structure called a **lattice**. The particles vibrate, but stay in position. To remember this, think of students sitting in neat rows to write an exam.

By heating the materials, we are giving energy to the particles, and it makes them vibrate faster. The attractive forces can't hold them together when they are vibrating with so much energy. The particles begin to roll and slide over each other.

On the **macro-scale**, we see the solid changing to a liquid. (The **particles** are not becoming liquid, of course, but when billions of them are sliding over each other, we see a liquid.) Imagine the particles as students in an exam-room – the moment the exam is over, everyone stands up in the exam room and begins to move around.

Figure 11.1 *At room temperature, the vibrating particles stay in neat patterns. The structure of the particles is called a lattice.*

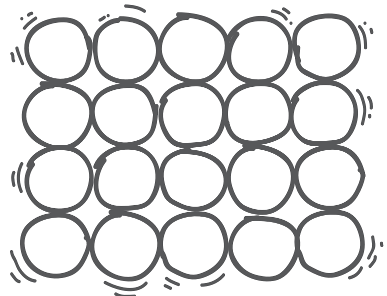
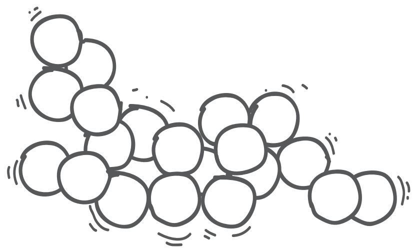


Figure 11.2 *When the particles are moving fast, the order and pattern breaks up, and the particles slide over each other.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 266 2016/01/05 3:19 PM

The temperature of a material

On the macro-scale, the whole piece of material has a temperature; the material may be cool or hot.

On the nano-scale, the moving particles have kinetic energy; they may have a little or a lot of kinetic energy.

So the temperature of a piece of material is a measure of how fast the particles of that material are moving. If we heat the material and raise the temperature, we are actually increasing the kinetic energy of the particles. (The particles themselves don't get hot, what really happens is that they move faster, but if we feel the material we'll say that it has a high temperature and it's hot.)

In Chapter 8 you worked with the table of melting points in the Resource Pages. You saw that materials have different melting points. The reason why different materials have different melting points is that the attractive forces between particles are different in different materials. In zinc the forces between particles are not very strong, but in copper the forces are very strong. So zinc melts at 419,5 °C and copper melts at 1 085 °C.

Does water really boil at 100 °C?

✻ **boiling point** (noun) – the temperature at which the pressure in the vapour under the surface of a liquid is equal to the pressure of the vapour above the surface of the liquid

In this section you'll learn why we talk of **boiling points*** instead of boiling **temperatures**.

In Chapter 8 you did Activity 5, **Graph the heating and cooling of water**. You will remember that we had two unanswered questions at the end of that chapter:

- **First,** why does the graph level out in the minutes after the water begins to boil?
- **Second,** why do people say that water boils at 100 °C, when in most parts of South Africa it boils at a lower temperature?

Now we'll try to answer those questions.

Your graph probably looked like Figure 11.4. You saw the temperature rising almost steadily, until the water began to boil. Then the temperature stopped rising and it stayed constant for as long as you kept the flame under the water. When you removed the flame, the temperature started to fall.

Figure 11.3 *You used this apparatus to plot the temperature of water as time passed.*

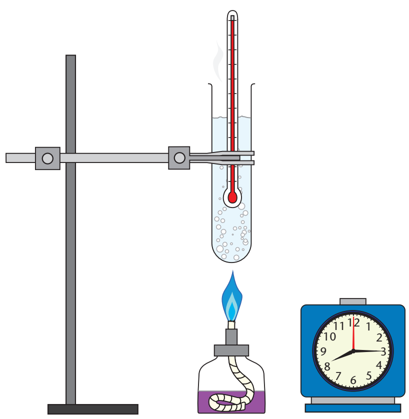
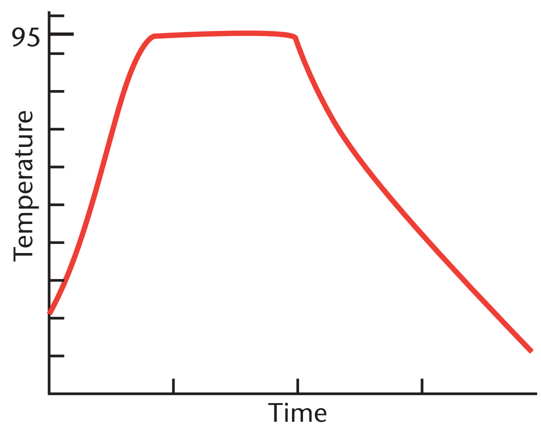


Figure 11.4 *Your graph showed how water's temperature changes as time passes.*



Many people would say that the longer you heat the water, the hotter it should get. But this does not happen, and so it needs an explanation. To explain this strange graph, we need to think on the nano-scale. What is happening to the water molecules?

First, we think about what's happening to the water molecules on the surface of the cool water. Look at Figure 11.5. Even when the water is cool, the water molecules are all moving, all the time. A few of them have enough energy to break away from the others on the surface. We call this break-away **evaporation**.

But not too many water molecules can escape, because some collide with air molecules and get sent crashing back into the other water molecules. In Figure 11.5 you see the green-coloured air molecules hitting the blue-coloured water molecules. Those moving air molecules together create atmospheric pressure (normal air pressure) that presses down on the surface of the water.

But now we heat the water.

The water molecules move faster and faster and faster; at places in the water they begin to form little pockets of water **vapour.** You see this in Figure 11.6.

When the molecules of water vapour are moving fast enough, they create pressure that equals the pressure of the air molecules above the water. The bubbles of water vapour form all over in the water, rise to the surface, and burst. We say the water is **boiling.**

So why does the temperature stay constant while the water is boiling?

The answer is that the escaping water molecules are taking some kinetic energy from other molecules as they escape. The water molecules that are left behind are still moving fast, but their kinetic energy is not increasing because of the escaping molecules taking away energy as they escape. In macro language, the temperature of the water is not increasing. That is why the graph stays level while the water boils.

Figure 11.5 *Some water molecules on the surface of the water escape and move in among the air molecules.*

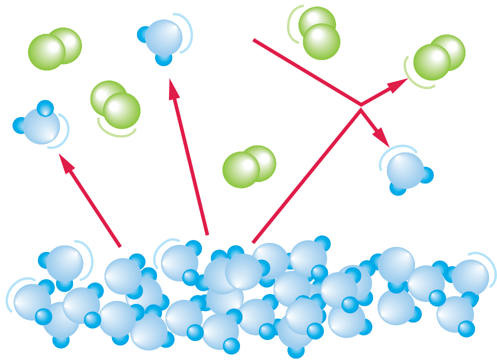


Figure 11.6 *The water boils when the pressure in the vapour under the surface is equal to the pressure from the air above the surface.*

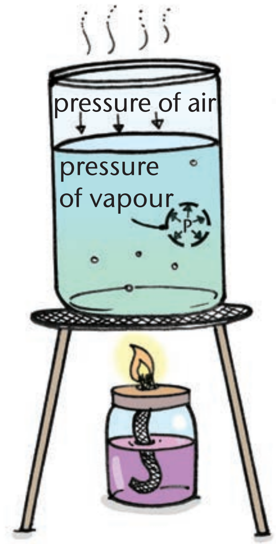
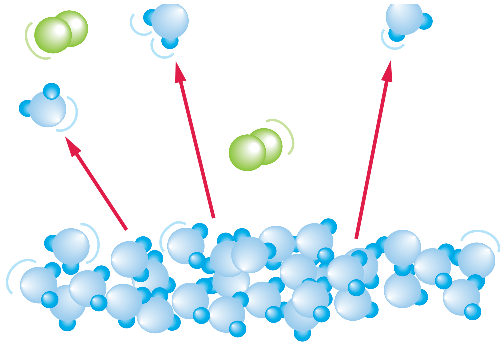


Figure 11.7 *If the air pressure is reduced, the air molecules don't press the water molecules so hard and the water molecules can form vapour more easily.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 268 2016/01/05 3:19 PM

The second question we had from Chapter 8 was: Why does water boil at less than 100 °C when you are not at sea level?

Let's think nano-scale again. Think about the air molecules that hammer down on the surface of the water. The atmosphere is all the air above us, above the highest clouds. And all that air presses down on us. At sea level, the air pressure is greater than air pressure at high places like Gauteng, or a high mountain. In places where the air pressure is less, water molecules don't have to move quite so fast to form water vapour bubbles. In macro language, we say that the water boils at a lower temperature.

Figure 11.8 *Mountain climbers find that water boils at less than 100 °C.*

So you may find that in Johannesburg water boils at 94,2 °C, but in Durban it boils at 100 °C.

Mountain climbers on very high mountains, such as Mount Everest, have difficulty cooking food or making tea. They can boil water, but it reaches a temperature of only 72 °C while it is boiling.

On the other hand, if you increase the pressure on hot water, it will boil at a higher temperature than 100 °C. Motor car radiators, for example, are sealed so that pressure builds up on the water, and the water can be as hot as 120 °C without boiling.

What does boiling mean?

A liquid boils when its particles are moving fast enough to create vapour bubbles under the surface of the liquid. The pressure in the vapour bubbles is equal to the pressure of the air on top of the liquid. Look at Figure 11.6 again.

The temperature of boiling depends on the pressure on the liquid.

Unit 11.1 Summary Activity

Use the parts of sentences below to write a complete paragraph. Then read your statement to a partner to check that it makes sense.

[A solid object is really made of]
[that are held together by attractive forces.]
[In some solids, like wax, the attractive forces are quite weak,]
[the attractive forces are very strong.]
[but in other solids, like steel,]
[billions of particles]
[but steel melts at a very high temperature.]
[wax melts at a low temperature]
[This is the reason why]

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 269 2016/01/05 3:19 PM

Unit 11.2 Thermal insulators and conductors

Thermal conduction and insulation are important and useful ideas to understand. In Civil Technology you have to think about how to keep buildings cool in summer and warm in winter. In Mechanical Technology you have to know how to cool a hot engine and how refrigerators work. In Electrical Technology you need to know how to cool electric transformers and power transistors.

Heat energy moves from an object with high temperature to anything that has a lower temperature.

Heat moves by conduction, convection and radiation. You probably remember these ideas from Grade 7, and you will meet these ideas again in Chapter 16 of this book.

Quick Activity:

In Figure 11.9 below, you see three mugs made of polystyrene, pottery and **tin-plate***. Tin-plate is actually steel with a thin layer of tin over the steel.

Get three mugs or containers like these.

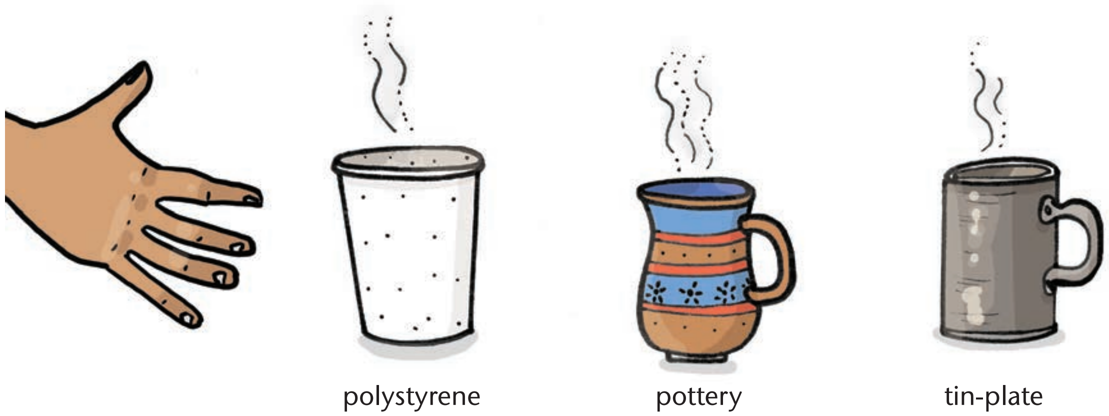
If you pour equally hot water into all three mugs, and immediately touch the mugs with your hand, what will you feel? Now do it, and test your prediction.

Let them stand for two minutes Describe what you will feel if you touch each mug after two minutes.

Now touch them – was your prediction correct?

> ✻ ***tin-plate** is made of steel, coated with a thin layer of tin
>
> ✻ ***jam-tin** and **tin-can** are words we use for containers that are made of tin-plate

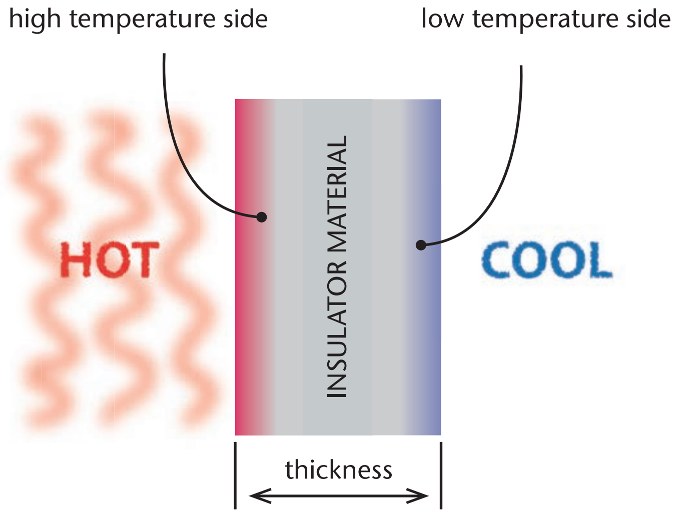
Figure 11.9 *Which material heats your hand fastest?*



The difference between thermal insulators and conductors

You will know from touching the mugs full of hot water in the Quick Activity that steel very quickly feels hot on the outside, but polystyrene only feels warm on the outside. The outside of polystyrene never gets up to the temperature of the steel. Pottery is in-between the results for polystyrene and steel.

Figure 11.10 *A good insulator keeps a high temperature on one side and a lower temperature on the other side.*



Steel is an example of a good **thermal conductor**. Polystyrene is an example of a poor thermal conductor and so it is a good **thermal insulator**.

Look at Figure 11.10. A good insulator can keep a high temperature on one side and a lower temperature on the other side. The low temperature side never gets very hot because the energy from the hot side travels only slowly through the insulator.

Let's look at some examples. A blanket is a good insulator if it keeps you warm while the air on the other side of the blanket is cold. (Of course, it's not the blanket that is warm – your skin is warm and the blanket stops that energy leaving your skin.)

Trapped air is a good insulator

Many insulating materials work because trapped air and other gases are very poor conductors. Mineral wool ("Aerolite" and "Think Pink") traps air in little pockets between the fibres. Polystyrene has thousands of little gas bubbles in every cubic centimetre. A jersey keeps you warm because the fibres trap air near your skin. A house with a ceiling is much warmer than a house with no ceiling, because the ceiling traps air above it. Thatched houses are warm on a cold night because the thatch grass traps air in the hollow grass stems.

Think: Will a thatched house be cooler than a house with a zinc-iron roof, on a hot day? Give a reason for your answer.

Many people have to live in corrugated zinc-iron shacks; these buildings are cold in winter and hot in summer. The reason is that zinc-iron is a good conductor and heat energy passes quickly through it: in winter it cannot keep a difference in temperature between the warm air inside and the cold air outside, and in summer it cannot keep a temperature difference between the hot air outside and the cooler air inside.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 271 2016/01/05 3:19 PM

Quick Activity: A scale of thermal conductivity

Use your experience to put the following materials on a scale of conductivity from 1 to 8:

oil, silver, copper, iron, wood, blanket-material, clay brick, ash brick, concrete, diamond, glass, polystyrene, mineral wool ("Aerolite"), air that is not moving

All the materials must be of the same thickness, otherwise we can't make a fair comparison between them. Let's say that each sample of material is a slab (a flat block) 10 cm thick. (Diamond? You will have to imagine a slab of diamond that thick!)

A scale of thermal conductivity

very good conductors					insulators (very poor conductors)		
1	2	3	4	5	6	7	8

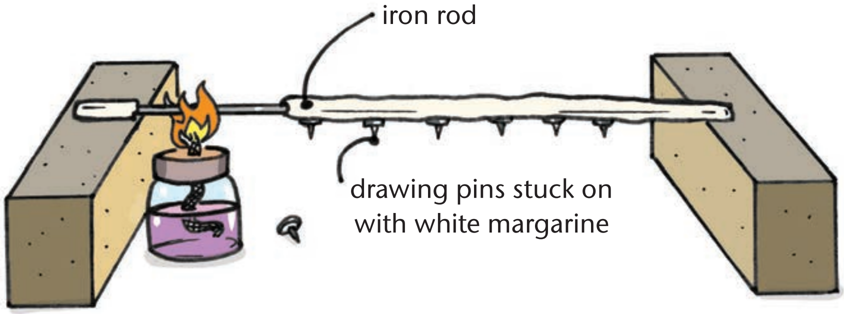
Activity 1 Do materials conduct heat equally fast?

A. Set up the apparatus as you see in Figure 11.11. Do not light the burner yet. Use the white margarine to stick drawing-pins onto the cold iron rod, at equal spacings.

Apparatus (per group)

- ❑ spirit burner and matches
- ❑ iron rod or thick iron wire
- ❑ copper or aluminium rod or wire, about the same diameter as the iron
- ❑ drawing-pins
- ❑ hard white margarine

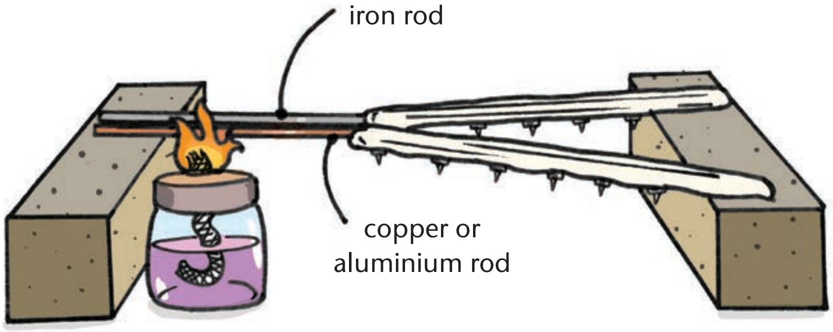
Figure 11.11 *Predict what will happen as the flame heats the left-hand end of the rod.*



B. Predict what you will see and hear as the flame heats the left-hand end of the iron rod.

C. Now set up the two rods, iron and copper (or iron and aluminium), as you see in Figure 11.12. Will the pins drop off at the same rate? Make your prediction.

Figure 11.12 *Heat the two metals at the same time.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 272 2016/01/05 3:19 PM

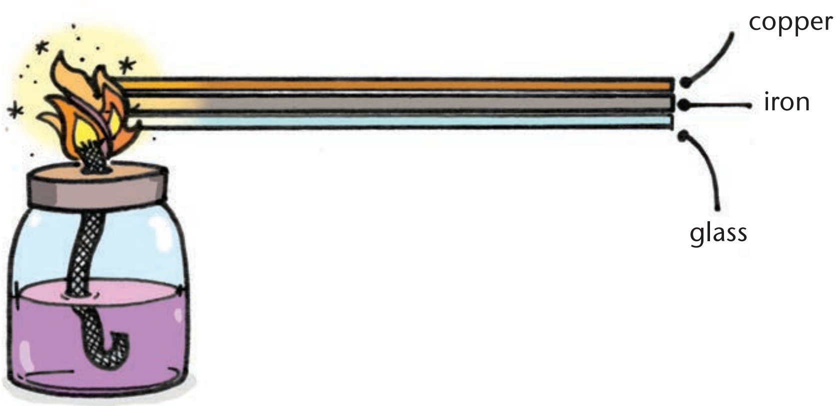
D. Get ready to check your prediction with a clock or cell-phone timer. You are going to measure how long it takes for heat to travel along the iron and the copper.

E. Start the clock and begin heating the rods at the same time. Start timing from the moment you put the flame under the rod, until the last pin drops off each rod.

Questions for discussion

1. The pins drop off, first near the flame, and then further away. If you look at the iron rod, you cannot see anything moving. What do you think is happening inside the iron?
2. If you put a glass rod of the same thickness in the place of the iron rod, you would see the pins drop off too. What would be different?
3. Do all metals conduct heat at the same rate? If you say no, describe what you saw. Talk about the iron and aluminium metals.
4. Copy the drawing in Figure 11.13 into your notebook and complete it. Colour in each rod to show where the high temperature will reach after 1 minute.

Figure 11.13 *The flame is just beginning to heat each rod.*



What we have learned from Activity 1

When a pin falls, it means that the rod is hot and the margarine has melted. The pin nearest the flame falls first, and then the other pins fall one after the other, as the temperature increases (rises) all along the rod.

The temperature rise takes a certain length of time to travel along the rod. It travels from the hot end towards the cold end. The temperature rise travels quickly in copper, slower in iron, and much slower in glass.

We cannot see any movement in the rod, so the energy must be transferred from the flame to the atoms in the rod. The atoms are too small for us to see.

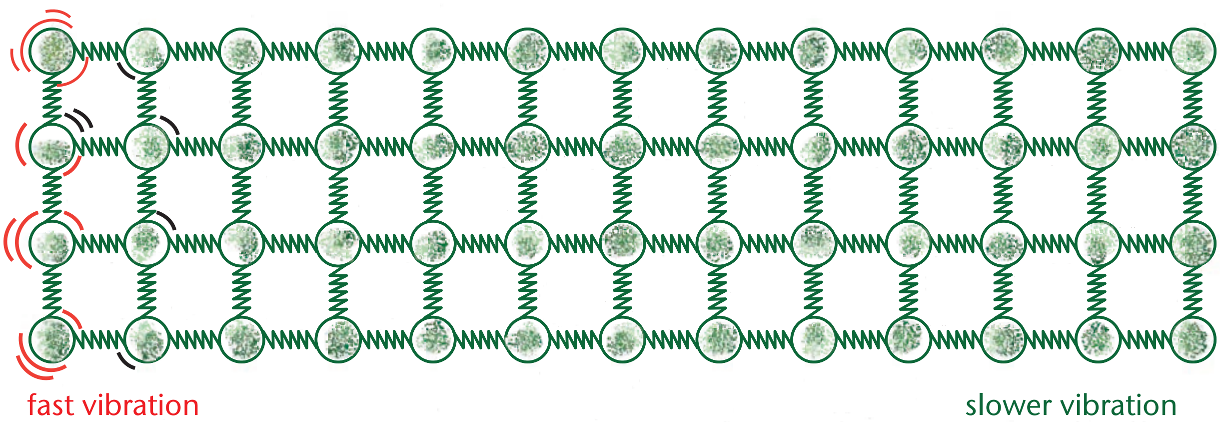
We need the PKMM to understand thermal conduction

All materials, not just metals, conduct heat energy from parts where the temperature is high to parts where the temperature is lower. When we talk about "high temperature" we are using macro language and thinking about the whole piece of material; to think about particles, we use nano language. We must say that particles are vibrating and moving very fast. The particles themselves do not have a temperature, they are just vibrating very fast.

The faster vibration spreads along the rod in Figure 11.11 from particle to particle, away from the high temperature end and towards the low temperature end.

Figure 11.14 shows you a model that helps you imagine the particles in the rod. The model is a lattice of balls, all joined together with springs. Each ball represents an atom, and the springs represent the forces that hold them together in the lattice. If you use your hand to shake the "atoms" at the left end, the vibration travels along the whole row. Soon the "atoms" at the right-hand end will also be vibrating faster.

Figure 11.14 *This is a ball-and-springs model of a solid rod. If the "atoms" at the left end vibrate faster, the energy of the vibration is transferred along the model to the "atoms" at the right end.*



The model shows us that when one real atom vibrates, it pulls on the atoms next to it; or the atom bumps against its neighbours, and makes them vibrate also.

In some materials, the energy of vibration spreads only slowly from particle to particle. These materials are called **thermal insulators**, and they are poor conductors. Insulators are very useful building materials because they help to control the air temperature inside buildings.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 274 2016/01/05 3:19 PM

Experiment 8 Test the insulation ability of a polystyrene cup

Focus question: How good is polystyrene at slowing down heat transfer, compared to steel?

We are going to make a fair comparison of the insulating ability of two materials, polystyrene and steel, by comparing how good these materials are at slowing down heat transfer.

Apparatus

- ❑ beaker and stand, to boil 200 ml of water
- ❑ meths burner, meths and matches
- ❑ 2 thermometers; one should have its bulb painted black
- ❑ cotton wool
- ❑ rubber bands
- ❑ polystyrene cup
- ❑ tin-can about the same size as the cup
- ❑ clock with seconds-hand
- ❑ cover for each container

Procedure

A. To compare the two materials, we will shape them into containers.

B. Look at Figure 11.15 and see what you are going to use. Each container will hold very hot water. Two thermometers will measure the temperature differences across the material; one thermometer will be inside the water and one will be outside.

⚠ **Be careful when you carry a beaker of boiling water.**

Figure 11.15 *The apparatus for investigating polystyrene*

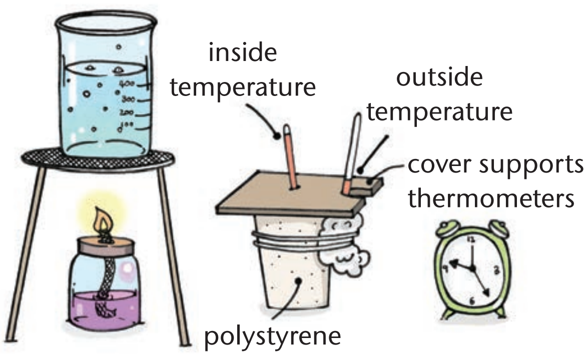
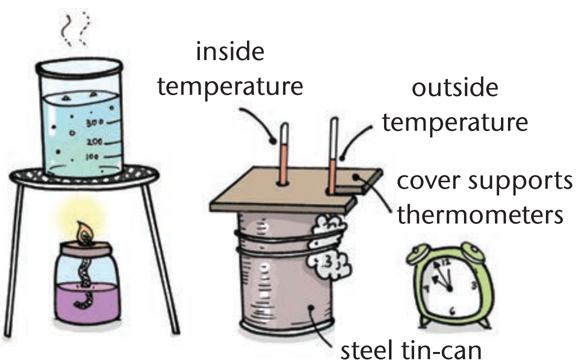


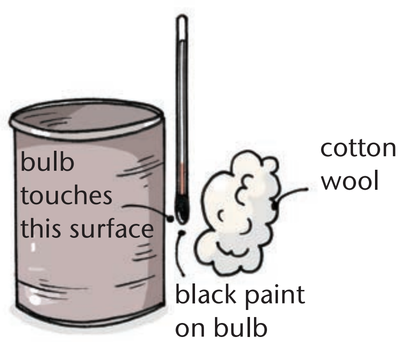
Figure 11.16 *The apparatus for investigating steel*



C. You have to make a cover for the containers, as you see in the pictures. This cover supports the thermometers and prevents rising hot air from carrying energy away from the hot water. Make a small hole for the thermometer. The hole must be so small that the thermometer fits tightly in the hole and will hang in the middle of the hot water.

D. **The "outside" thermometer must touch the outside of the polystyrene cup or the tin-can**. To prevent the energy escaping past the thermometer, cover the outer side of the thermometer with cotton-wool or folded tissue paper. Hold the cotton-wool in place with rubber bands. This "outside" thermometer should have black paint on its bulb.

Figure 11.17 *The bulb of the outside thermometer must touch the surface.*



E. To be fair when you compare the materials, you must keep certain things the same in each container. For example, the containers must be the same **size***, and you must add the same **volume*** of hot water to each container. Try to ensure that the **starting temperature*** of the water is the same for each container.

> ✻ the container **size**, **volume** of water and the **starting temperature** are called the **variables** in this investigation

F. Prepare your table to collect data in Question 1.

G. Prepare your graph paper, as you see in Figure 11.18. On the same axes, you will have two graphs for polystyrene: **(a)** inside temperature and **(b)** outside temperature. Also on these graph axes, you will have temperatures for the steel container: **(c)** inside temperature and **(d)** outside temperature.

H. Begin with the polystyrene container. Make sure that the “outside thermometer” is in position. Have the cover and “inside thermometer” ready. When the seconds-hand of the clock crosses the “6”, pour in your boiling water and put the cover on the container so that the thermometer is in the water.

I. Wait for the seconds-hand of the clock to cross the “12” and then read the inside and the outside temperature. The time is zero minutes and these are your first temperature readings.

J. Record the inside and outside temperature every half-minute, for at least 15 minutes.

K. Answer Questions 3 to 6.

L. Now repeat the procedure for the steel container and answer Questions 7 to 10.

Questions

1. Copy this table into your notebook. You will record results for the polystyrene and then for the steel.

Material: polystyrene																	
Time (min)	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$	8
Temp (°C) inside																	
Temp (°C) outside																	
Time (min)		$8\frac{1}{2}$	9	$9\frac{1}{2}$	10	$10\frac{1}{2}$	11	$11\frac{1}{2}$	12	$12\frac{1}{2}$	13	$13\frac{1}{2}$	14	$14\frac{1}{2}$	15	$15\frac{1}{2}$	16
Temp (°C) inside																	
Temp (°C) outside																	
Material: steel																	
Time (min)	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	. . .	. . .	. . .
Temp (°C) inside																	
Temp (°C) outside																	

...continue with your table in same way that you did for polystyrene.

2. Have you prepared your graph paper?
3. Plot the data points on your graph axes. Each data point shows two bits of information: a time and a temperature. You should have at least 30 data points from each thermometer.
4. Now draw a line that passes through the data points (the dots), or close to them. If one point lies very far from this line, you can ignore it – perhaps you made a mistake in reading the clock or the thermometer.
5. Write *temperature inside polystyrene* and *temperature outside polystyrene* next to each of your graphs.
6. What was the **difference in temperatures** between the inside and outside thermometers after 4 minutes, 8 minutes, 10 minutes and 12 minutes?
7. Plot the data points for the inside and outside thermometers in the steel container.
8. **Use a different colour pen** and draw a line that passes through or very close to the data points. Write *temperature inside steel* and *temperature outside steel* next to each of your graphs.
9. For steel, what was the **difference in temperatures** between the inside and outside thermometers after 4 minutes, 8 minutes, 10 minutes and 12 minutes?
10. Which material, polystyrene or steel, keeps the greatest difference between the inside and outside temperatures? Explain how your graphs tell you which material is the better insulator.

Figure 11.18 *The bottom left part of your graph axes will look like this.*

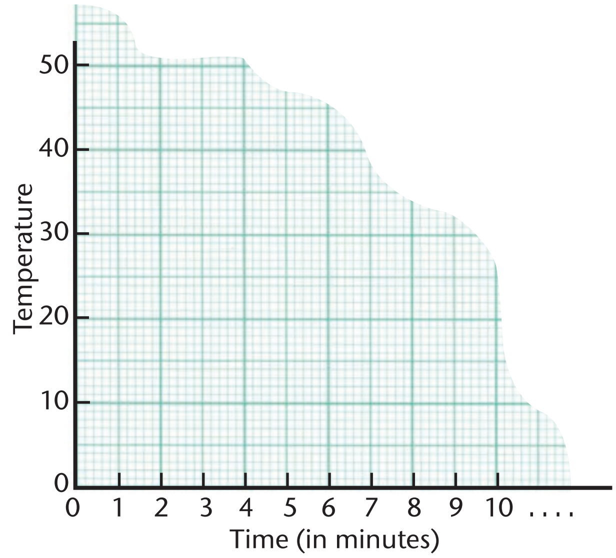
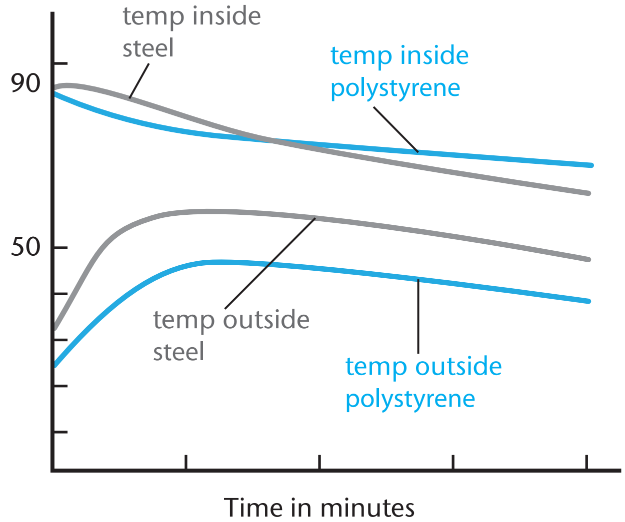


Figure 11.19 *Your graphs will have this sort of shape.*



What we have learned from Experiment 8

Polystyrene is better at slowing down heat flow than steel. We know this because after about 8 minutes the temperature difference between the inside and outside of the polystyrene is much greater than the difference between the inside and outside of the steel.

A thermal insulator slows down heat flow, no matter which side of the insulator is the hotter side.

Builders put slabs of polystyrene in the roofs and walls of buildings. On cold days, the polystyrene slows down heat flow from **inside** the warm building to the cold air outside. On hot days, the polystyrene slows down the heat flow from the hot air outside to the cool air inside the building.

Unit 11.2 Summary Activity

Use these parts of sentences, below, and write two paragraphs about conduction. Read your statement to a partner to check that it makes sense.

[Heat energy flows through a material] [with lower temperature.] [from parts with high temperature] [to parts]

[A good thermal insulator] [its hot surface and] [its cold surface.] [can keep a large temperature difference between] [the kinetic energy of vibration from one particle to the next.] [It can keep this temperature difference because] [its particles are not good at transferring]

Unit 11.3 Electrical insulators and conductors

In this unit, you have to recall what you learned about electricity in Grade 9 in Natural Science and Technology.

Conductors

You learned that copper, silver, gold and iron, and all the other metals, allow electric current to flow along them. But substances like plastic, paper, wool, glass, and cotton cloth won't let electric current flow along them.

The first kind of materials are called **conductors** and the second kind are called insulators.

Insulators

All the electrical appliances that you might use at home have insulating material in all the places where your hand can touch them. So conducting wires are covered with plastic, the handles of kettles are made of plastic and of course the plug that you push into a socket is made of a plastic material. The conducting metal parts of the plug are all safely inside the insulating cover.

An electrician's screwdriver has an insulating plastic sleeve over the shaft, almost down to the tip.

Electricians use special insulating gloves when they work with high voltages, so that their skin will not touch conductors that might be carrying electricity.

Figure 11.20 *Power-lines hang from a string of glass insulators.*

High-voltage cables hang from glass insulators, as you see in Figure 11.20. The cable cannot hang from a conducting material because that would allow current to flow from the cable to the pylon.

Semi-conductors

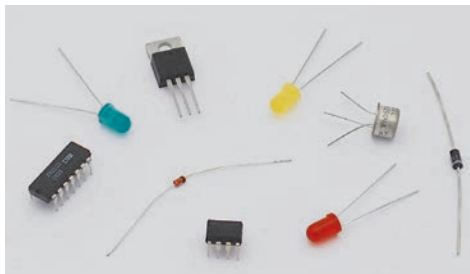
You read in Chapter 9 about the elements silicon ($_{14}Si$) and germanium ($_{32}Ge$). You see a photo of silicon in Figure 11.21.

These elements don't look or feel like metals, but they will conduct an electric current. Their ability to conduct is not as good as metals' ability, but their conduction ability increases as they get hotter. We call them **semi-conductors**. Silicon and germanium are semi-conducting elements; in electronics you will use semi-conductors that are alloys of silicon with other elements.

Many electrical appliances have a little red or green light that glows, to tell you that the appliance is connected. This little light is a light-emitting diode or LED, such as you see in Figure 11.22. The red LED and the transistor and amplifier in the picture all contain small pieces of semi-conductor material.

Figure 11.21 *A piece of silicon: silicon is a semi-conducting material.*

Figure 11.22 *These electronic components contain very small amounts of semi-conductor material.*



Why do metals conduct electric current so well?

Here you will have to go back to the periodic table of the elements in Chapter 9 and remember what you learned about the valence electrons of different types of atoms. The valence electrons are the electrons in the outer shell of each atom's electrons.

Quick Activity:

1. Find these elements on the left-hand side of the periodic table: lithium ($_{3}Li$), sodium ($_{11}Na$), aluminium ($_{13}Al$), iron ($_{26}Fe$) and copper ($_{29}Cu$). These elements are all metals.
2. Find these non-metal elements on the right-hand side of the table: carbon ($_{6}C$), phosphorus ($_{15}P$), sulfur ($_{16}S$) and iodine ($_{53}I$).
3. Find the semi-conducting elements silicon ($_{14}Si$) and germanium ($_{32}Ge$).

The atoms of metals don't hold their valence electrons tightly

The atoms of metals don't hold their outer electrons tightly in each atom. Instead, the outer electrons (the valence electrons) can move from atom to atom, and they jiggle between atoms, at high speed. Figure 11.23 on the next page has a blue line that shows you the path of a valence electron that moves from atom to atom. We say that these valence electrons are **mobile** electrons.

If you connect a battery across the piece of metal, the mobile electrons continue jiggling between atoms but they also begin to drift towards the positive terminal of the battery. Notice the blue line in Figure 11.24 – the line shows a movement toward the positive terminal.

Figure 11.23 *The outer electrons in a metal move rapidly from atom to atom. The blue line shows the movement of just one electron, but there are billions of electrons.*

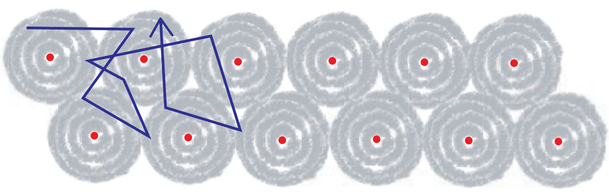
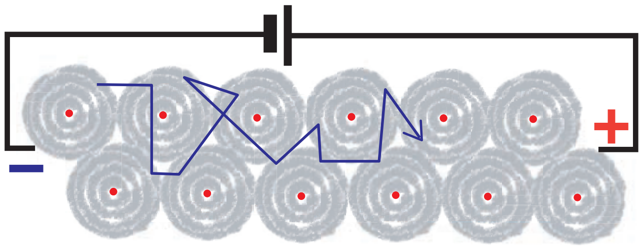


Figure 11.24 *The electrons now begin to drift slowly towards the positive terminal of the battery. They drift quite slowly, at about 3 millimetres per second.*



Atoms of non-metals hold their valence electrons tightly

On the right-hand side of the periodic table, we have the atoms of non-metals. These atoms have greater electron-pulling ability and they hold their electrons very tightly. So if you connected a battery across a plastic teaspoon, no electrons would begin to drift along the plastic.

Most of the plastic, wool, cloth, glass, rubber and other non-conductors you know are polymers; they are made of mostly non-metal elements.

This difference in the way atoms hold their electrons explains why metals are good electrical conductors and non-metals are such poor conductors. **Very poor conductors are insulators.**

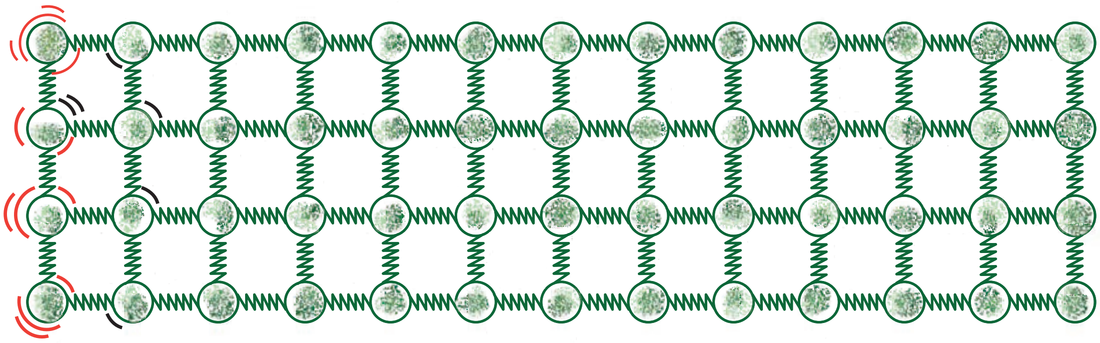
Why are good electrical conductors also good thermal conductors?

The better a metal is at conducting **electric current**, the better it is at conducting **heat energy.** For example, silver is the best electrical conductor and it is also the best thermal conductor. Copper comes second for both electrical and thermal conduction.

But materials like plastic conduct heat energy very slowly and don't conduct electric current at all.

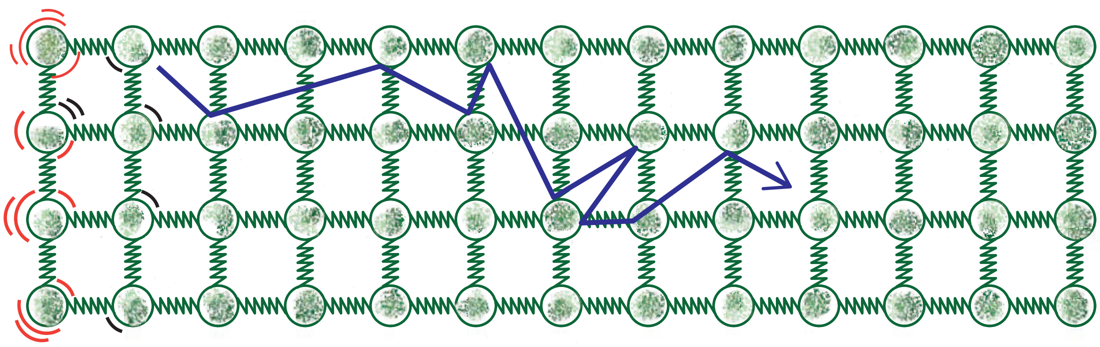
In Unit 11.2 you saw the model shown in Figure 11.25 and learned how heat energy spreads through a solid by conduction. The fast vibration of particles in one place is transferred to particles further away.

Figure 11.25 *In all materials, the atoms at the heated end vibrate and pass the vibration on to atoms nearby.*



This energy transfer happens in all solids, both metals and non-metals. But in **metals**, something extra happens when you heat one end of a metal object. You already know that metals have valence electrons that can move freely and quickly from atom to atom. These free electrons absorb energy at the heated end of the metal. They are negatively charged, and so when they move between the metal atoms they pull at the positive cores of the atoms. Look at the blue zigzag line in Figure 11.26.

Figure 11.26 *In metals, there are also free electrons that can move across the atoms and make them vibrate much more.*



This pulling and tugging of these billions of electrons adds to the energy of the vibrating metal atoms.

So the mobile electrons in metals are the reason why:

a) metals conduct heat so much faster than non-metals

b) metals conduct electric current so much better than non-metals

Experiment 7: Formal assessment task

NOTE: You might be assessed on this task: **Determine the electrical conductivity of different materials.**

This task is similar to Activity 4 in Chapter 10. You need to know about resistance, current and multimeters, so we will keep this task until you have done Chapters 13 and 14.

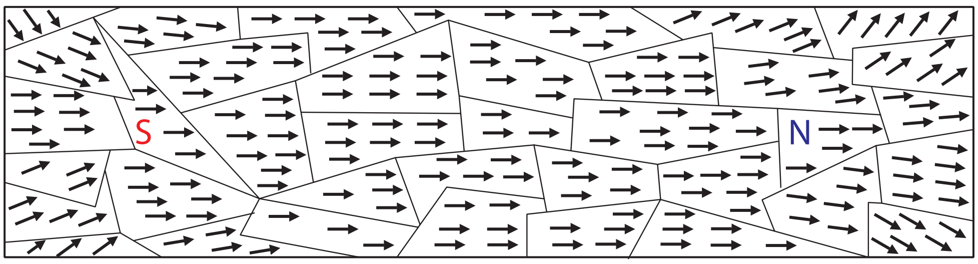
The PKMM helps explain magnetic properties

In Chapter 8 you learned about permanent magnets. Now that we know more about atoms, we can explain some of the properties of magnets.

How magnets induce magnetism in iron objects

The iron in a pin or paper-clip becomes a magnet when it "feels" the force of a permanent magnet in your hand. Iron atoms normally group together in very small clumps called domains. The iron atoms in a domain line up so that each domain has a tiny N pole and S pole. So when the iron "feels" the force of a magnet, the iron becomes like thousands of little bar-magnets that line up, with N poles attracting S poles. This is what you see in Figure 11.27.

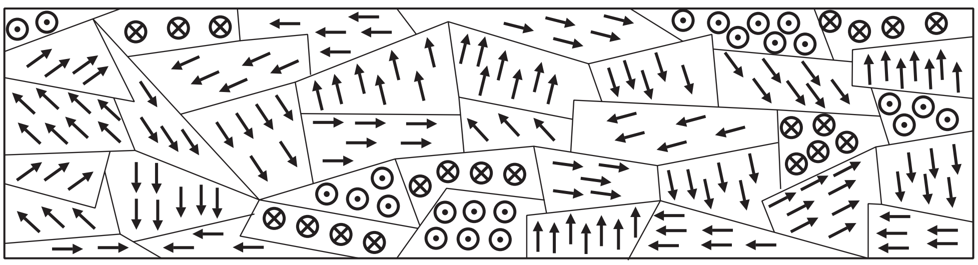
Figure 11.27 *The iron atoms line up in domains with magnetic N and S poles in the same direction.*



Now the thousands of little domain bar-magnets in the iron are like a single magnet, which is attracted by the big magnet in your hand.

When you take the big magnet away, most of the little domain magnets go back to random positions, and the iron is no longer a magnet or it is a very weak magnet. So iron can be magnetised for a short time, and then it loses its magnetisation. The paper-clip was only a temporary magnet, but the magnet in your hand is a permanent magnet.

Figure 11.28 *When you take the magnet away, the domains go back to random positions, with N and S poles in any direction.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 282 2016/01/05 3:20 PM

Iron can lose its magnetisation very quickly, and this is an important, useful property in electromagnets and transformers, which you will learn about in Grade 11. And remember that you learned about **electromagnets** that you can switch on and off, in Grade 7 Technology.

Permanent magnets keep their magnetism because they are made of an alloy of iron atoms along with other kinds of atoms such as carbon. These other atoms prevent the domains switching back to their random positions.

If iron is very hot, you can't magnetise it with a permanent magnet because the iron atoms are moving and changing the magnetic direction of domains all the time. You can't attract the red-hot iron with a magnet.

However, a permanent magnet will lose its magnetism if you drop it, hammer it or heat it. Heating, for example, makes the iron atoms vibrate fast enough to move into random positions.

The PKMM helps explain some properties of alloys

Why is steel harder than iron?

Steel is not pure iron; it has an impurity in it that makes it harder than iron. The impurity is carbon, and the manufacturers have carefully added various amounts of carbon to the steel. In Figure 11.29 and Figure 11.30, you see how the iron atoms slide over each other if a force bends the iron.

Some kinds of stainless steel are not magnetic. Stainless steel is iron that has been alloyed with other metals such as chromium and molybdenum.

The atoms of the other metals change the crystal structure of the steel so that the iron atoms cannot line up with the magnetic force.

Figure 11.29 *A simplified picture of iron atoms*

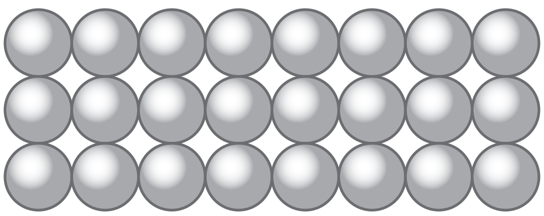
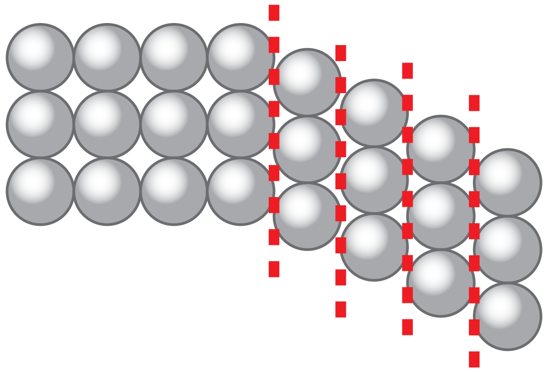
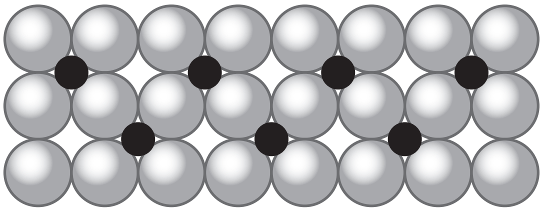


Figure 11.30 *If the iron bends, the atoms have to slide over each other. The red lines show some of the places where the atoms slide over each other.*



Now look at Figure 11.31. In between the iron atoms you see carbon atoms. The carbon atoms lock the iron atoms in position and now the iron is much harder to **bend**.

Figure 11.31 *The carbon atoms lock the layers of iron atoms and prevent the iron atoms from sliding over each other.*



Why do most alloys have a lower melting point than the materials they were made from?

In the table of melting points, in the Resource Pages, you saw that solder melts at about 183 °C but the two metals that solder is made from both have higher melting points. (What are those two metals? The answer is in the table of melting points.)

The reason for the lower melting point is that the atoms in an alloy have different sizes and different sets of valence electrons. The distances between atoms are greater in some places and therefore the forces are weaker at these places. The forces that hold the atoms together are weaker between the different kinds of atoms than if the atoms were all of the same kind.

You can find some interesting graphs of the melting points of mixtures of metals (alloys) such as brass and solder in this website: http://www.engineeringtoolbox.com/melting-points-mixtures-metals-d_1269.html

Now we heat the alloy. The forces between atoms are weaker in some places; the vibration of the atoms more easily overcomes the forces between them and the atoms begin to slide over each other. In other words, we see the alloy melt. The melting temperature is lower than the melting temperature of the "parent" substances that formed the alloy.

Learn more about why metals are such good conductors of heat, in the following website: http://resources.schoolscience.co.uk/Corus/16plus/steelch1pg2.html

Unit 11.3 Summary Activity

Answer these questions in your notebook.

1. Why do elements on the left-hand side of the periodic table conduct both heat and electric current, but most elements on the right-hand side don't conduct electric current and are poor thermal conductors?
2. A glass full of hot water will conduct heat and feel hot. Does this mean that glass is an electrical conductor? Explain your answer.
3. To make a permanent magnet, what material would you use? Give a reason for your answer.

Chapter summary

- On the macro-scale, we see solids melt and liquids boil. We know that metals conduct heat energy better than non-metals. We know that metals conduct electric current but non-metals do not.
- On the nano-scale, we can explain why these events happen if we think about what is happening to the particles in the materials.
- Solids are made of vibrating particles that remain in a pattern called a lattice. Attractive forces hold the vibrating particles in their positions.
- The temperature of a piece of material is really a measure of the average kinetic energy of its particles.
- The solid melts when the particles vibrate with enough kinetic energy to break the attractive forces.
- A pure substance melts at one specific temperature, called its melting point.
- A liquid boils when its particles have enough kinetic energy to form vapour bubbles, with pressure inside them that is equal to the pressure on the surface of the liquid.
- Some materials transfer heat energy quickly from a hot side to a cold side, and these are called good thermal conductors. Other materials transfer heat energy very slowly from a hot side to a cold side, and these are good thermal insulators.
- The particles of a material transfer energy by vibrating more quickly and making the neighbouring particles vibrate more quickly. But the particles of materials differ, and so materials conduct heat energy at different rates.
- Metal atoms have valence electrons that can move from atom to atom, and this makes them good electrical conductors. The mobile valence electrons can flow together in one direction.
- Non-metal atoms hold their electrons tightly, so the electrons cannot move from atom to atom and so they cannot become a flow of electrons. This is why non-metals are non-conductors.
- Semi-conductors have some mobile electrons that can move from atom to atom, and when the temperature increases, more electrons are freed to move.
- Good electrical conductors have free valence electrons and this makes them good thermal conductors too.
- Iron becomes magnetised by a permanent magnet when groups of atoms called domains align their little magnetic N and S poles to lie in the same direction. The iron temporarily becomes a magnet but then loses its magnetisation when the permanent magnet is taken away.
- A permanent magnet can lose its magnetisation if its iron atoms are dis-ordered by heating or being knocked.
- Steel is iron with carbon impurities. The carbon atoms prevent the iron atoms from sliding past each other when a force acts on the steel to bend it or dent it.

Challenges and projects

1. Imagine you are in a deep mine, 4 000 metres below the surface. When you boil water for tea, will the boiling water be hotter, less hot or at the same temperature as when you are at the surface? Explain your answer.
2. Can you raise the temperature of boiling water above 100 °C by using a more powerful burner or stove?
3. If you add a compound like salt to water, does the boiling point change? Do an investigation and find out.
4. If you open the radiator cap of a car engine when the engine is hot, the water in the radiator may suddenly begin to boil and shoot out. Why does this happen?
5. In Experiment 8, you could use **two** polystyrene cups, one inside the other, to slow down the energy transfer from the hot water on the inside to the outside. Would you get different graphs of inside temperature and outside temperature in this double polystyrene cup? Sketch the graphs you think you will get, and compare them to the graphs in Figure 11.19.
6. Look at the girls in the picture. Is that jersey good at keeping the girl warm? Explain what it means to say that "a jersey is warm".

Figure 11.32

7. Test the hypothesis that if an iron nail is very hot, it is not attracted to a magnet. If this is true, can you explain the reason?
8. Brass is an alloy made mostly of copper with some zinc added. But brass is only about 28% as good as copper at conducting electric current. Suggest a reason why this is so.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 286 2016/01/05 3:20 PM

CHAPTER 12 Electrostatics

In Chapter 9 you learned that atoms have parts with positive and negative charge. In this chapter you will learn that we store energy by separating negative charges from positive charges. In the chapter that follows, you will learn how the stored energy of the charges makes a current flow through resistors and give off their energy.

Unit 12.1 Two kinds of charge

You already know something about static electricity. You have pulled off some clothing that is made of nylon, and you have heard little crackling sounds; if the room is dark, you can see sparks.

Do you remember walking across a carpet and then touching a door-knob – and you felt an electric shock on your hand?

Some people have long straight hair, and when they comb their hair it stands out and it will not lie flat.

Figure 12.1 *Some people hate static electricity because it makes their hair stand up.*

Quick Activity: Say what you know about static electricity

1. Have you felt little shocks when you touch metal objects? Tell what happened, and tell what you were doing before you touched the metal.
2. People may have explained to you why you get those shocks. What have people told you?
3. Tell about other times you have seen sparks. Did you do anything to cause those sparks?
4. Have you seen dust sticking to plastic objects like a lunch box, or dust sticking to a TV screen? Why does it happen, do you think?

The small sparks and the dust sticking to things is caused by electrons being separated from their atoms which make up the nylon, the carpet, the dust. We'll soon learn more about how it happens.

Activity 1 How can we explain this?

Apparatus
- ❑ plastic straws
- ❑ a small object, like a bottle cap, pill box, or large eraser
- ❑ torn up tissue paper, in pieces the size of rice grains

A. You need a plastic straw and a small object to balance the straw on. The object can be an eraser or bottle-cap, for example.

NOTE: The plastic straw does not conduct electricity – you probably know this from your Grade 9 science. Your dry skin also does not conduct electricity.

B. With dry fingers, stroke or wipe the straw about 5 times. Wipe just one end of the straw.

C. Using your other hand, balance the straw on the object. Now put your fingers that wiped the straw near to the end that you wiped. Can you move the straw without touching it? Answer Questions 1 to 3.

D. Bring the wiped end of the straw near to the paper pieces. Try to pick them up with the straw. Answer Questions 4 and 5 below.

Figure 12.2 *Balance the plastic straw on a small object.*

Questions

1. How does the straw respond when your fingers come near it?
2. The straw seems to be attracted to your fingers. But do your fingers attract the other end of the straw that you did not wipe?
3. How has the wiping changed the straw and your fingers, do you think?
4. Why do the paper pieces move, do you think?
5. Do the paper pieces jump off the straw after a few seconds? Why does that happen?

In the next section you will learn why these things happen.

How the word "electricity" came into the English language

Thousands of years before scientists had batteries or bulbs, people knew about static electricity. They knew that if you rub a material called **amber** with cloth or animal fur, the amber will attract small bits of paper or dust or hair.

Amber is a hard orange-brown substance that you might find near the sea-shore. The Greek people who lived long ago had a name for amber: they called it *elektron*. And from that word *elektron* we got our English word electricity.

Figure 12.3 *This is amber.*

Electricity was a puzzle to the most brilliant minds of those days

Although people long ago knew about static electricity, they could not explain it. They often confused it with the forces between magnets.

We know that in the 1700s scientists in Europe and America made machines to give sparks, and they experimented with static electricity. They wrote letters to each other about their experiments and they began to find out how to control static electricity. They experimented with ways to prevent lightning strikes, and Benjamin Franklin invented the lightning rod you can see on buildings nowadays. These scientists called themselves "electricians".

Figure 12.4 *Benjamin Franklin did a very dangerous experiment with lightning in 1749. You can read about him in the Resource Pages.*

However, they still did not know what electricity was and they could not explain what actually happens when you rub two materials together.

So if you find it hard to understand electricity, you can remember that the most brilliant minds of those years struggled to explain what they were seeing.

But you can already explain some of the observations because you studied atoms and electrons in Chapter 9.

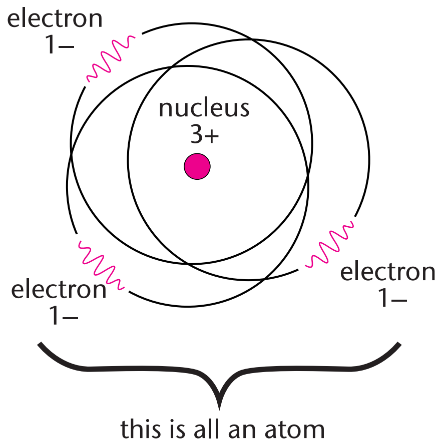
Electrons are the answer to the puzzle

All materials are made of atoms that are bonded together. The negatively-charged electrons and the positively-charged nuclei in the atoms attract each other and form the bonds that hold the atoms together. You learned this in Chapter 9.

An atom is so small you could line up a million atoms across the width of a human hair. But remember that each atom has even smaller parts called electrons; they are moving fast around its nucleus. Look at Figure 12.5 and find the nucleus, count the electrons, and decide which part of the picture is an atom.

- Which parts have + and – signs next to them?
- What do those signs mean?

Figure 12.5 *Even though an atom is so small, it has much smaller electrons orbiting around the nucleus.*



In any piece of material the number of electrons is equal to the number of protons – this is true most of the time. We say that the material is **electrically neutral** if the number of positive charges is equal to the number of negative charges. But when two solids touch or rub together, electrons near the **surface*** of one solid can be pulled off it and onto the surface of the other solid.

* **surface** – the outside area of something; not deep inside

So when a plastic straw slides over your dry skin, the plastic takes some electrons from your skin, and gets a negative charge. Your skin is now missing those electrons, and so it has a positive charge.

Other materials that easily get a charge when you rub them together are Perspex and silky cloth, or polythene and woollen material, or rubber and furry material.

Law of attraction and repulsion between electric charges

From Chapter 9 you should know that positive charges attract negative charges, while negative charges repel other negative charges and positive charges repel other positive charges.

We say that **unlike** charges **attract** each other, but **like** charges **repel** each other.

The force between electric charges is called the **electric force**.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 289 2016/01/05 3:20 PM

The meaning of "positive charge" and "negative charge"

- All objects have huge numbers of atoms, and each atom has many positive and negative charges.

If an object has a surplus of electrons, it has a **nett*** negative charge. If an object has a deficiency of electrons, it has a nett positive charge. When we say that an object has positive charges on it, we mean that the object has fewer electrons than protons.

* **nett** – the charge left over when you have added the positive and negative charges together. If there are 10 million positive charges and only 9 million negative charges, the nett charge will be +1 million.

Experiment 10: Option 1 Push and pull with the electric force

Apparatus

- ❑ two plastic straws
- ❑ a piece of tissue or toilet paper
- ❑ a bottle to balance the straw on

A. Use the tissue paper to wipe both straws, as you see in Figure 12.6. You are wiping each straw in the same way. Electrons from the paper go onto both of the straws.

B. Balance one straw on the bottle as you see in Figure 12.7 and bring the other straw closer to the balancing straw. The balancing straw will move as your straw comes closer.

C. Observe in which the direction the balancing straw moves.

Figure 12.6 *Use the paper to wipe both straws quickly, about 5 times.*

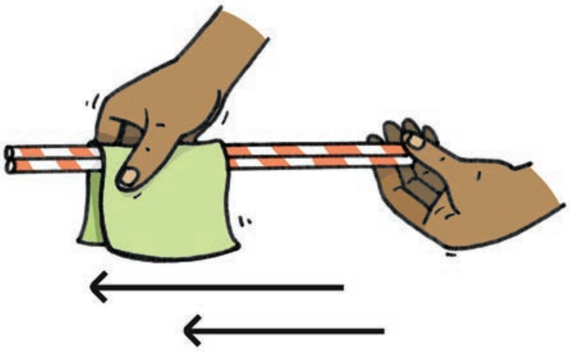
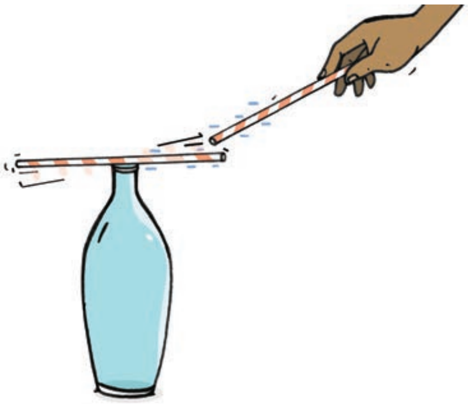


Figure 12.7 *Balance one of the straws on the bottle.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 290 2016/01/05 3:20 PM

D. Bring the **rubbed part** of the tissue paper close to the balancing straw, as you see in Figure 12.8. What do you see?

E. Again, observe in which the direction the balancing straw moves.

F. You rubbed both straws together so that each straw got the same kind of charge from the paper. Plastic gets electrons from the paper, so the straws have some extra **negative charge** on them. The paper has lost electrons and so it has extra **positive charge**.

Figure 12.8 *Bring the tissue paper close to the end of the straw that you rubbed.*

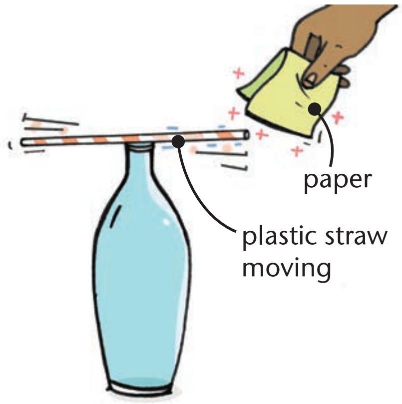
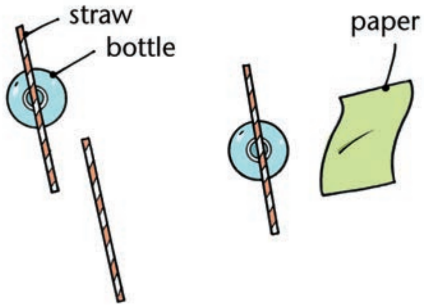


Figure 12.9 *Draw two sketches like this in your book, and show the direction of the forces.*



Questions

1. Is the electric force between the two charged straws a pulling force or a pushing force?

2. The tissue paper got the opposite charge to the straws, in the places that touched the straws. Is the electric force *between the paper and the straws* a pulling force or a pushing force?

3. Why is the electric force called a non-contact force?

4. Why do electrons but not protons move from the paper to the straws?

5. Do two sketches like Figure 12.9 in your notebook that show (a) the straws pushing each other and (b) the paper pulling a straw. Remember to write the minus and plus signs on the straws and paper.

6. Complete the statements in your notebook:
If two objects have the same kind of electric charges on them, they...
If the objects have opposite charges on them, they...

7. Complete the statements, using *some* of the words from the box on the right:
If an object has more negative charges than positive charges, we say the object is ...
If an object has fewer negative than positive charges, we say it is...

negatively charged
uncharged
highly charged
positively charged
positive charges

8. Read the paragraph below and then make a complete statement, using the words "like" and "unlike". The sentence has been broken up, and you must write it correctly in your book:
[unlike charges] [like charges] [repel each other] [attract each other] [but]

NOTE: We say that the **negative** charges on the two straws are "alike" (the same), and we call them "like charges". But the paper has **positive** charges and we say that the paper and straws have "unlike charges". Like charges can mean negative and negative charges, or it can mean positive and positive charges.

Experiment 10: Option 2 Investigate positive and negative charges with Perspex and polythene rods

Apparatus

- ❑ two Perspex rods
- ❑ two polythene rods
- ❑ a woollen cloth
- ❑ small pieces of paper, about the size of rice grains
- ❑ a retort stand from which to hang a paper stirrup

A. Set up a stirrup to suspend the rods, as you see in Figure 12.10.

B. Rub the two Perspex rods with the woollen cloth.

C. Put one rod in the stirrup so that it can turn freely.

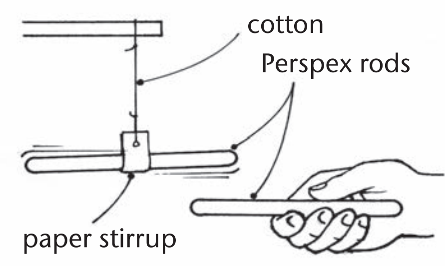
D. Bring the second Perspex rod that you have rubbed near to one end of the first Perspex rod.

E. Observe that the second rod rotates away from your free Perspex rod. In other words, the two Perspex rods **repel** each other. Therefore they must have the same charge on them.

F. Repeat the steps with the polythene rods. If they also repel each other they must have the same electric charge on them.

G. The Perspex rods take a positive charge and the polythene rods take a negative charge.

Figure 12.10 *Suspend one rod from the retort stand.*



Questions

1. What happens if you rub both a Perspex and a polythene rod with woollen cloth and then bring the Perspex rod near to the polythene rod?
2. What happens if you bring the charged Perspex rod near to the small pieces of paper?
3. What happens if you bring the charged polythene rod near to the small pieces of paper? Explain why this happens.

The gold-leaf electroscope

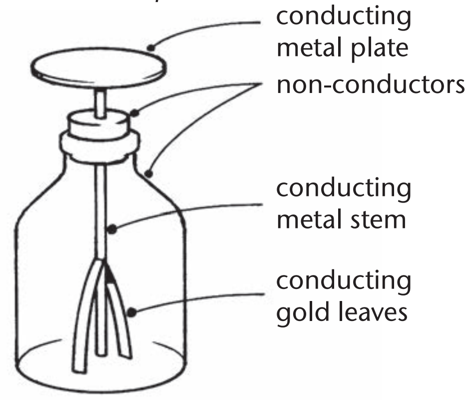
The gold-leaf electroscope is a sensitive instrument that we can use to identify electric charges. Some high-quality electroscopes allow us to estimate the quantity of charge on an object. The electroscope you see in Figure 12.11 is a simple kind that just shows the presence of electric charge and shows its sign (positive or negative).

At the top is a metal plate, which is connected to a long conducting stem. Two very thin, light gold leaves are soldered onto the bottom of the stem.

The stem passes through a plastic stopper and it is protected from air currents inside a glass container.

When the electroscope has no charge on it, the leaves hang down as you see in Figure 12.11.

Figure 12.11 *The construction of a gold-leaf electroscope*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 292 2016/01/05 3:20 PM

How the electroscope works

If you bring a charged Perspex rod near the plate of the electroscope, positive charges on the Perspex rod attract the negative electrons along the stem up to the plate. The leaves are left with a deficiency of negative charge, which means that they both have a nett positive charge. Therefore they repel each other. The force of repulsion makes them diverge and rise, as you see in Figure 12.12.

If you bring a charged polythene rod near the plate of the electroscope, the leaves again rise and diverge, as you see in Figure 12.13. This time, the reason is that the negative charge on the polythene rod repels electrons from the plate, down the stem to the leaves. The leaves then have an excess of electrons and they repel each other.

Figure 12.12 *The leaves repel each other.*

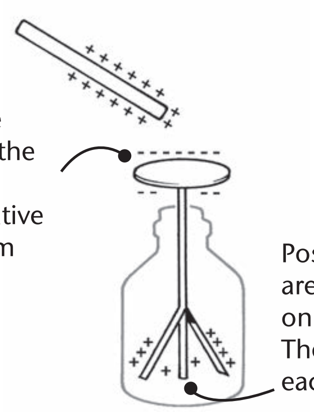
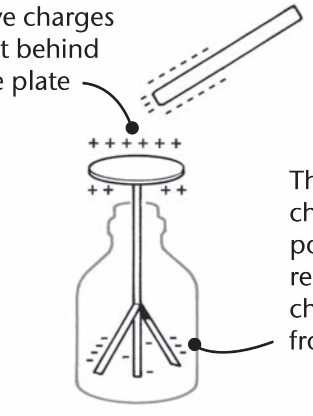


Figure 12.13 *Again, the leaves repel each other.*



So the gold-leaf electroscope tells us when an object has a nett positive or a nett negative charge on it.

However, which charge is it? We need to go a step further if we want to know whether a charge on an object is positive or negative.

Experiment 10: Part 3 Use a gold-leaf electroscope to identify positive and negative charges

A. Give a positive charge to the electroscope in the following way: rub the Perspex rod with the woollen cloth and then roll the rod over the plate of the electroscope.

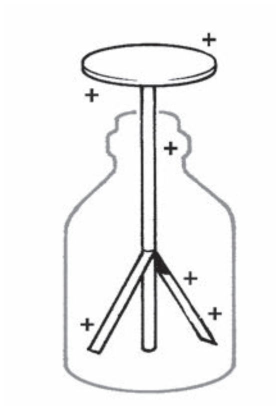
B. Electrons from the plate will be attracted to the sites on the Perspex which have a deficiency of electrons, and when you remove the Perspex the plate will have a deficiency of electrons which means that the plate will be positively charged. The electron deficiencies are positive charges and they will repel each other as far apart as they can, which means that the leaves will have a nett positive charge, repel each other, and diverge.

Apparatus
- ❑ an electroscope
- ❑ a Perspex rod
- ❑ a woollen cloth
- ❑ a silky cloth
- ❑ a clean beaker or drinking glass
- ❑ a plastic straw
- ❑ some tissue paper

C. Now the electroscope is positively charged. Positive charges (electron deficiencies) repel each other and spread out over the electroscope.

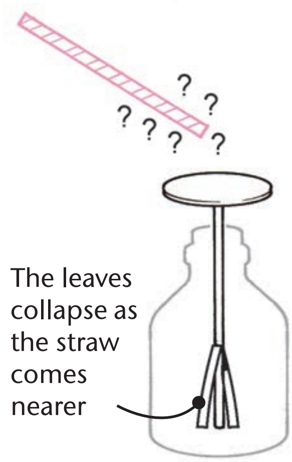
Figure 12.14

Figure 12.15 *The whole electroscope is positively charged.*



D. We can use the charged electroscope to identify an unknown charge. If we bring a charged object near the plate, and the leaves diverge further, it means more positive charge is being repelled down to the leaves. In other words, more electrons are being attracted up to the plate. Therefore the unknown charge must be positive.

Figure 12.16 *Is the charge on the straw positive or negative?*



Questions

1. Rub a clean beaker or drinking-glass with a silky cloth. Bring it near to the positively-charged electroscope and identify the charge on the glass.

2. Rub a plastic straw with some tissue paper and bring it near the charged electroscope, as you see in Figure 12.16. Identify the charge on the straw. Is it positive or negative?

We have used fingers and plastic straws to generate charges, but scientists use special charge generators to separate lots of positive and negative charge.

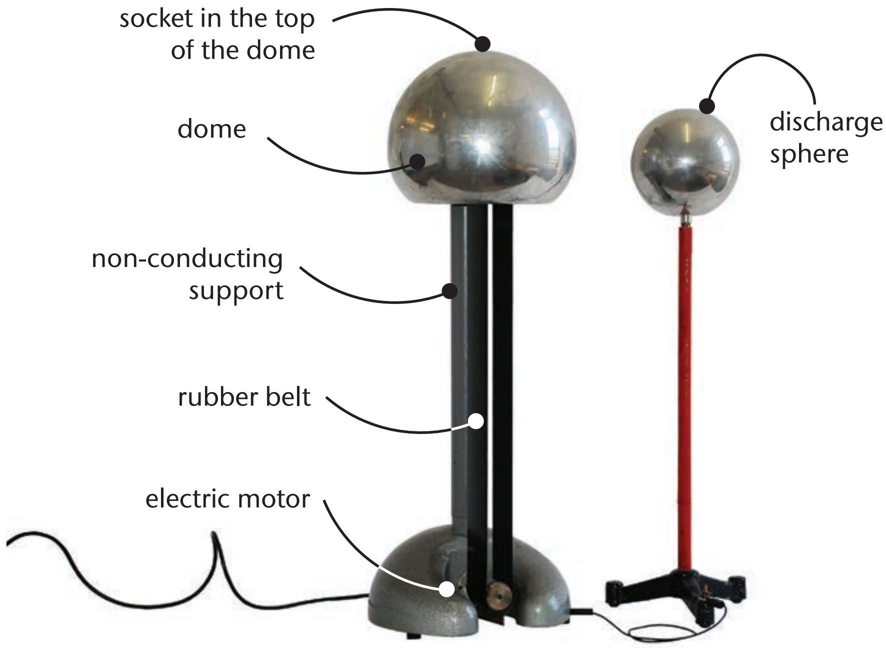
The van de Graaff electrostatic generator

The van de Graaff electrostatic generator is a machine that puts large quantities of positive and negative charge onto a metal sphere. The machine is called a generator but it is not the kind of machine that is used to provide 230 volt electricity supply.

Look at Figure 12.17 on the next page. The large sphere is called the dome. The energy to separate the charges comes from the person turning the large pulley. This pulley turns a small plastic roller. A long rubber belt goes around the roller.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 294 2016/01/05 3:20 PM

Figure 12.17 *Your school may have a van de Graaff generator that looks like this. Perhaps an electric motor pulls the rubber belt around.*



The belt moves up into a hollow metal dome. Thin wires near the belt collect electrons from the belt, which repel each other so that they spread as far apart as they can go, on the metal dome. The metal dome gets a big negative charge.

When the charge on the dome is big enough, the air begins to conduct and sparks come off the dome to any object that is connected to the Earth.

Figure 12.18 *The inside of a van de Graaff generator*

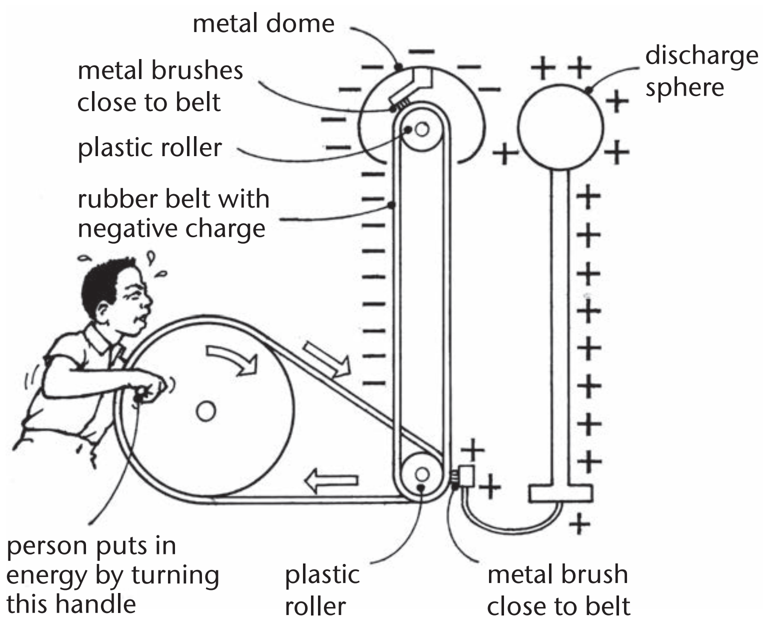


Figure 12.19 *This man's hairs are charged alike.*

In Figure 12.19 you see a man with his hand on the dome of a van de Graaff generator. The electric charge from the dome is charging his body and hair. Because his hair is getting charge of the same kind, the hairs repel each other.

He has to stand on a non-conducting block so that the charge does not pass through his feet into the Earth.

The generator you can see in Figure 12.19 can develop 150 000 volts potential difference between the dome and the Earth, but the man is not being harmed because the current is very small.

Activity 2 Investigate electric charge using a van de Graaff generator

Apparatus

- ❑ a van de Graaff generator, powered by the 230 volt mains or by hand
- ❑ a conducting sphere for discharging the dome
- ❑ thin strips of paper taped together as seen in Figure 12.20
- ❑ a pointed metal spike that plugs into the dome as in Figure 12.21
- ❑ detergent solution and wire loops for blowing soap bubbles
- ❑ aluminium pie dish to hold confetti or paper discs from a punch

A. Start the generator and let it build up charge on the dome. Bring the discharge sphere near to the generator and allow the sparks to jump across to the sphere.

B. Use a charged gold-leaf electroscope to work out whether the dome has a positive or negative charge. Do not connect the plate of the electroscope to the dome, just bring it about 20 cm away from the dome.

C. Put a bunch of paper strips taped together at one end onto the socket in the dome and start the generator. You should see the strands of paper rise and stand out from the dome. Look at Figure 12.20.

D. Put the dish of paper confetti on top of the dome. The charges on the dome repel each other so strongly that they move onto the non-conducting paper confetti. All the pieces of confetti repel the dome and repel each other, flying up into the air.

E. Blow soap bubbles so that they float near the dome. Charges being repelled off the dome join atoms in the soap bubbles and the bubbles have the same charge as the dome. What happens to bodies that have like charges?

F. Put the mini-lightning rod into the socket at the top of the dome, as you see in Figure 12.21. Start the generator and try to build up a charge on the dome. Now bring the discharge sphere close to the dome and see whether you can get a spark to jump from the dome.

Figure 12.20 *The paper strips repel each other away from the dome.*

Figure 12.21 *When the lightning rod is on top of the dome, electric charges can't build up.*

Questions

1. You know that rubbed polythene takes a negative charge. How can you use the polythene rod to work out whether the charge on the dome is positive or negative?
2. Some people believe that a lightning rod attracts lightning, but it actually prevents most lighting strikes. How does it do this?

What do we learn from the demonstration of the van de Graaff generator?

The dome is not able to build up a big charge if there are sharp points on it. Electric charges repel each other, and at any sharp point the charges pack close together there and the repulsive force on the charges is greatest there.

Lightning between the ground and storm clouds happens when the cloud builds up a big charge and the opposite charge begins to build up on the ground and on houses.

Houses have lightning rods with sharp points so that a big charge cannot build up on the house; the charge leaks off the points into the air.

Unit 12.2 Charge conservation

Any object is made of atoms, and atoms have positive protons and negative electrons. So any object has millions of millions of positive and negative charges, and we cannot count them all.

If we count charges, the unit is the coulomb

When you put sugar in your tea, you don't count each grain of sugar. Instead, you count the number of teaspoons of sugar.

We deal with electric charges in the same way. Instead of counting individual charges, we count charges in the unit of coulombs. A coulomb is like the teaspoon – but one coulomb is $6{,}25 \times 10^{18}$ positive or negative charges.

This is 6,25 × 1 million × 1 million × 1 million charges, or 6,25 billion billion charges; that is, 6,25 × 1 000 000 000 000 000 000 charges.

NOTE:

- We write one coulomb as 1 C.
- The symbol for charge is Q or q. We measure charge, Q, in the unit of coulombs.

The principle of charge conservation

From the activities in this chapter and Chapter 9 you can work out for yourself that, normally, materials don't have a nett electric charge. If the number of positive and negative charges in nature were different, the electric force would be acting on everything around us all the time.

So, in Activity 1, when you wiped the straw with your fingers, and the straw got some negative charges, your fingers got some positive charges. You and the straw were a **system**. If you were standing on some non-conducting material, no charges were coming into the system or leaving it. So the number of positive and negative charges stayed equal.

The principle of charge **conservation*** tells us that for every positive charge there is always a negative charge somewhere.

> * **conserve** (verb) – to keep things the same; to make sure nothing gets lost
>
> * an **isolated system** is, for example, you and the straw, provided you are standing on a non-conductor and the straw is not giving away its charge to the air

Definition: **The principle of conservation of charge states that the nett charge in an isolated system* is constant during any physical process.**

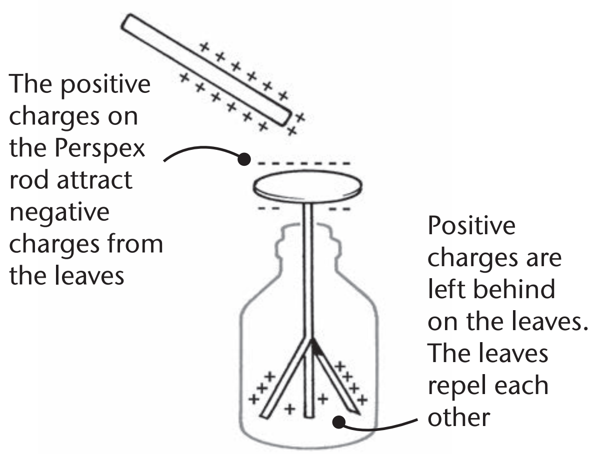
In other words, the total overall charge in a system stays the same, even if the parts of the system give charges to each other.

Applying the principle of charge conservation

First example

Look at the picture of the electroscope in Figure 12.12, and here in Figure 12.22. The electroscope as a whole had no charge to begin with. Now the electric force from the Perspex rod is separating the negative and positive charges, but for every positive charge there is still a negative charge.

Figure 12.22 *On the electroscope as a whole, the total of positive and negative charges is still zero.*



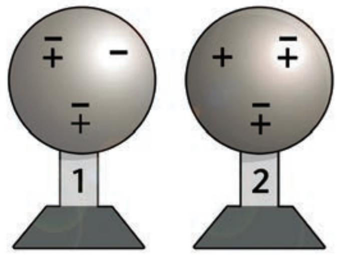
Second example

Imagine you have two conducting metal spheres (balls) like the ones in Figure 12.23. They are the same size, shape and material. Let us say that each + sign represents a million positive charges and a – sign represents a million negative charges.

The spheres are on non-conducting glass stands, so the charges do not flow down to the table. We say that this is an "isolated system", which means that no other charges can come onto either sphere.

Count the plus and minus signs in Figure 12.23. You find that Sphere 1 has one more – sign than Sphere 2, and Sphere 2 has one more + sign than Sphere 1. If you add them together, the result is zero. The system has a **nett charge** of zero.

Figure 12.23 *We represent the positive and negative charges with + and – signs.*



Now what will happen when the spheres touch?

When we let the two spheres touch, in Figure 12.24, the million excess electrons are attracted by the million electron-deficient atoms on Sphere 2.

On the electroscope as a whole, the total of positive and negative charges is still zero.

Figure 12.24 *When the spheres touch, the nett positive charge attracts the excess electrons from Sphere 1.*

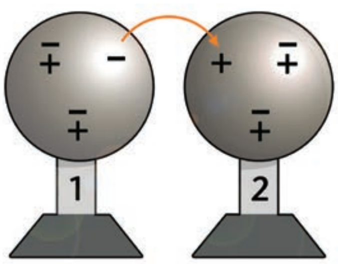
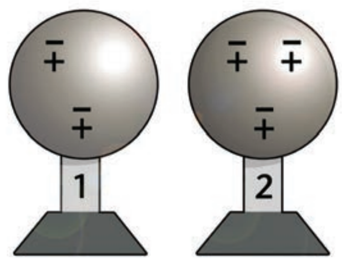


Figure 12.25 *On each sphere, there is a negative charge for each positive charge, and the nett charge for each sphere is zero.*



So the nett charge in the whole system of two spheres is zero before they touch, and it is still zero *after* they touch.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 299 2016/01/05 3:20 PM

The formula for calculating the charge on each of the identical conductors

In physics, scientists usually take the letter Q to stand for the word "charge". In this formula below, Q_{final} means the charge on **each** of the spheres after they have touched.

$Q_{final} = \frac{Q_1 + Q_2}{2}$ is a formula for working it out.

This formula works only for objects that are conductors and have the same size and shape.

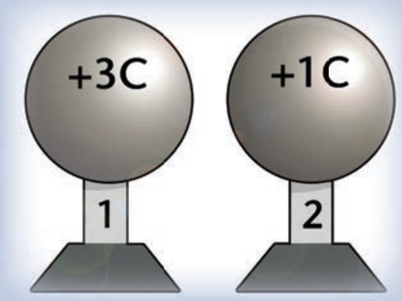
You can't use it for non-conductors because the charges don't move across a non-conductor.

You can work out many of these problems by common sense and drawing diagrams, but let us apply the formula also.

Worked examples: Calculate charges

1. In Figure 12.26 you see two metal spheres; one has a charge of +3 coulombs and the other has a charge of +1 coulomb. What will be the charge on each sphere after they touch?

Figure 12.26 *What will be the charge on each sphere after they touch?*



Solution

The common-sense method is to look first at Sphere 1: its 3 C of positive charges are repelling each other and they will spread out on Sphere 2 if the spheres touch.

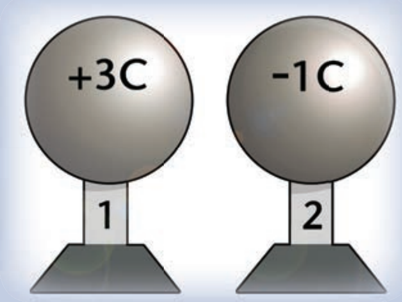
Then if Sphere 2 gets more positive charge than Sphere 1, the repulsion will push charges back in the other direction until they each get half, or +2 C each.

By the formula:

$$Q_{final} = \frac{Q_1 + Q_2}{2}$$
$$= \frac{+3 + (+1)}{2}$$
$$= \frac{4}{2}$$
$$= +2 \text{ C each}$$

2. What will be the final charge on each of the spheres in Figure 12.27, after the spheres have touched?

Figure 12.27 *What will be the charge on each sphere after they touch?*



Solution

By the formula:

$$Q_{final} = \frac{Q_1 + Q_2}{2}$$
$$= \frac{+3 + (-1)}{2}$$
$$= \frac{2}{2}$$
$$= +1 \text{ C each}$$

Activity 3 Calculate charges

1. What will the charge be on each sphere in Figure 12.28 after they have touched?
   a) Use the formula to work out what the charge will be on each sphere after they have touched.
   b) Then use your drawing method to check the answer. For –5 coulombs, write five minus signs on Sphere 1. For +2 coulombs, write two plus signs on Sphere 2.
2. In Figure 12.29, Sphere 2 has no nett charge.
   a) Use the formula to calculate the charge on each sphere after they have touched.
   b) Use a drawing method to show why your answer in (a) is correct. (A hint: all the electrons on Sphere 1 are repelling each other.)
3. Why can you use neither the formula nor the drawing method to work out what will happen if two charged golf balls touch each other?

Figure 12.28 *What will be the charge on each sphere after they touch?*

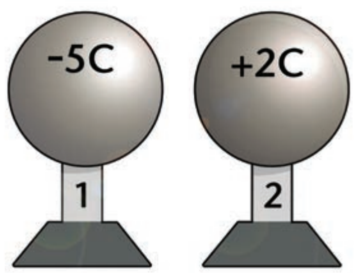
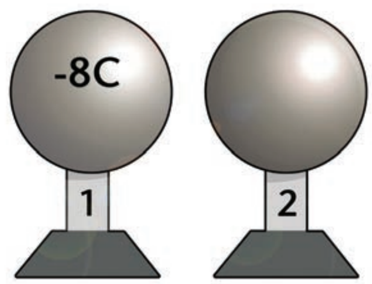


Figure 12.29 *Sphere 2 is electrically neutral.*



A third application of charge conservation – the capacitor

If you are doing Electrical Technology you will soon have to use capacitors. You will learn that they are used, for example, to absorb energy for short periods of time and prevent sudden high voltages; they are also used to store energy that is needed for starting electric motors.

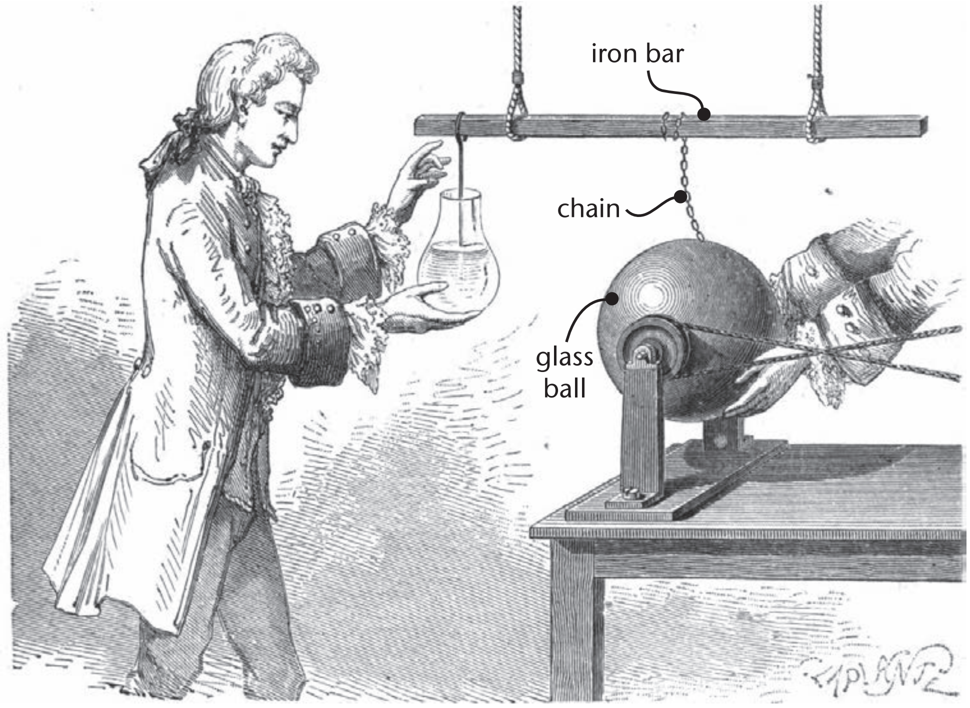
A capacitor has two conducting plates; a battery puts opposite charge on the two plates, and the quantity of positive and negative charge is the same on each plate.

The discovery of the first capacitor (Enrichment)

In about 1746, in the city of Leyden in Holland, a scientist called Pieter von Muschenbroek was studying electricity. He used a charging apparatus like the one you see in Figure 12.30 on the next page. There are three people doing this experiment: von Muschenbroek (you can see only his hands), his assistant Andreas Cuneus on the left of the picture, and another assistant who is off the right side of the picture.

von Muschenbroek's hands are touching a dark glass sphere. The assistant, whom you cannot see, is turning a pulley that spins the glass sphere. Electrons come from von Muschenbroek's hands, onto the moving glass sphere. The brass chain conducts the charges off the glass. The charges flow across the iron bar and down the wire into the water in the flask.

Figure 12.30 *Assistant Andreas is going to touch that wire!*



The assistant holding the glass flask is called Andreas Cuneus. You see that his finger is going to touch the wire hanging in the water.

When Cuneus touched the wire, he got a powerful electric shock.

News of this discovery in the city of Leyden spread quickly. Soon many people around the world were making these flasks; now they could do experiments with electricity. They called the flasks Leyden jars.

Would you like to make one too?

Activity 4 Make a Leyden jar

The first Leyden jar had salt water in a glass flask. Instead of water we will put metal foil inside a small plastic bottle. We do this because foil is a better conductor than water.

A. Look at Figure 12.31 on the next page – this is what you are going to make.

B. Cut two strips of foil. Each strip must be about $\frac{2}{3}$ the height of the pill bottle, and it must be long enough to wrap the strip around the pill bottle.

C. Wrap one strip of foil around the outside of the bottle, and fasten it in place with sticky-tape. Now wrap a piece of copper wire around the **outside** of the bottle and shape it as you see in Figure 12.31. The top of the wire is curved back; the wire must not end in a sharp point.

Apparatus

- ❑ plastic pill bottle, or another small plastic bottle with straight sides. The bottle should be at least 50 mm tall and about 30 mm in diameter.
- ❑ copper wire
- ❑ thick cooking foil (aluminium foil) about $\frac{1}{3}$ of an A4 sheet
- ❑ a round-head paper fastener, or a bolt with a ball-shaped head, or a drawing pin with no paint on the head
- ❑ scissors
- ❑ sticky-tape

Figure 12.31 *The Leyden jar looks like this from the outside.*

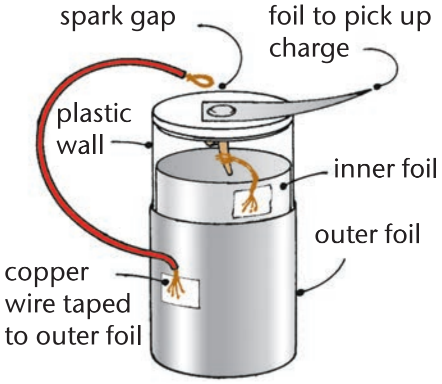
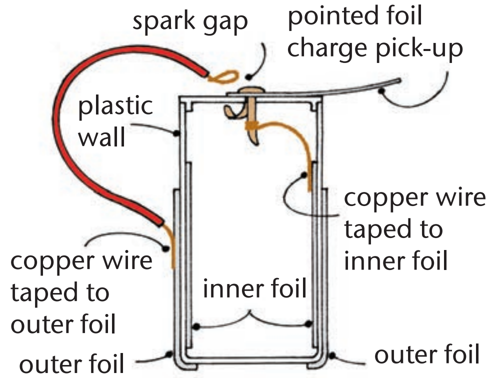


Figure 12.32 *This is what it looks like if you cut it from top to bottom.*



D. Take the other strip of foil and spread it smoothly **inside** the wall of the bottle.

E. Now make the top of the Leyden jar as you see in Figure 12.33. Make a small hole in the lid, just big enough for the legs of the fastener. Push the fastener through the foil pick-up and into the hole. Bend the legs so that they press firmly on the inner foil.

F. If the legs are not long enough, you can use stranded copper wire. Use sticky tape to connect the strands to the inner foil.

G. Bend the stiff copper wire so that it is near the round-head fastener, about 6 mm away.

Figure 12.33 *Make a lid like this.*

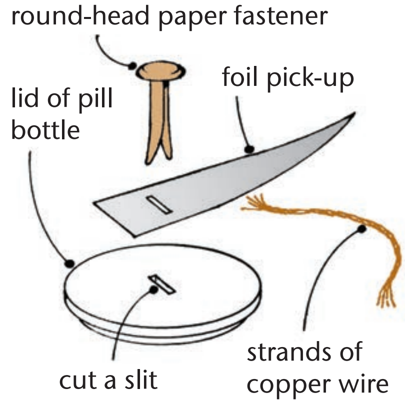
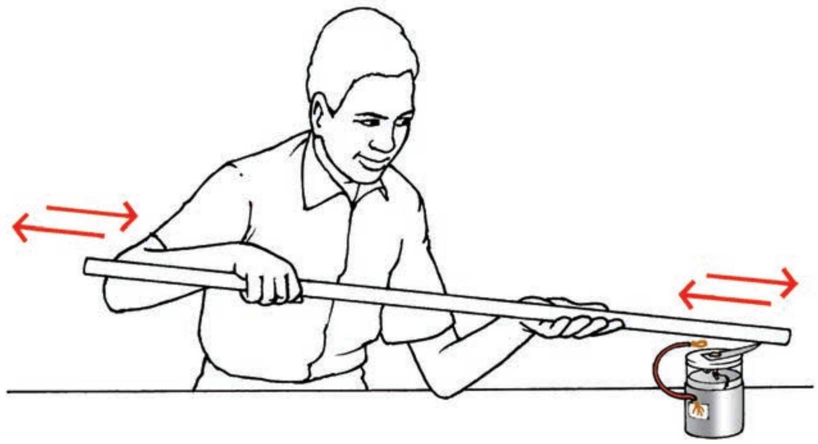


Figure 12.34 *How to charge your Leyden jar. The pipe must brush against the sharp tip of the foil pick-up on each stroke.*



H. Now give the jar a charge. You need a PVC plastic conduit pipe about 80 cm long. Your fingers must be dry. When you slide the PVC pipe through your hand, you will give negative charge to the PVC pipe and positive charge to your dry skin. You might hear little crackling noises from sparks after you have pushed the pipe through about 5 times.

I. Ask a friend to hold the jar steady, touching only the outer foil. Push the PVC pipe through your fingers about 10 times. On each stroke, the pipe should brush against the pick-up foil on the top of the Leyden jar. After about 20 strokes, you should see a spark jump across the gap between the copper wire and the round-head. You should see a spark about every five times you stroke the pipe past your fingers.

J. If you touch the round-head at the top of the capacitor, you should feel a small shock, as though a pin has pricked you.

Questions

1. In dry air, a spark will jump 10 mm if the voltage is 30 000 volts. If your spark is 6 mm long, what is the voltage of the charge in your Leyden jar? The answer will surprise you!
2. Even though the voltage is so high, you feel only a small shock from the jar. Think of a reason why the current does not injure you.

You can improve your Leyden jar; read more about it in the Resource Pages.

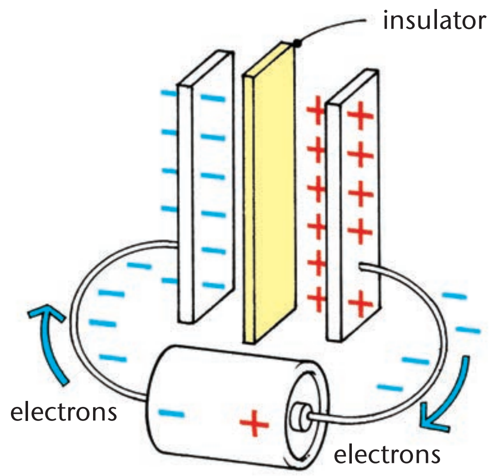
Capacitors are electrical systems that store energy

A capacitor is really two conducting plates with a sheet of non-conductor between them. Look at Figure 12.35.

You see a cell connected across the capacitor and it is pushing electrons onto the left-hand plate.

Think: Why is positive charge building up on the right-hand plate?

Figure 12.35 *If you push electrons onto the left-hand plate, they repel electrons away from the right-hand plate.*



The battery pushes more and more electrons onto the left-hand plate, but electrons repel each other. Soon the electrons that are on the left-hand plate push back at the incoming electrons, and so the flow of electrons stops. We say the capacitor is "fully charged". The left-hand plate has as many negative charges as it can hold, and the right-hand plate has as many positive charges as it can hold.

The **principle of charge conservation** tells us that the numbers of positive and negative charges are equal. Overall, the nett charge is still zero, but the charges are attracting each other with the electric force. So the capacitor stores energy.

Because the capacitor has potential energy, you could connect it in a circuit, as if it were a battery. You could light a bulb or LED with the stored energy. Electric force between the positive charges on one plate and the negative charges on the other plate will pull charges around the circuit.

To put more charges onto the plates, you can use bigger plates.

How a factory makes capacitors (Enrichment)

Capacitors' plates are two sheets of foil with a non-conducting sheet between them. This non-conducting sheet is called a **dielectric**.

A capacitor can hold more positive and negative charges apart if it has a large plate area. To keep the capacitor small, the manufacturer rolls up the foil plates and seals them inside a casing.

Figure 12.36 *This is what the capacitor looks like inside.*

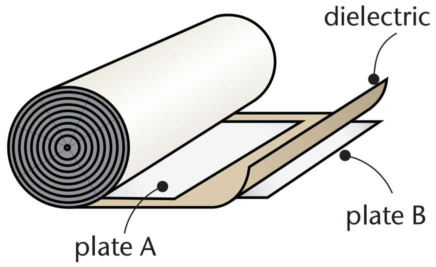


Figure 12.37 *This is a large capacitor.*

Unit 12.2 Summary activity

Complete this activity in your notebook and show it to your teacher for assessment.

1. Write some sentences that explain what a van de Graaff generator does.

2. Explain how a capacitor stores energy.

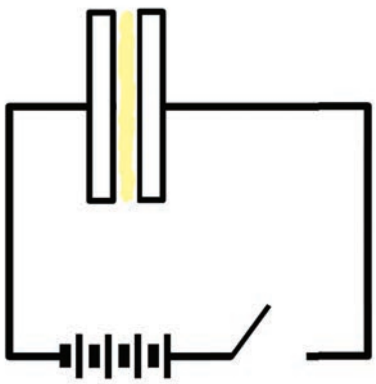
3. How can you increase the quantity of positive and negative charge that your Leyden jar can hold separate?

4. Copy and complete the diagram of a capacitor connected to a battery in Figure 12.38.

  a) Show where charges will go after you press the switch.

  b) Label the yellow material between the plates, and say what it does.

Figure 12.38 *Copy and complete this diagram.*



Chapter summary

- All materials are made of atoms, which have particles that carry positive or negative charges.
- Protons have positive charge and electrons have negative charge. The atom is electrically neutral when the numbers of protons and electrons are equal.
- Non-conducting materials can have electrons pulled off their surfaces, or added to their surfaces, even though the electrons cannot flow on the material.
- If a material has a deficiency of electrons, it has a nett positive charge, and if it has a surplus of electrons, it has a nett negative charge.
- Like charges repel each other, but unlike charges attract each other.

- We can separate unlike charges. We have to do work on them by rubbing two materials together. The work stores potential energy between the separate positive and negative charges.
- The **principle of charge conservation** is that the number of positive and negative charges remains the same in an isolated system.
- When two identical charged conductors touch, they share their nett charge equally, by the rule that $Q_{\text{final}} = \frac{Q_1 + Q_2}{2}$.
- A capacitor stores energy by keeping positive and negative charges separate on two conducting plates.

Challenges and projects

1. Re-design a plastic comb

A plastic comb and your hair give each other opposite charges when you comb your hair. How can you re-design the comb so that it does not charge up people's hair?

2. Make a better Leyden jar

In the Resource Pages you can find the information that you need.

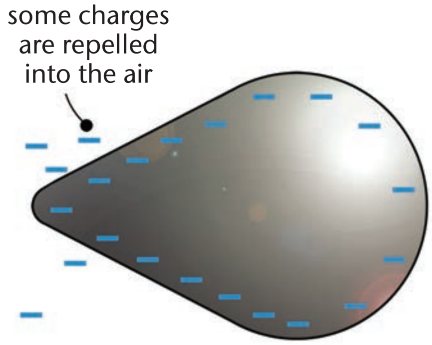
3. Why do we avoid sharp corners and edges when we want to keep electric charge on a conductor?

a) Find three pictures in the chapter that show smooth, round conductors that can carry charge. Explain why a shape like a sphere is best for holding charge.

Electric charges repel each other (if they are all negative or all positive). Near sharp points on a conductor, the charges crowd together and some charges are pushed off the sharp point, onto molecules of water vapour in the air.

b) Lightning conductors on buildings are there to get rid of charges into the air. Find a picture of a lightning conductor in the Resource Pages and explain why it has that shape.

Figure 12.39 *Electric charge "leaks" into the air at a sharp point.*



CHAPTER 13 Circuits and Potential Difference

In this chapter you will revise some of the ideas about electric circuits you met in Grade 9 Technology and Natural Sciences.

You will learn about a complete electric circuit, and the difference between an open and closed circuit. A cell gives energy to electric charges; the energy difference between the terminals causes the charges to flow around a circuit. This flow is a current. An ammeter measures current, while a voltmeter measures potential difference. You will do calculations of voltage and current.

Unit 13.1 Electric circuit diagrams and components

Definition: An electric circuit is a path along which electrons flow from a voltage source. Electric current flows in a closed path called an electric circuit.

You have worked with real electric circuits, so you know how they work. But you would need a lot of time to make realistic drawings of every part.

Technicians and scientists use diagrams instead. Their diagrams simplify complicated circuits. They just show symbols for parts and straight lines for conductors that connect the parts. Parts are also called **components**.

There are four basic components that are needed to build circuits.

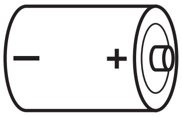
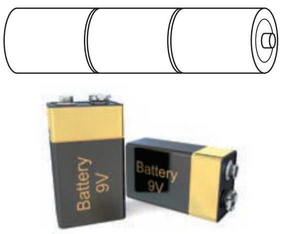
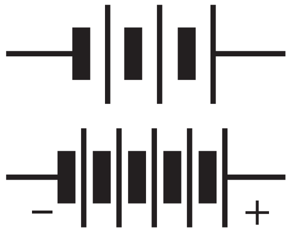
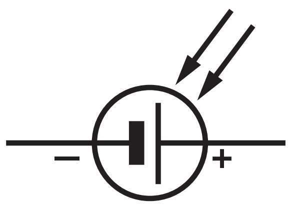
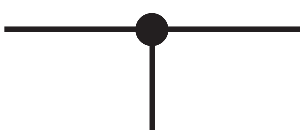
- **source**: to provide power or energy; e.g. a cell, a generator
- **conductor**: to provide a pathway for the current to flow; e.g. copper, aluminium
- **controlling device**: this opens and closes the circuit; e.g. switches, a relay (this is not always present)
- **load**: draws power from the source in order to operate; e.g. a light bulb, an electric motor

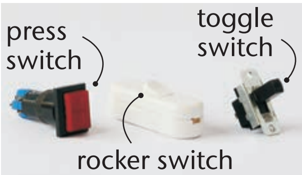
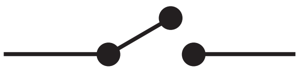
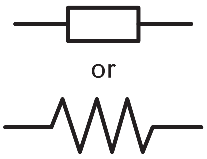
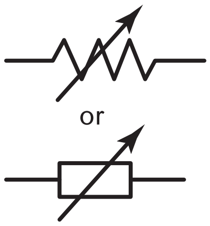
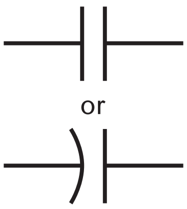
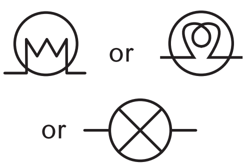
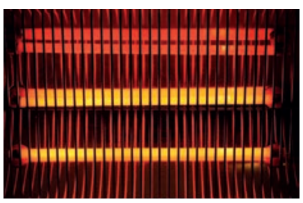
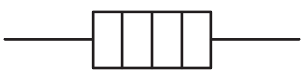
Symbols for circuit components

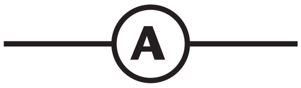
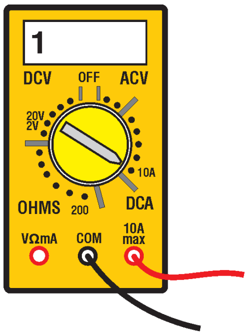
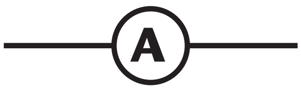
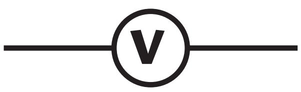
Electrical and electronic wiring symbols are used for drawing schematic diagrams as well as circuit diagrams. These symbols represent electrical and electronics components.

Table 13.1 shows some of the components we often use.

Table 13.1: Symbols for common circuit components

Sources		
Picture of the part	**Symbol for the part**	**Meaning**
		**A cell** The short fat line is the negative (–) terminal of the cell. These cells usually give 1,5 volts.
		**A battery** Here we have: • a battery of three cells, giving 4,5 volts • a battery of six cells, giving 9 volts
		**A generator** A generator is an energy input device, or an **energy source.** It has a magnet that spins between copper wires, which transfers energy to electricity. A generator needs its own energy input from a steam turbine, a petrol engine, or the legs of a person pedalling a bicycle.
		**A photo-voltaic cell** This input device transfers energy from the Sun, so it is another kind of **energy source**. The photo shows a panel with about 35 cells.
Conductors		
Picture of the part	**Symbol for the part**	**Meaning**
		**Electrical wire or any conductor** A metal spoon or a coin can also be a conductor, but we always use this straight-line symbol.
		**Connected wires**

Controlling devices		
Picture of the part	**Symbol for the part**	**Meaning**
		**A switch** A switch is a control device. It lets you break a path of conductors when you want to: it can make a gap that has non-conducting air in it.
		**Nichrome wire: a resistor** Nichrome wire is a medium-bad conductor and so we call it a resistor.
		**A carbon resistor** Carbon resistors are made with specific resistances. You can work out the resistance from the colour bands on the resistor.
		**A rheostat, or variable resistor** Dimmer switches are variable resistors. The bottom picture of a rheostat shows you the resistance wire inside the rheostat.
		**A capacitor** A capacitor keeps positive and negative charge apart, on separate metal plates. In this way, it stores energy for short periods of time.
Loads		
Picture of the part	**Symbol for the part**	**Meaning**
		**A bulb, or lamp** Bulbs are loads or output devices. Don't forget that bulbs are also resistors, which is why you see a resistor symbol in the first bulb symbol.
		**A heater** The resistance wire in the heater gets hot. A kettle, a soldering iron and a clothes-iron also have resistance wires that get hot. These are all output devices that produce heat.

Measuring devices		
Picture of the part	**Symbol for the part**	**Meaning**
		**An ammeter** An ammeter is used to measure the current in a circuit. An ammeter must be connected in series.
		**A voltmeter** A voltmeter is used to measure the potential difference across a component in a circuit. A voltmeter must be connected in parallel.
		**A multimeter, set to measure current** The "1" on the display tells you that it is ready to use.
		**A multimeter, set to measure voltage** The "1" on the display tells you that it is ready to use.

NOTE: Technicians in Europe, America, Japan, South Africa and other countries use slightly different symbols. There are two main standards that are used in different countries, the **IEEE*** standards and the **IEC*** standards. You will soon learn all the symbols because they are quite similar.

* **IEEE** – Institute of Electrical and Electronics Engineers
* **IEC** – International Electro-technical Commission

Types of circuits

We talk about "open circuits" and "closed circuits"

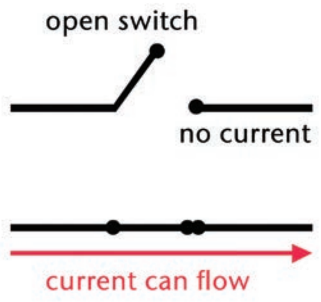
A switch has an air gap where the conductors do not make contact. When you press the switch, you complete the circuit and the current can flow. We say that you have **closed** the switch.

When you move the switch to **break** the circuit, we say that you have **opened** the switch. Look at Figure 13.1.

The circuit is said to be an **open circuit** when the switch is in an **open position**. Current will not flow through the switch and so the light bulb will be off.

The circuit is said to be a **closed circuit** when the switch is in a closed position. Current will flow through the switch and so the light bulb will be on.

Figure 13.1 *Open switch and closed switch*



NOTE: This is the opposite way round from opening and closing a tap: when you open a tap the water comes out. In circuits, if you open the switch the current stops flowing. Remember too that electricity is not like a flow of water through a hose or pipe; it is very different.

Activity 1 How to draw a circuit diagram

Look at the picture of a real circuit in Figure 13.2. What kind of material is the teaspoon made from?

Figure 13.2 *A real circuit. Draw the circuit diagram.*

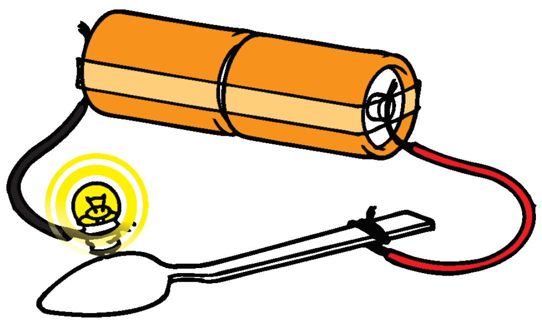
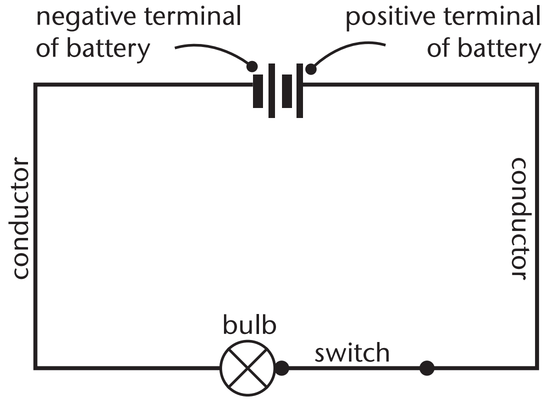


Figure 13.3 *A circuit diagram showing the same parts*



The circuit diagram in Figure 13.3 shows a symbol for two cells, a bulb and straight lines for conductors. The real wires are bent, and the spoon has its special shape, but they are all good conductors: we show good conductors with straight lines in circuit diagrams.

Questions

1. Look at the figures below. Why does the circuit diagram in Figure 13.4 represent both the real circuits in Figure 13.5 and Figure 13.6?

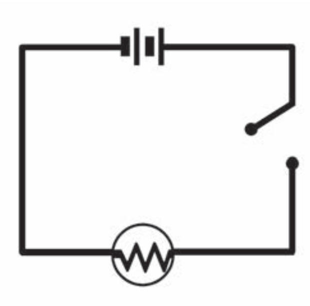


Figure 13.4 *The circuit diagram*

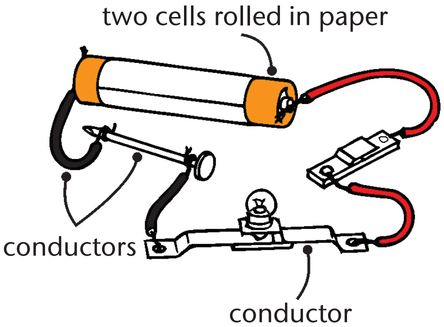


Figure 13.5 *The first real circuit*

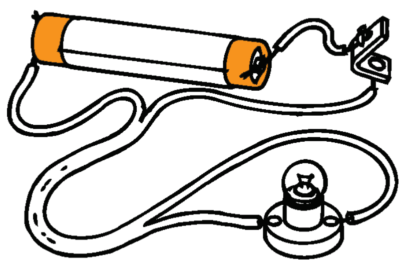


Figure 13.6 *The second real circuit*

2. In your notebook, draw a circuit diagram to represent the circuit in Figure 13.7. Show your drawing to your teacher.

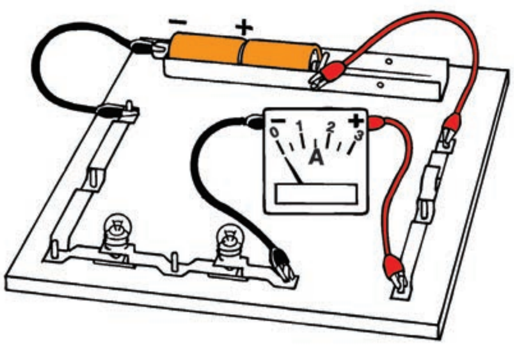


Figure 13.7 *The circuit diagram*

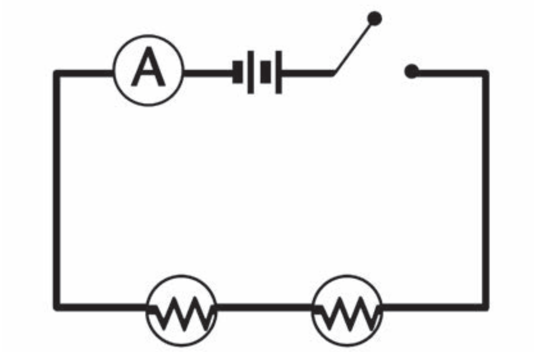


Figure 13.8

3. Describe the circuit in Figure 13.8, in words. You can begin with, "The diagram shows two cells in series with ..."
4. Draw a circuit with the following components. Please use wiring symbols:
   - two cells connected in series
   - an open switch
   - a light bulb
5. Draw a circuit with the following components. Please use wiring symbols:
   - two cells connected in series with two light bulbs
   - an ammeter in series with the cells
   - a closed switch

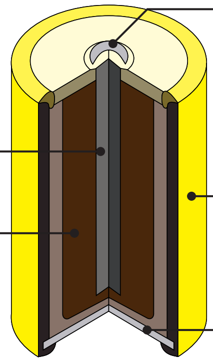
A cell can transfer energy to charges all round the circuit

A cell contains special compounds between two metal electrodes. In Figure 13.9 you see the brass rod that ends in a cap or knob: that is the **positive** electrode. All the chemical substances are inside a steel casing; the steel is the **negative** electrode.

The chemical compounds can react and transfer energy to the electric circuit. This energy transfer takes place by means of an electron transfer around the circuit.

However, the chemical compounds will not react until you connect the positive and the negative electrodes with a conductor. In other words, they have **potential energy**.

Figure 13.9 *The inside of a cell*



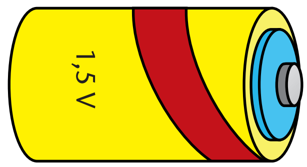
Definition: **Electromotive force (emf) is the potential difference across the terminals of the cell when there is no current flowing in the circuit.**

Let's think about what that definition means.

The emf of a cell

Look at Figure 13.10 The cell has a number, 1,5 V, printed on it. This number means 1,5 volts, which is the **voltage** of the cell.

Figure 13.10



Definition: **The voltage tells you about the maximum energy that the cell can give to charges in a circuit.**

We call this voltage the "emf" of the cell. The cell will, however, not give you all that energy when it's working, because some of the energy is wasted inside the cell.

When you connect the electrodes through a conductor, the chemicals react and push electrons into the circuit at the negative (–) terminal. **At the same time**, the reaction takes electrons off the positive (+) terminal. So the negative terminal pushes electrons away and the positive terminal pulls electrons in. Every electron in the conductors and bulbs feels the pull from the positive terminal and the push from the negative terminal and they all begin to move at the same time.

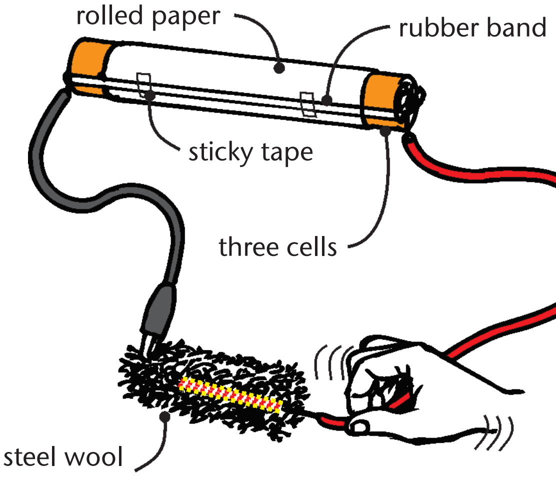
When this happens we say that the cell has **transferred** its potential energy to the bulb, the wires, and other parts of the circuit.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 313 2016/01/05 3:20 PM

Activity 2 Let cells transfer their potential energy to steel wool in a circuit

Look at Figure 13.11. Set up your circuit in the same way.

Figure 13.11 *Connect the wires to the three-cell battery like this. Stroke the steel wool with the wires for a few seconds.*



Apparatus

- ❑ 3 or 4 large torch cells
- ❑ two pieces of wire
- ❑ a small piece of steel wool

A. Connect the cells to form a battery of 3 or 4 cells.

B. Touch one wire to the steel wool.

C. Stroke the wires lightly on the steel wool.

D. Try A, B and C again with only one cell.

E. Pull out one strand of steel and hold it next to a torch-bulb.

F. What will happen if you connect the one strand to the battery? Discuss with a classmate.

Safety box

- Do not touch the wires onto each other; touch only the steel wool.
- Do not leave the wires connected to the steel wool for longer than a few seconds.

Questions

1. The steel glows red-hot; you know that means the atoms of steel are moving very fast. What is making the atoms move like this?

2. Why does the steel wool not glow when you touch only one wire on it?

NOTE: The steel wool is getting energy from the flowing charges when it glows red hot. The cell is transferring energy to the steel wool.

3. Did the experiment work with one cell? Why does it work better with 3 cells?

4. In what ways are the strand of steel and the filament wire in the bulb the same?

5. In what ways are they different?

An electric current is many charges all going in one direction

In Chapter 12, Electrostatics, we said that electric charges can flow along metals. A battery produces a steady flow of charges and the current can flow steadily for many hours.

When the chemicals in the cell have reacted as much as they can, the current will stop flowing.

Some people think of a cell, a switch and wires as if they are like a water-tank with a tap and a hose. They imagine opening the tap and waiting for the water to come out of the hose.

In fact, when you switch on a circuit, all the electrons everywhere in the circuit feel a push and begin to flow at almost the same time. That is why the light in a circuit comes on at the moment you press the switch.

We say that electric currents flow away from the positive terminal of a cell and towards the negative terminal of the cell. We call this the **conventional direction of current**.

Definition: **The conventional direction of current flow in a circuit is away from the positive terminal and towards the negative terminal.**

Activity 3 What is inside a torch bulb? (Enrichment)

For this activity, you need a real torch-bulb to look at. Imagine you could cut away one side of the bulb.

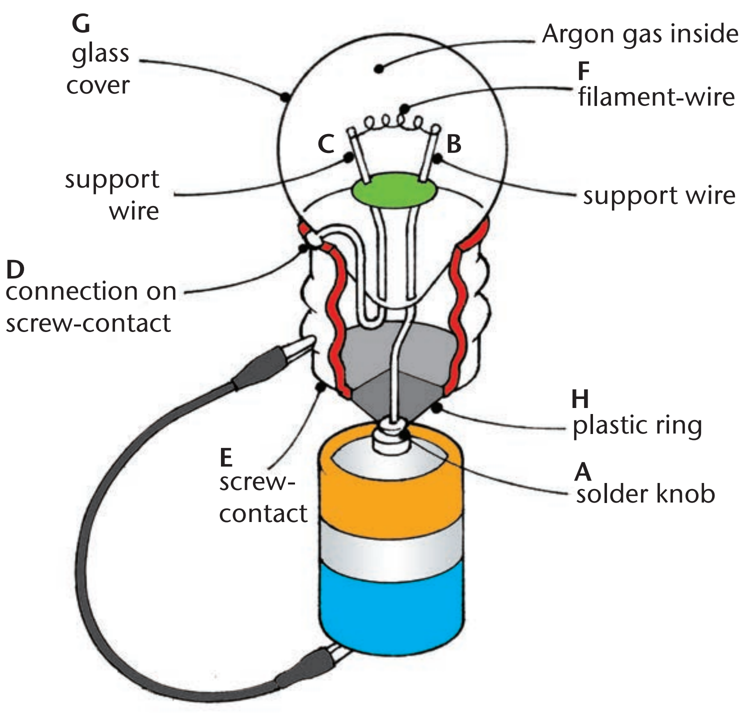
In Figure 13.12, you can see inside the bulb. The red lines show where the metal part was cut away.

A. Find the solder knob A on the bottom of the bulb in the diagram, and then find the same solder knob on your real bulb.

B. The solder knob is touching the positive terminal of the cell. Now point with your finger, and follow the current path from the knob A to the filament wire F.

C. Go all the way around to the screw-contact D and E and the flat end of the cell. The croc wire connects the screw contact to the flat end, which is the negative terminal of the cell.

Figure 13.12 *This is what the bulb looks like inside*



The solder knob is one **terminal** of the bulb, and the metal screw-contact is the other terminal.

D. Next, look inside your real bulb and try to see the support wires and the filament wire that glows white-hot.

E. Look carefully at a bulb-holder. You need a real one to look at; you see an example in Figure 13.13. How does the current flow through the bulb when you screw the bulb into position?

F. Look at the filament of your bulb. Figure 13.14 shows you the filament wire in a household bulb. The picture has been enlarged in a microscope; the real size is only 1 millimetre from the left to the right side of the picture. If your eyes are good, you will be able to look inside a real bulb and see the way the real filament is twisted. Use a magnifying lens if you can get one.

Figure 13.13 *What is the path of the current through the bulb-holder and the bulb?*

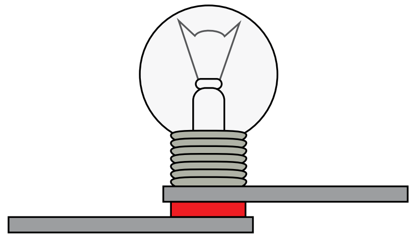
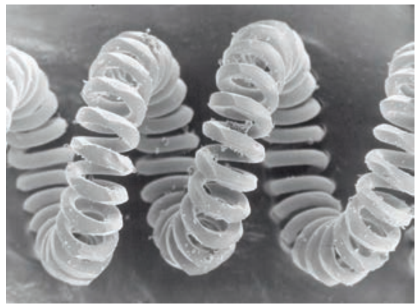


Figure 13.14 *This is what the filament wire looks like under a microscope.*



Questions

1. The coiled filament wire you see in Figure 13.14 is actually only 1 mm long between left and right ends. How long do you think this piece of wire would be if you stretched it out?

2. Write a sentence that is a rule for connecting a torch bulb. Begin like this: "To make the bulb glow, you must connect wires..." Use the phrases "solder terminal" and "screw terminal".

3. Imagine you could cut away one side of the bulb-holder in Figure 13.13. Draw a **cross-section** of the bulb and the bulb-holder, to show the parts inside.

4. Use a colour pen to show the path of the current through the holder and the bulb.

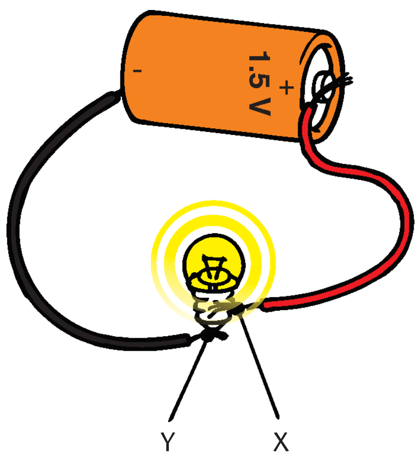
The energy difference across a bulb in a circuit

Look at Figure 13.15. The cell has potential energy that makes the charges flow. The filament gives off energy from the charges as it glows white-hot. You can feel this energy if you touch the bulb, and you can see it too.

So, as the flowing charges push through the filament, they come in at X with a certain amount of energy and they come out at Y with less energy. But the number of charges does not change. What has happened?

The difference between the energy at **X** and **Y** is the energy that the bulb has transferred to the air, to your eyes, to your skin.

Figure 13.15 *The energy difference between points X and Y is the same as the energy that the bulb is giving off.*



We call this difference the **potential difference** across the bulb. It means the same as the **voltage** across the bulb.

In the next Unit, you will measure potential difference with a voltmeter.

Unit 13.1 Summary Activity

1. What is a complete circuit? Write a full sentence.
2. What is an electric current? Write a full sentence.
3. What does a cell do to the charges in a circuit? Write a full sentence.
4. Here is a statement about potential difference. The parts of the sentences have been mixed up; rewrite the 3 sentences of the statement and read them to a partner. Your partner must tell you whether the statement makes sense.
   - **a)** [the charges coming out of the filament] [than the charges going in] [have less energy]
   - **b)** [the same energy that] [the energy they have given away is] [heats up the filament]
   - **c)** [across the bulb] [is called the potential difference] [this difference in the charges' energy]

Unit 13.2 How to measure potential difference and current

You can measure the potential difference across a bulb with an analogue voltmeter like the one you see in Figure 13.16. You see that the meter has a "V" printed on the scale.

Figure 13.16 *The voltmeter measures the potential difference across the bulb.*

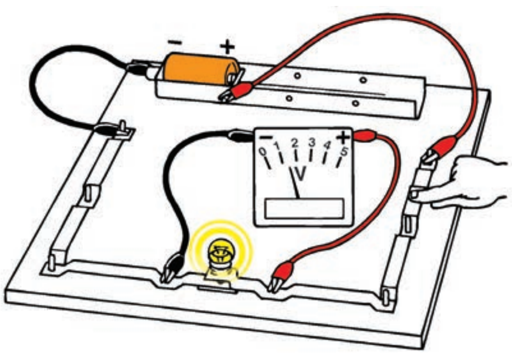
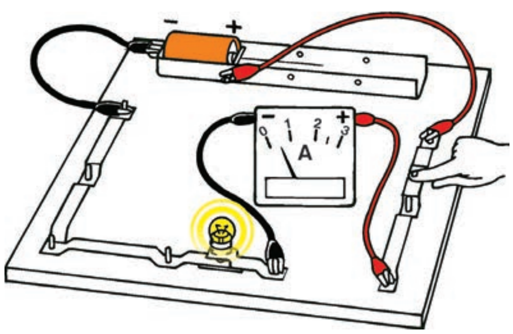


Figure 13.17 *The ammeter measures the current.*



Notice that the croc wires from the voltmeter are connected in **parallel** with the bulb, so that the voltmeter measures the energy drop across the bulb. The bulb current does not pass through the voltmeter.

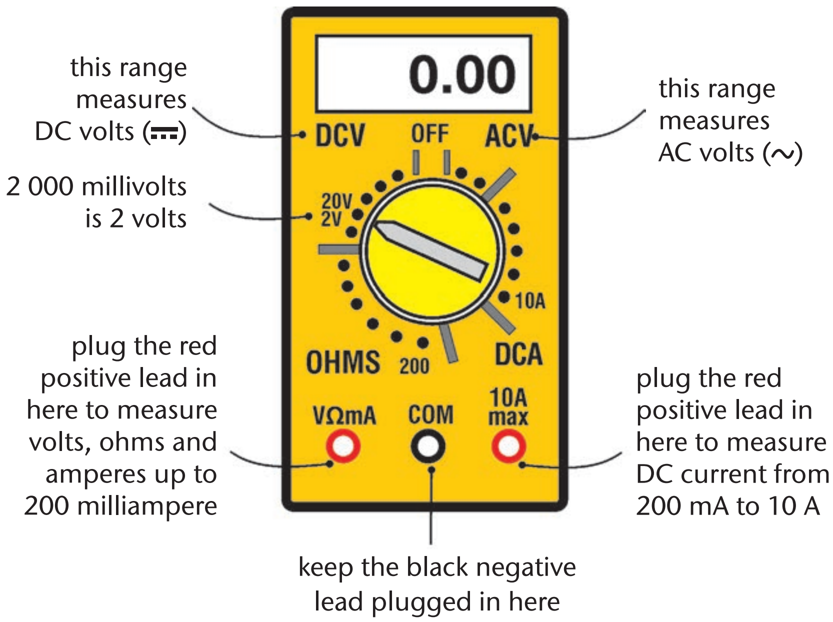
Now compare this with Figure 13.17. That is an analogue ammeter and it looks almost the same as the voltmeter. But an ammeter measures current and it has an "A" printed on the scale.

You have to connect all ammeters so that the bulb's current passes through the ammeter. Look carefully at Figure 13.17. Can you see that the circuit was broken so that the ammeter could be connected in **series** with the bulb? The ammeter now completes the circuit.

Activity 4 Learn how to read voltage on a multimeter

Focus question: What is the voltage across the bulb when the bulb is glowing?

Figure 13.18 *The front of your multimeter will look something like this.*



Apparatus (per group)

- ❑ a circuit board
- ❑ a cell: 1,5 volts
- ❑ connecting strips and croc leads
- ❑ a switch
- ❑ a bulb
- ❑ a moving-coil voltmeter
- ❑ a multimeter

In most schools and workshops you will use an electronic multimeter like the one in Figure 13.18. This meter can measure voltage, current and resistance. You have to choose the correct **range** on the multimeter for the **quantity** you want to measure.

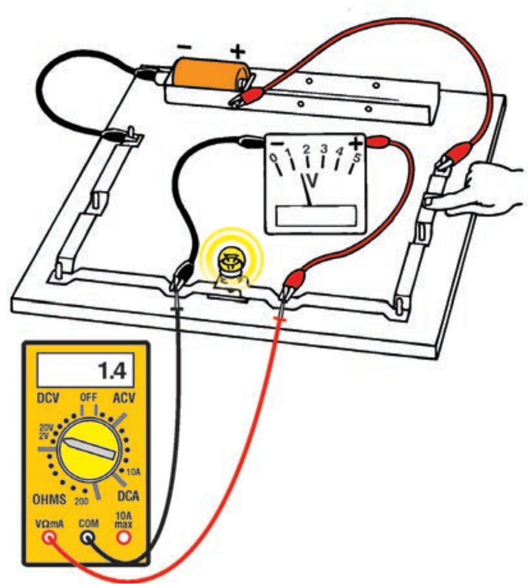
Process

A. Set up the circuit as you see in Figure 13.19. Connect the multimeter across the bulb. Notice where the red and black leads are plugged in. Also notice which colour lead goes to each side of the bulb.

NOTE: You may have a voltmeter that has a moving needle to show the reading. Check whether the needle points to the same voltage as you see on the multimeter display.)

B. Turn the rotating switch to set the multimeter on the 2 volts-maximum **range**. Now your multimeter is a voltmeter. We use the 2 volts-maximum range because the cell gives a maximum of 1,5 volts.

Figure 13.19 *The multimeter can work as a voltmeter and measure potential difference.*



C. Press the switch so that the bulb glows. Now the display should show nearly 1,5. It will not show a “V” and you have to remember that you set the switch to read volts.

D. Connect another cell in series with the first cell. Notice what changes in the bulb and in the voltmeter.

E. Connect across the ends of one brass connector strip. Read the potential difference across the strip. Are you surprised?

F. Feel the connector strip – is it warm? Answer Question 3.

G. Remove the bulb from the circuit and press the switch. No current will flow around the circuit because there is a break in the circuit. Connect the voltmeter leads back where they are in Figure 13.19. Answer Question 4.

Questions for discussion

1. The display does not show a “V” for volts. How do you know the display is showing volts and not amperes?
2. What changes happen when you add a second cell to the circuit? Think of the bulb and think of the voltmeter reading.
3. Why do you find zero potential difference across the connector strip? Think about how the strip feels when you touch it.
4. When you remove the bulb, you leave a gap in the circuit and no current can flow. **Predict** what potential difference you will measure across the gap.
5. Now measure the potential difference across the gap. Are you surprised? Explain why the potential difference was not zero.
6. The potential difference you measured was the same as the emf of the cell. Explain why this is so.

What we have learned from Activity 4

You set the multimeter to measure voltage, so you make it into a voltmeter.

- The voltmeter shows the potential difference across the bulb; the potential difference is equal to the quantity of energy that each coulomb of charge is transferring to the bulb.
- If you add cells and make the potential difference greater, then the bulb gives off energy faster and is hotter.
- Along a good conductor, there is no potential difference because no energy is being transferred to the conductor.
- Across a gap in the circuit, the voltmeter measures the full emf of the battery.

Activity 5 Learn how to read the current on a multimeter

Focus question: How much current is flowing through the bulb when the bulb is glowing?

We measure current in the unit of **ampere**, and the symbol for an ampere is an **A**. You can use your multimeter to measure the current that flows through the bulb.

A. Turn the multimeter's rotary switch until it points to the current range (DCA) with label "10 A max".

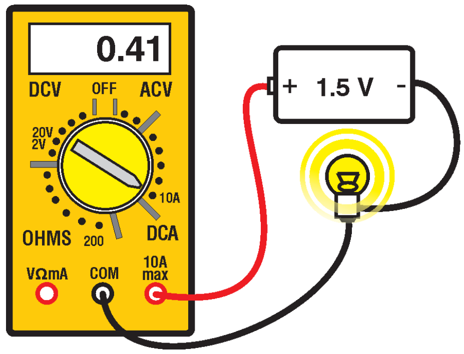
B. Pull out the red plug from its socket and plug it into the socket marked "10 A". Now we can call the multimeter an **ammeter**, because it will measure amperes passing through the bulb.

C. Connect the circuit you see in Figure 13.20 and leave the bulb glowing. Notice that you have to break the circuit to connect an ammeter because the bulb current must flow through the ammeter.

D. Measure the current through the bulb.

E. Now add a second cell to the circuit. What changes?

Figure 13.20 *The multimeter can measure current too.*



Questions for discussion

1. The display does not show an "A" for amperes. How do you know that the display is showing amperes and not volts?
2. What changes happen when you add a second cell to the circuit? Name two changes.
3. What is the difference between the way in which you connect the ammeter in Figure 13.20, and the way in which you connect the voltmeter in Figure 13.19?

Measuring potential difference and current

In Activity 4 and Activity 5 you learned how to measure potential difference with the voltmeter and current with the ammeter. Now we must look more carefully at the quantities we were measuring.

Experiment 11: Measurement of voltage (pd) and current

In this experiment you must show that you can measure both the voltage across a bulb and the current through the bulb.

Apparatus (per group)

- ❑ a circuit board
- ❑ 3 cells: 1,5 volts
- ❑ connecting strips and croc leads
- ❑ a switch
- ❑ a bulb
- ❑ a voltmeter
- ❑ an ammeter

Part One

Draw a circuit diagram showing a cell in series with a switch and a bulb. Now add an ammeter symbol and a voltmeter symbol to your drawing, showing how they are connected in the circuit. Show the diagram to your teacher.

Part Two

A. Use only one cell, and connect a circuit like the one you see in Figure 13.21.

B. Measure the **voltage across** the bulb. This is the potential difference across the bulb.

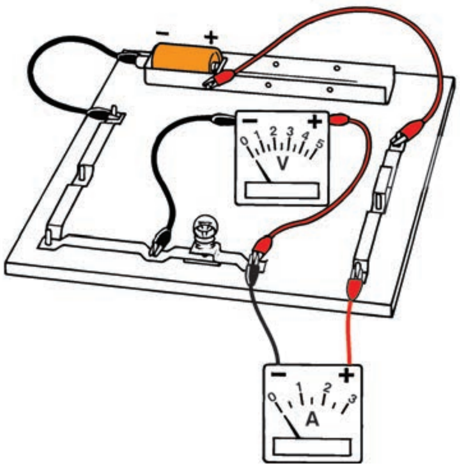
C. Measure the **current through** the circuit. This is the current through the bulb.

D. Record the current and voltage.

E. Now add another cell in series and measure the current and voltage again. Record your measurements.

F. Add a third cell in series, measure current and voltage again and record the measurements.

Figure 13.21 *Connect a circuit like this.*



Questions

1. Record your measurements in a table like this:

Number of cells	Potential difference (voltage) across the bulb (in volts)	Current through the bulb (in amperes)
One cell		
Two cells		
Three cells		

2. How does the brightness of the bulb change as you add more cells?

3. How does the potential difference change as you add more cells?

4. How does the current change when the potential difference changes?

The voltmeter measures the quantity of energy each charge gives away when it passes through a resistor. So the cell must have potential energy to begin with, which it passes on to the charges.

The potential difference across a resistor is the same as the quantity of energy that the cell gives per coulomb of charge. Remember that "per coulomb" means "for every coulomb".

Definition: **The quantity of energy that each coulomb of charge transfers to a bulb is also called the "work done" by the cell. So we can define potential difference across the bulb as the work done by the cell, per coulomb of charge.**

We can calculate potential difference using the following formula:

$$V = \frac{W}{Q}$$

where:

- V is potential difference measured in volts (V)
- W is work measured in joules (J)
- Q is charge measured in coulombs (C)

What does the ammeter really measure?

An ammeter shows the average quantity of charge passing though the ammeter every second. That is the same as saying that the ammeter measures the **rate** of charge passing through the ammeter. A **high rate** means a **big current**, or many coulombs per second. A **low rate** means a **small current**, perhaps a small part of a coulomb per second.

Definition: **Current (I) is the rate of flow of charge. It is measured in the ampere (A), which is the same as the coulomb per second.**

We can calculate current using the following formula:

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

where:

- I is current measured in amperes (A)
- Q is charge measured in coulombs (C)
- Δt is the change in time measured in seconds (s)

Worked examples: Calculations with voltage and current

1. Calculate the current in a conductor if 2 C of charge passes a point in a conductor in 0,4 s.

Solution

Given $Q = 2$ C; $t = 0{,}4$ s

Unknown I

Formula $I = \frac{Q}{\Delta t}$

$= \frac{2}{0{,}4}$

$= 5$ A

2. Calculate the quantity of charge that passes through a conductor if a current of 2 A flows past a point in the conductor for 10 s.

Solution

Given $I = 2$ A; $t = 10$ s

Unknown Q

Formula $I = \frac{Q}{\Delta t}$

$Q = I \times \Delta t$ (rearrange the formula)

$= 2 \times 10$

$= 20$ C

Activity 6 Calculations with voltage and current

1. Camera flashguns use a current from a capacitor to make the bright flash. A camera has a battery that charges up a capacitor until it cannot hold any more separated charge. When you press the shutter button 0,001 coulombs of charge flows out of the capacitor in 0,001 of a second, and you see a bright flash. Calculate the current that passes through the flash bulb.
2. The camera battery actually charges the capacitor with 0,002 coulombs of separated charge. The quantity of work that the battery does to store the energy in the capacitor is 0,012 joules. Calculate the voltage of the camera battery.

Chapter summary

- A **complete circuit** is a path of conductors that has no breaks in it. A circuit is **open** if there is a conductor missing, and current cannot flow across that break. A circuit is **closed** if the path of conductors has no break in it.
- A cell gives **energy** to electric charges. The energy difference between the terminals of the cell causes the charges to flow around a circuit. This flow of charges is a **current**.
- An **ammeter** must measure the current that is flowing through the bulb and so the current must flow through the ammeter as well as the bulb. For this reason we connect the ammeter in **series** with the bulb.
- We connect a **voltmeter** in **parallel** with the bulb because the current must not flow through the voltmeter.
- The energy that a glowing bulb gives off is **equal** to the potential energy that the cell is giving away. A voltmeter measures the **potential difference** across the bulb while the current is flowing through the bulb and giving off that energy.

Challenges and projects

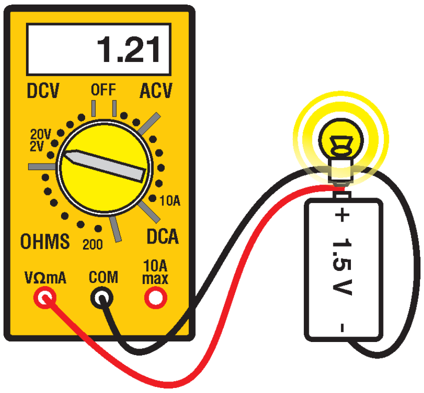
Practise reading your multimeter to measure volts and amperes

You will need to practise reading the display on your multimeter because it is easy to mistake the numbers on the display and forget what you are measuring.

Look at Figure 13.22 on the right.

- You have set the multimeter to read volts ("DCV" stands for Direct Current Voltage), and so we can call the multimeter a "voltmeter".

Figure 13.22 *This range can measure up to 2 volts.*

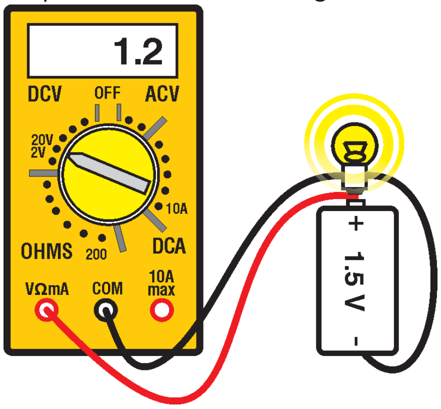


- The arrow on the rotary switch points to 2 V. That means the display will show up to 2 V. If the voltage is more than 2 V, you will see a "1" on the display. This means the voltmeter is working but it can't show more than 2 volts on this range. So you must turn the rotary switch to the 20 volt range.

Questions for discussion

1. What is the biggest voltage the meter can read, when it is set like this?
2. How many volts of potential difference is the cell putting across the bulb?
3. Suggest a reason why the bulb is getting less than the 1,5 volts that the cell is supposed to give.
4. You see that the bulb is glowing. If you disconnect the wires from the meter, the bulb will carry on glowing. Explain why this is true. (To disconnect the meter, you remove its red and black wires.)
5. Look at Figure 13.23. The bulb is connected in the same way as before, so why is the display showing only 1,2 volts?

Figure 13.23 *The 20 V range can measure up to 20 volts, but it is not as precise as the 2 volts range.*



6. You can also turn your multimeter into an ammeter, to measure amperes of current. Look at Figure 13.24. What current is flowing through the bulb? Give your answer in amperes.

Figure 13.24 *The ammeter measures the current flowing through the bulb, but that current must go through the ammeter too.*

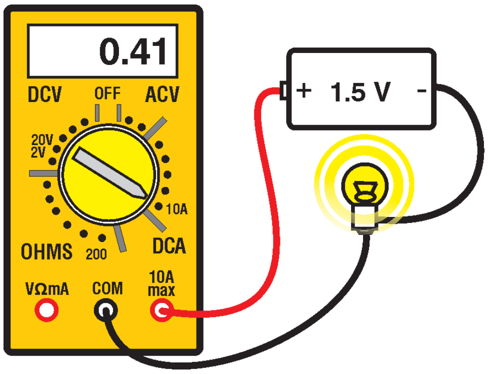
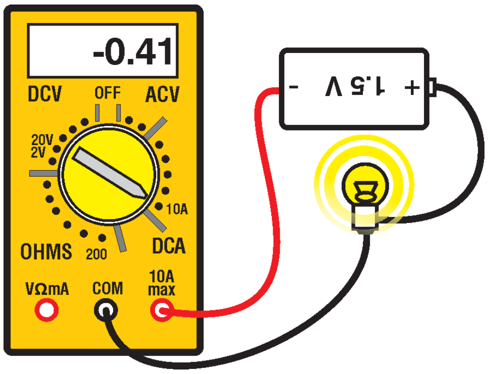


Figure 13.25 *This is what you see if you connect the cell the wrong way around, or the red and the black leads the wrong way around.*



7. The red wire (the lead) has been moved to a different socket to measure current. What is the label above that socket?
8. What is the important difference between Figure 13.22, where you measure voltage, and Figure 13.24, where you measure current?
9. A very big current will damage the ammeter. What is the maximum current that the ammeter can measure?

CHAPTER 14 Resistance and factors that change it

In Chapter 13 you learned that a potential difference can cause a current in a circuit. But how big is that current? In this chapter you will learn that the current can be big or small depending on the resistance in the circuit; you will learn about the relationship between voltage, current and resistance. You will go on to learn the four factors that affect resistance – length, thickness, temperature and the nature of the substance – and conduct an experiment involving these. In Chapter 15 you will learn how to connect resistors in series and parallel and how to work out the resistance in a circuit.

Unit 14.1 Conductors and resistance

Resistance

Definition: Resistance is the opposition to the flow of an electric current. The unit of resistance is the ohm (Ω): 1 Ω = 1 V A^{-1}

When you connect a light bulb in a circuit with one cell and one indicator light bulb, that light will glow. However, as you add bulbs in series to such a circuit, the indicator light becomes dimmer and dimmer. As we add more bulbs in series, the battery finds it harder to push current around the circuit, and the current becomes smaller and smaller. Why is this? The reason is that the filament wire in each bulb has **resistance**.

Electric charges in a resistor must push past the electrons of metal atoms, and so they give up energy to the metal atoms. The energy makes the resistor hot, and the charges flow slowly because they are losing energy. The resistor opposes the flow of charges and we say a resistor has **resistance**.

The **higher** the resistance, the **smaller** the current. The **lower** the resistance, the **bigger** the current.

Good conductors have low resistance, **bad conductors** have high resistance. We can therefore also say that insulators have extremely high resistance – we use insulators because they have such high resistance that current will not pass through them.

Good conductors are copper, gold, silver and aluminium, for example. They have very low resistance.

Medium-bad conductors are tungsten, graphite (the black stuff in your pencil) and nichrome. They conduct electricity, but not very well. The filament wire in a bulb is made of tungsten.

Semi-conductors you will use are mixtures of silicon or germanium, with small amounts of other elements like phosphorus. Their resistance decreases as you increase the pd (voltage) across them. They conduct better and better as they get hotter and hotter.

Very bad conductors are plastic, glass and wood, for example. They have such high resistance that a battery cannot make any current flow through them. We say they are **good insulators**. The plastic covering on electrical wire is the **insulator** on the wire.

But even good insulators will conduct current if the voltage across them is high enough. For example, air will conduct a current of lightning when the voltage between the cloud and the ground is millions of volts.

Quick Activity: A range of resistivity* from very low to very high

Draw the diagram below in your notebook, then write the names of these substances at a suitable place on the scale:

nichrome wire; plastic; copper; gold; glass; cooking foil; pencil graphite; dry paper; paper wet with salt water; wet human skin; moist air; dry air

Very good conductors: very low resistivity	Good conductors:	Poor conductors:	Very poor conductors: very high resistivity
e.g. silver			

The reason why materials have different resistivity*

NOTE: When we talk about the tendency of a specific material to resist the flow of current, we use the word "resistivity" instead of "resistance". This is because "resistance" is a quality of a specific **object** and it depends on the object's length, thickness and shape. "Resistivity" is a quality of a specific **material** – it depends only on the nature of the material and not on its length, thickness or shape.

> * **Resistivity** is a quantitative measure of a material's resistance to the flow of current. It depends only on the nature of the material and not on the material's shape or size.

We know that even good conductors, such as copper, have some resistance. The reason for this resistance is that electrons (which have negative charge, remember) do not move in straight lines; they tug on the positive nuclei of the metal atoms as they go past and the nuclei tug on them. Remember that if the current is 1 ampere, $6{,}25 \times 10^{18}$ electrons pass each point in the resistor every second! That huge number of electrons can make the metal atoms vibrate faster as each electron pulls on every atom it passes. The result is that the metal gets hot.

> $6{,}25 \times 10^{18}$ electrons is
>
> 6 250 000 000 000 000 000 electrons!

But why is copper such a good conductor and plastic such a poor conductor? The answer is that they are made of different kinds of atoms and molecules. The atoms of a copper wire have lots of electrons that can move from atom to atom if they feel an electric force pulling them. But in the plastic, almost all the electrons are tightly held in the atoms, and they cannot move from atom to atom. You cannot pass a current through a non-conductor; however, as you saw in the electrostatics activities, you can remove some electrons from the **surface** of a non-conductor.

Measuring resistance – two methods

The unit of resistance is the **ohm**, and its symbol is **Ω**.

We use two methods to measure resistance: in the first method we compare current and voltage, and in the second method we use the multimeter on the ohms range.

1. The method of comparing current and voltage

Imagine a very long piece of copper wire. If we need 2 volts to push 2 amperes of current through the wire, we say that the resistance of that wire is 1 ohm (1 Ω).

For that piece of wire, we will need 3 volts to push a 3 ampere current through the wire, because its resistance is 1 ohm.

The resistance of that piece of copper wire is 1 ohm and this means that when the voltage changes, the current also changes. But if we compare the voltage and the current, we get a ratio that is always the same – 1 ohm for that piece of copper wire.

The resistance is a ratio:

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

This ratio is called the formula for resistance.

In symbols:

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

where:

- R is resistance measured in ohms (Ω)
- V is voltage measured in volts (V)
- I is current measured in amperes (A)

To calculate V, we need V as the subject of the formula:

$$R \times I = V$$

We write:

$$V = RI \qquad \text{or} \qquad V = IR$$

To calculate I, we need I to be the subject of the formula:

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

2. The method of reading an ohm-meter

Your multimeter has a resistance range, too. It may be marked with an ohm symbol, Ω.

A. Turn the rotary switch until the arrow points to 200 Ω.

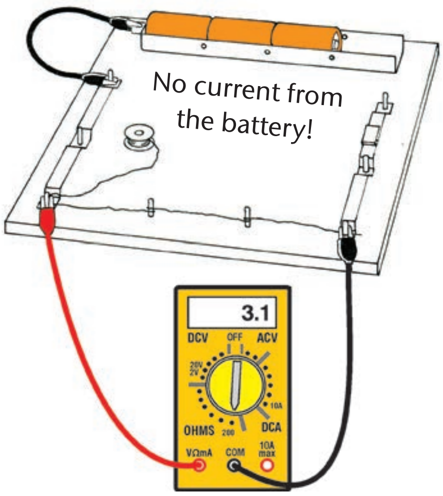
B. Plug the red lead into the V Ω mA socket. Touch the probes or croc clips together: you should hear a faint beeping noise and the display should show approximately zero ohms resistance.

C. Switch off the current through the nichrome wire. This is important, because you cannot measure resistance while a circuit is connected to battery or power supply.

D. Connect the red and black leads to the ends of the nichrome wire.

E. **Think:** What is the resistance of that piece of nichrome wire, according to the ohm-meter?

Figure 14.1 *Measure the resistance in the nichrome wire.*



Worked examples: Calculating the resistance of a conductor

Here are two examples of how we calculate the resistance of a conductor.

1. If the voltage across a piece of nichrome wire is 6 volts, and this causes a current of 2 ampere through the wire, what is the resistance of the wire?

Solution

Given $V = 6$ V; $I = 2$ A

Unknown resistance

Formula
$$R = \frac{V}{I} = \frac{6}{2} = 3\ \Omega$$

2. If the voltage across a glowing bulb is 1,4 volts and the current is 0,5 ampere, what is the resistance of the bulb?

Solution

Given $V = 1{,}4$ V; $I = 0{,}5$ A

Unknown resistance

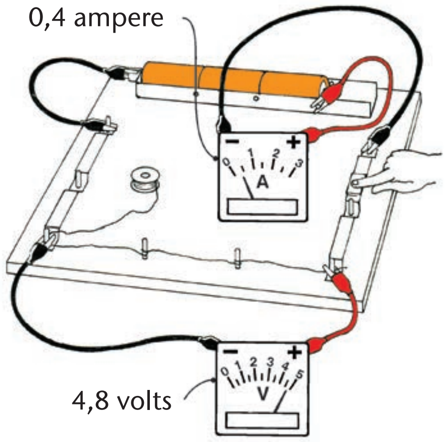
Formula
$$R = \frac{V}{I} = \frac{1{,}4}{0{,}5} = 2{,}8\ \Omega$$

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 328 2016/01/05 3:21 PM

Activity 1 Calculation exercises

1. Calculate the resistance of the piece of nichrome wire in Figure 14.2. Give your answer in ohms.
2. We can put 3 cells in the circuit, or 2 cells, or 1 cell. By changing the numbers of cells in Figure 14.2, we can put different voltages across the nichrome wire. Calculate the resistance of that piece of nichrome wire when:
   - **a)** the voltmeter reads 6 volts and the ammeter reads 0,5 amperes
   - **b)** the readings are 3,6 volts and 0,3 amperes
   - **c)** the readings are 1,2 volts and 0,1 amperes
   - **d)** the readings are 2,4 volts and 0,2 amperes
3. What do you notice in the resistances in **Question 2**? This quantity is the resistance of that piece of nichrome wire you see in Figure 14.2.
4. Light-emitting diodes (the small red, green, white or yellow lights you see on electronic equipment) are also called LEDs. If you use an LED in a circuit, you must connect a resistor in series with it so that the current through the LED is 0,02 ampere or less. If the circuit uses a 9 volt battery, what is the ohm value of the resistor?
5. You measure a current of 0,01 ampere through a resistor of 470 ohms. What is the potential difference *V* across the resistor?
6. A resistor of 5 ohms is connected to a 1,5 volt cell. What current does this potential difference cause?

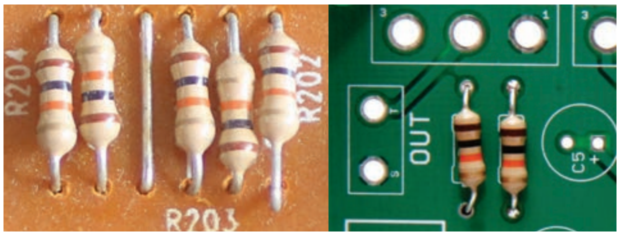
Figure 14.2 *Calculate the resistance in the nichrome wire.*



Resistors let us control current in electrical equipment

Inside electrical equipment like a radio, you will see many small coloured cylinders. Look at Figure 14.3. Many of these coloured cylinders are resistors. The radio **designer*** chose the right resistors to let small currents go to some parts of the radio and big currents to other parts.

Figure 14.3 *Resistors in a circuit board*



These resistors are made from carbon, and the factory carefully cuts away some carbon until the resistor has a certain resistance, which stays **constant***.

The factory then puts coloured rings on each resistor to show how much resistance it has. They use a code which you will find in the Resource Pages.

* See Glossary.

Activity 2 Work out the resistance of some carbon resistors

Learn to use the resistor colour guide in the Resource Pages to work out the resistance of the two resistors shown in Figure 14.4a and Figure 14.4b. The Resource Pages are at the back of this book.

Questions

1. In Figure 14.4a, the first three colour bands of the first resistor (from the left) are red, red, and brown. The first red band stands for 2, the second red band stands for ____ and the third band stands for "× 10". So the resistance of this resistor is ______ ohms.

Figure 14.4a *The colour bands are red, red, and brown, with a gold band at the end.*

Figure 14.4b *The colour bands are brown, black, and yellow, with a gold band at the end*

2. In Figure 14.4b, the first three colour bands of the resistor are brown, black, and yellow. The first band stands for ____, the second for ___ and the third for _____. So the value of this resistor is _______ ohms. The gold band on the right means that _______.
3. Draw a colour picture of a 470 ohm resistor.
4. Determine the value of resistors with the following colours:
   - **a)** yellow, violet, yellow, gold
   - **b)** grey, red, black, silver
   - **c)** orange, orange, grey, gold

Unit 14.2 Design resistors to control currents

Conductors have differing resistance, and the resistance **depends** on several **factors**. The factors are the things that could change the resistance of a conductor. Here they are:

1. the length of the conductor
2. the thickness of the conductor
3. the temperature of the conductor
4. the substance the conductor is made from

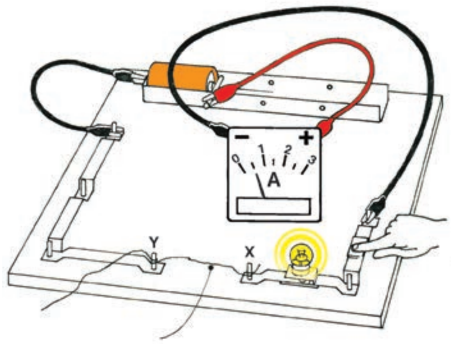
We are going to investigate them in a four-part experiment, but we will first discuss the situation.

Activity 3 What factors can change the resistance of conductors?

A. Look at the circuit in Figure 14.5. Find the nichrome wire connected at X and at Y. You see that the left-over piece is not connected to anything.

B. Your teacher asks: "I want the current through this circuit to be smaller. What could I do to change the resistance and so make the current smaller?" Discuss this question.

Figure 14.5 *How can you change the resistance in this circuit, to make the current smaller?*



Questions for discussion

1. What would happen if you used the whole length of the nichrome wire you see in Figure 14.5? (You must make a **prediction**.) Give a reason for your prediction.

2. You can buy nichrome wire that is as thin as a hair.

  a) If you put such a very thin piece of nichrome in the circuit, between X and Y, how would the current change, do you think?

  b) Give one reason for your prediction.

3. Let's say you connect a silver wire across X and Y, instead of the nichrome wire. Predict how the current will change.

4. Let's say you heat the nichrome wire with a flame until it glows orange.

  a) How would the current change, do you think?

  b) Give one reason for your prediction.

Experiment 12: Investigate the factors that affect the resistance of a conductor

Focus question 1

How does the resistance of a nichrome wire **depend** on the length of the nichrome wire?

Length of nichrome wire (in cm)	30	60	90	120	150	180
Resistance (in ohms)						

Apparatus for Question 1

- ❑ multimeter on 0 to 10 A range
- ❑ ruler
- ❑ 2 m of nichrome wire
- ❑ three 1,5 V cells

Focus question 2

How does the resistance of a wire depend on the thickness of the wire? (The thickness of the wire is the **diameter** of the wire.)

Wire diameter (in mm)	0,2	0,4	0,6
Resistance (in ohms)			(Predict what this resistance will be.)

Apparatus for Question 2

- ❑ nichrome wire: 0,2 mm diameter
- ❑ nichrome wire: 0,4 mm diameter
- ❑ 1,5 V cell
- ❑ multimeter

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 331 2016/01/05 3:21 PM

Focus question 3:

Does the resistance of a resistor depend on the material you use to make the resistor?

Focus question 4:

Does resistance depend on temperature? If it does, in what way?

Apparatus for Question 3

- ❑ circuit board
- ❑ multimeter, set to read resistance (the ohm scale)
- ❑ three kinds of wire (such as nichrome, eureka and iron), of the same thickness (diameter)

Apparatus for Question 4

- ❑ circuit board
- ❑ multimeter, set to read 200 milliamperes maximum
- ❑ 1 metre of nichrome wire (any thickness)
- ❑ 3 cells of 1,5 V each
- ❑ spirit burner

Activity 4 Match the factors to their applications

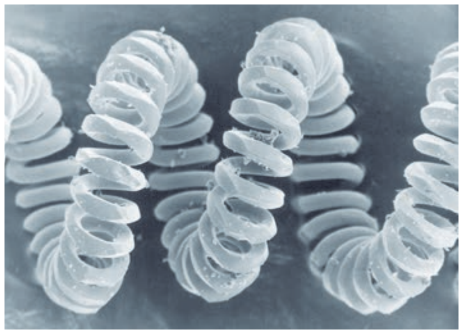
This can be a group discussion activity with reporting to the class, or it can be a written task.

Questions

1. Tungsten is a good metal for a bulb filament because, even at 1 400 °C, it does not melt and it glows brightly. But tungsten is also a medium-good conductor. The filament in a light bulb must have a much higher resistance than the copper wires in the circuit. The reason is that we want only the filament to give off the energy, and not the copper wires.

- **a)** How do engineers make a filament with high enough resistance?
- **b)** A hint to help you with Question (a): Look at Figure 14.6. This photo was taken through a microscope. The real width of the tungsten coil is 1 mm (from top to bottom in the photograph). Estimate the length of the tungsten wire you can see.

Figure 14.6 *This picture shows only 1 mm of the tungsten filament; it was taken through a microscope.*



2. Electricians who install wires in houses know that they must use thick, expensive copper wire for the stove, while they can use thinner, cheaper copper wire for the lights. See Figure 14.7.

- **a)** What is the reason for this?
- **b)** Which of the resistance factors is relevant here?
- **c)** Explain what would happen if the electrician tried to save money by using thin copper wires to connect the stove.
- **d)** Do you know the building regulations that tell you which wires to install for lights, plugs and stoves?

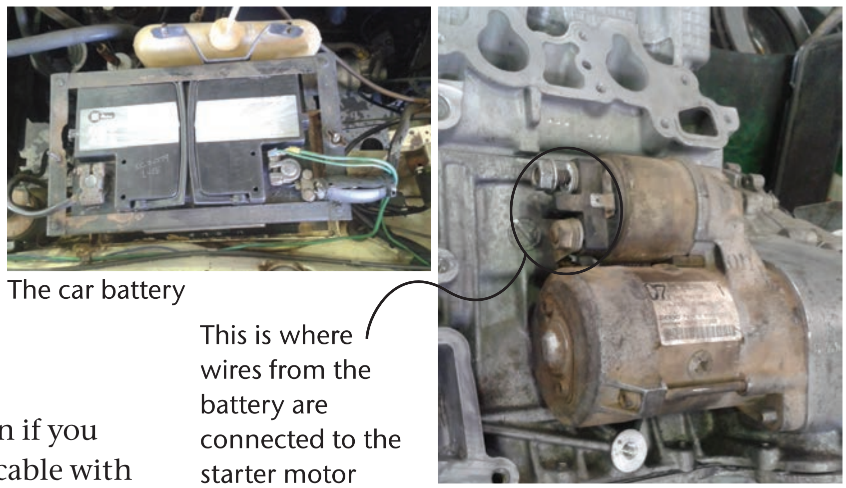
Figure 14.7 *The wires used for wiring a house*

3. Magnetic Resonance Imaging (MRI) machines in hospitals can create a picture of the inside of a patient's body, without hurting the patient in any way (see Figure 14.8). Their electromagnets need a very large current, and so the wires of the electromagnets are cooled with liquid helium. Liquid helium is very, very cold – as cold as –269,1 °C. When the wires are so very cold, they can conduct a much larger current. Explain why this is so.

Figure 14.8 *An MRI scanner in a hospital*

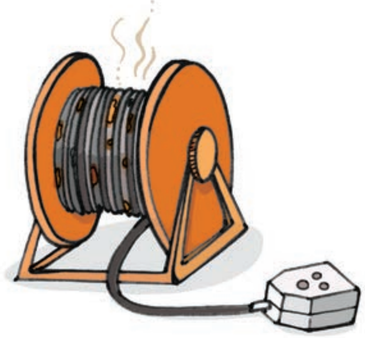
4. Computers use circuits with very thin conductors to calculate numbers and show images on the screen. Computers work much faster if the circuits are kept cold (that is the reason computers have fans inside). Explain why this is so.
5. Copper is an expensive metal and that is why thieves steal copper cables. When these cables are stolen, vital services stop. For example, a person who needs an electrical machine to keep her breathing may die if the power goes out. So municipalities replace copper cables with aluminium cables, because the *izinyoka* thieves don't want aluminium. However, aluminium cables give off more energy than copper and waste it. Explain why this is so.
6. **a)** Why does a car battery need such a thick copper cable connecting it to the circuits in the car? Look at Figure 14.9 and explain what you see there.
   b) Predict what would happen if you replaced the thick cable with wire from a desk lamp.
   c) Predict what would happen if you replaced the thick copper cable with iron wire of the same thickness.

Figure 14.9 *A car starter motor takes current from a battery to start the car.*



7. Let us say that you were working on a building site, welding steel beams. Electric welding machines need large currents. You have been using an extension cable on a reel, like the one in Figure 14.10. You needed only a short length of cable, so you left the rest of the cable wound on the reel. On Monday the building foreman is furious with you because the insulation on the cable has melted, and the cable is now unsafe to use.
   a) What resistance factors are relevant here?
   b) Explain what happened. How could you prevent such damage?

Figure 14.10 *The insulation on this electric cable has melted. Why?*



Chapter summary

- **All conductors** have some resistance. **Good conductors** have low resistance; **bad conductors** have high resistance.
- The resistance of a conductor reduces the current that flows in the conductor. The current gives off energy that heats up the conductor.
- A cell does not always give the same current. The current may be big, small or zero, because the current depends on the resistance in the circuit.
- For a particular cell, if the resistance in the circuit is big, the current is small, and if the resistance is small, the current is big.
- The current depends on the resistance in this way:

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

Challenges and projects

Project 1: Make a graphite resistor from a pencil

Figure 14.11 *Cut the pencil until you see the graphite.*

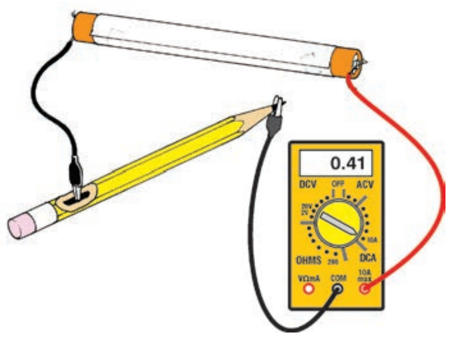
A. Take a long pencil and cut away some wood at the top end, until you can touch the graphite.

B. Now make the circuit you see in Figure 14.12 using three cells. Check that the indicator bulb is working and notice how bright it is.

C. Next, connect the graphite in the circuit and look at the indicator bulb. You will see it light up, but not as brightly as before.

D. You have made a resistor. Resistors keep the current small in circuits where it must not get too big. Radios, tape recorders and all kinds of electronic circuits have resistors in them. Measure the resistance of your graphite resistor. Put the correct coloured bands on it to show the resistance.

Figure 14.12 *Connect the graphite rod in the circuit like this.*



Project 2: Is the resistance of a bulb always the same?

The filament wire in a bulb has resistance. When the bulb is not glowing, the filament wire is cold. When the bulb is glowing brightly, the filament wire is white-hot.

A. Do you think that the resistance of a hot bulb will be the same as the resistance of a cold bulb? Make a prediction.

B. Now set up a circuit to test your prediction.

C. Think of a way to vary the current through the filament. Take measurements for 5 different values of current and work out the resistance for each current.

D. Draw a graph to display your results.

CHAPTER 15 Series and parallel circuits

In Chapter 14 you learned about resistance and how a resistor opposes the flow of charges. You learned that the charges' energy is given off in the parts of the circuit that have the highest resistance. In this chapter you learn what happens when you connect resistors in series so that there is only one current path, or you connect them in parallel so that there are two or more current paths.

A series circuit has only one path for current and therefore all the current must go through all the series resistors. The charges in the current transfer some of their energy in each resistor, but the current itself is not used up.

The voltage we measure across a resistor is really the amount of energy that is transferred from each coulomb of charge as the charges pass through the resistor. The difference between the energy of charges before, and after, going through the resistor, is called the potential difference across the resistor.

In a series circuit, the highest resistor has the biggest potential difference across it. The potential differences across all the series resistors are in proportion to the values of the resistors.

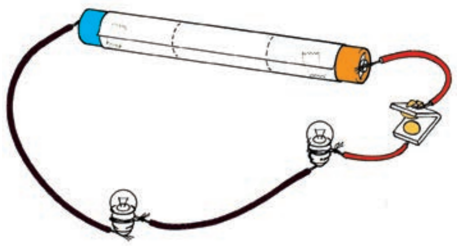
In a parallel circuit, all the resistors that are in parallel have the same potential difference across them, no matter whether their resistances are high or low.

Unit 15.1 Resistors in series

Look at Figure 15.1. Imagine that you press the switch and the bulbs all light up. With your finger, trace the path of the current through the bulbs.

There is only one path for the current – all the current must go through each bulb.

Figure 15.1 *Follow the path for current.*



Activity 1 The current in a series circuit

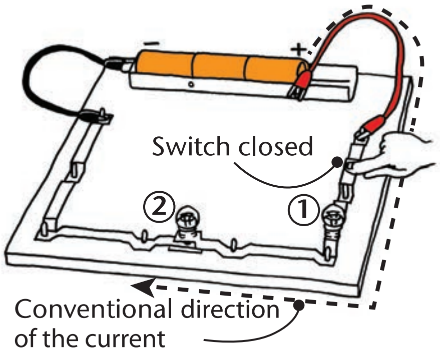
Focus question: Is the current around a series circuit the same in all parts of the circuit?

Procedure

A. You are going to set up the circuit that you see in Figure 15.2, close the switch and make both the bulbs light up. That's easy. The harder part is to think what is going to happen when the current flows through each of the bulbs.

B. So, answer the questions on the next page **before** you make the circuit.

Figure 15.2 *What happens to the current as it pushes through Bulb 1 and then Bulb 2?*



Questions

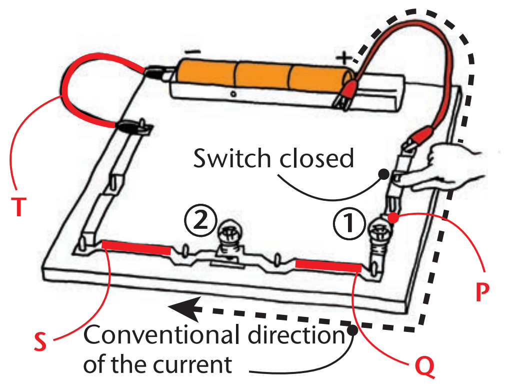
1. Predict how bright each bulb will be when you close the switch. Will Bulb 1 be brighter than Bulb 2, or will Bulb 2 be brighter than Bulb 1? Or will they be equally bright? The two bulbs are of the same type.

2. Will current flow in the wire that goes to the negative terminal of the battery?

3. Write down your predictions, and give a reason.

4. Now make the circuit, and close the switch so that the bulbs light up. Was your prediction about the bulbs correct?

Figure 15.3 *Measure the current at P, Q, S and T.*



5. Which of the following is the **best explanation** for your observation?

a) Some current comes from each side of the battery and the two streams meet in the bulbs.

b) The bulbs use up the current, but they share the current equally.

c) The first bulb is really brighter than the second bulb, but it's difficult to see.

d) The bulbs don't use up the current, they take energy from the current.

Procedure continued

C. Test your ideas: break the circuit at point P, and connect an ammeter in series in the gap. Measure the current and record it. Now replace the connector across the gap you made at P and make a new gap at Q. Connect the ammeter and measure the current again.

D. Repeat these steps at S and finally at T.

Further questions

6. Is the current different in those parts of the series circuit? (If your measurements differ by less than 0,05 A, you can say they are the same.)

7. What is the reason the measurements are like this?

What we have learned from Activity 1

The current does not get used up in the resistors, even though the resistors (the bulbs) get white-hot. The current is a stream of charges that are transferring their energy to the bulbs, but the charges are not being used up. Remember the principle that charge is conserved – you learned that in Chapter 12.

All the current goes through each resistor, so we write an equation:

$$I_{total} = I_1 = I_2 = I_3$$

where:

- I_{total} stands for the total current
- I_1 stands for the current through the first bulb
- I_2 stands for the current through the second bulb

... and so on if there are more than three bulbs.

Experiment 13: Measure the voltage across each resistor in series

Apparatus (per group)

- ❑ 3 cells of 1,5 volt emf
- ❑ 3 bulbs of the same type (i.e. the same power rating)
- ❑ nichrome wire, 60 cm or longer
- ❑ connector strips or wires
- ❑ a voltmeter, or a multimeter set to the 20 V range

Procedure

A. Set up a circuit like the one you see in Figure 15.4 and close the switch.

B. Set your multimeter to the 20 V range and measure voltages V_1, V_2 and V_3 across each resistor. You see some voltage readings for V_1, V_2 and V_3 filled in for you in the diagram. What actual voltages do you find on your real circuit? Answer **Questions 1 and 2** in your notebook.

C. Also measure the voltage across all three bulbs.

D. Now look at Figure 15.5. It shows the same circuit as Figure 15.4 but it replaces bulb R_3 with a piece of nichrome wire, **about** 60 cm long (that is twice the length of a ruler). We'll call the nichrome wire resistor R_3.

⚠ R_3 does not have to be exactly 60 cm, and you should not break off a piece of wire.

E. The resistance of 60 cm of nichrome is different to the resistance of a hot bulb.
Make a prediction: will the voltages across each of the three resistors be almost the same, as they were in Figure 15.4?

F. Answer **Questions 3 to 6** in your notebook.

Figure 15.4 *Measure the voltages across each of the three bulbs, which are resistors in the circuit.*

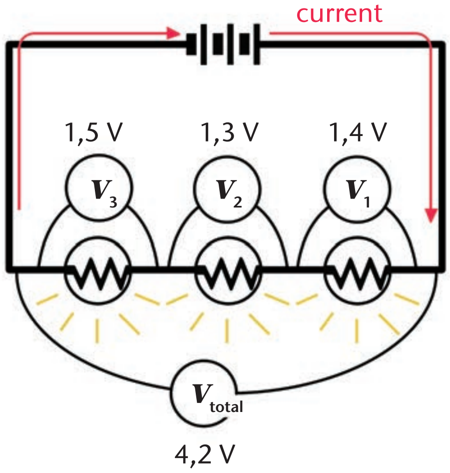
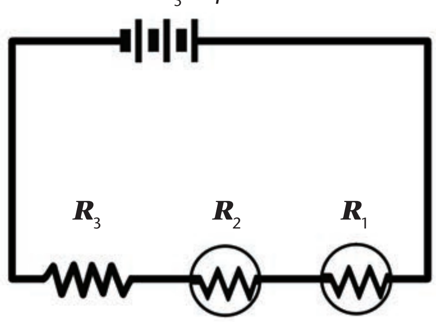


Figure 15.5 *Connect the nichrome resistance wire R_3 in place of one bulb.*



Questions

1. Copy and complete the following table in your notebook:

	From the diagram	From my real circuit
V_1	1,4	
V_2	1,3	
V_3	1,5	
$V_1 + V_2 + V_3$	4,2	
V_{total}	4,2	

2. Three new cells in Figure 15.4 will give you an emf of 4,5 volts. You see that V_{total} is less than 4,5 volts. Explain why that is so. **Hint**: You learned about emf in Chapter 14.
3. When you connect nichrome wire as R_3 in place of the last bulb, what is the voltage across the 60 cm of nichrome wire?
4. Do the remaining two bulbs show the same voltages as before, in Figure 15.4?
   Copy and complete the table below in your notebook:

	The voltage across this part
V_1 (across bulb resistor)	
V_2 (across bulb resistor)	
V_3, (across nichrome wire)	
$V_1 + V_2 + V_3$	
V_{total} across the battery	

5. What do you notice about the V_{total} and $V_1 + V_2 + V_3$?

What we have learned from Experiment 13

You can see that the voltages across the resistors add up to the total battery voltage. This is true even if the resistors have different values.

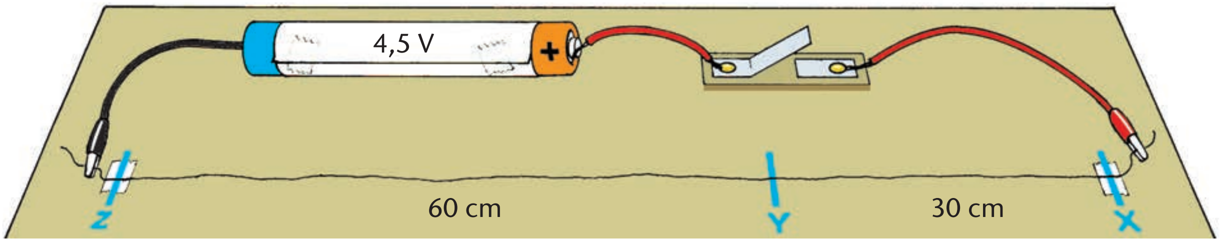
But if the resistors have different values, which resistor will have the biggest voltage across it? We look at this below.

Activity 2 Make a voltage divider

A. Instead of using bulbs as resistors, use nichrome wire.
B. Connect the nichrome wire so that you have 90 cm in the circuit, as you see in Figure 15.6. Try to stretch out the nichrome wire on the desk, and hold it down with tape.
C. You know that the resistance of the nichrome wire depends on its length. So a 30 cm piece of nichrome wire has a different resistance to a 60 cm piece.

Apparatus (per group)
- ❑ 3 cells of 1,5 V emf
- ❑ a switch
- ❑ nichrome wire, 95 cm or longer
- ❑ parcel tape / packaging tape
- ❑ connector strips or wires
- ❑ a voltmeter, or a multimeter set to the 20 V range

Figure 15.6 *Connect the 90 cm of nichrome wire and mark a point 30 cm from the right-hand end*



D. Use a felt-tip pen and make a mark 30 cm from the end nearest the positive terminal of the battery. Look at Figure 15.6 again and find the points labelled X, Y and Z. Your felt-tip mark is at **Y**.

E. **Before you press** (close) **the switch**, make a prediction about the voltages you will find across XY, YZ and XZ. Answer **Questions 1 and 2** below.

F. Now make the measurements and test your prediction. Complete the table for **Question 3**.

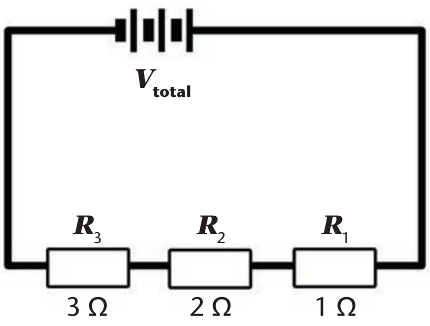
Questions

1. What are the lengths of the wire part XY and the part YZ?
2. What do you predict you will find when you measure the voltages across length XY and length YZ of the nichrome wire? Write down your prediction.
3. Now do the measurements and complete the table below in your notebook.

	Voltage that I predict across this part when I close the circuit	The actual voltage that I measure across this part when I close the circuit
V_{total} (battery voltage) e.g. this may be 4,2 volts	Let us say it will be 4,2 volts.	
V_1 (across 30 cm, length XY)		
V_2 (across 60 cm nichrome, length YZ)		
V_{total} (across the whole 90 cm, length XZ)		
$V_1 + V_2$		

4. Which length of resistor wire gets the bigger voltage?
5. What fraction of the battery voltage does each of these resistors get? You can **estimate** the fraction because your voltage measurements might not be exact.
6. If you have a circuit like the one in Figure 15.7, what fraction of the battery voltage does each resistor get?
   Hint 1: What fraction is each resistance of the total resistance?
   Hint 2: Choose your own value for V_{total} and work out the voltages across each resistor; then work out the fraction of V_{total} that each resistor gets.
7. Now you can go on and try the Challenges at the end of this chapter.

Figure 15.7 *What fraction of the battery voltage does each part of the resistor get?*



The effective resistance R_{eff}

In Figure 15.7 on the previous page, the resistances of $R_1 + R_2 + R_3$ add up to a total resistance of 6 ohms (because $1\ \Omega + 2\ \Omega + 3\ \Omega = 6\ \Omega$). We say that the battery, which is pushing current through the 6 ohms, "sees" an effective resistance of 6 ohms. All the resistors together have the **effect** of one 6 ohm resistor, and we write R_{eff} for this effective resistance.

Unit 15.1 Summary activity

1. Use these parts in brackets to make a complete sentence. Then read the sentence aloud to see if it makes sense.
   [in the resistors] [transfers] [energy] [to the resistors.]
   [but the current] [the current] [is not used up]
2. In what ratio does the battery voltage divide across resistors in series? Which resistor has the greatest voltage across it?
3. How did you find out whether the current is the same at all points around the circuit?

Unit 15.2 Resistors in parallel

Parallel connections: Two, three and more paths for current

You know what will happen in a circuit like Figure 15.8, when you press the switch. All the bulbs light up. But there is another way to make bulbs light up, and you see it in Figure 15.10.

The first bulb after the switch we will call the indicator bulb – it will indicate to us whether the current from the battery is big or small.

Figure 15.8 *An indicator bulb and another bulb. The indicator bulb shows that the current is small.*

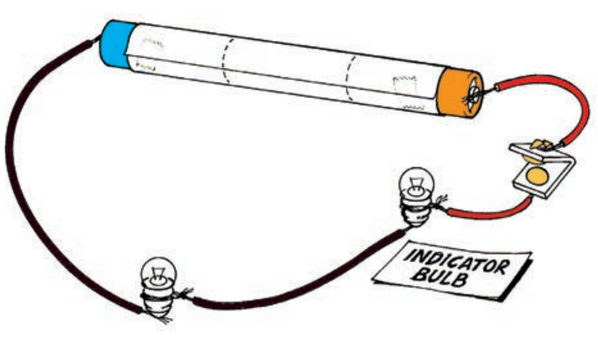
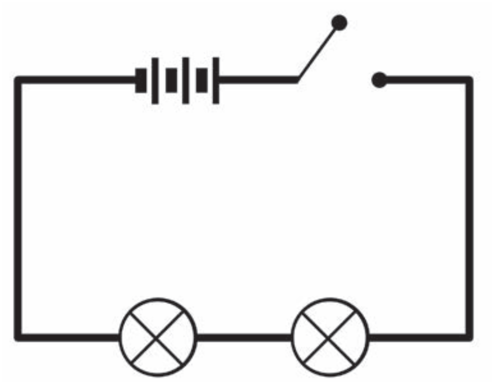


Figure 15.9 *A circuit diagram of the same circuit*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 340 2016/01/05 3:21 PM

Activity 3 Connect resistors in parallel

This activity has two parts. In Part One, you look at circuit diagrams and make **predictions***. In Part Two, you build a circuit and test those predictions. **You must do this activity in order to do well in your Formal Assessment task,** Experiment 14.

Apparatus (per group)
- ❑ a battery of 3 good cells
- ❑ 4 bulbs in holders
- ❑ a press switch
- ❑ 8 connecting wires or connectors for a circuit board

* **predict** – to use your knowledge to say what is going to happen, and give reasons

Part One

A. Look at the circuit that you see in Figure 15.10. The terminals of all 3 bulbs are connected to the same point at the indicator bulb.

B. How many paths for current do you find? In Figure 15.10, follow the paths for current from the positive terminal of the battery through the bulbs, to the negative terminal of the battery.

Figure 15.10 *Three bulbs connected in parallel. The indicator bulb will show that the current is bigger than before.*

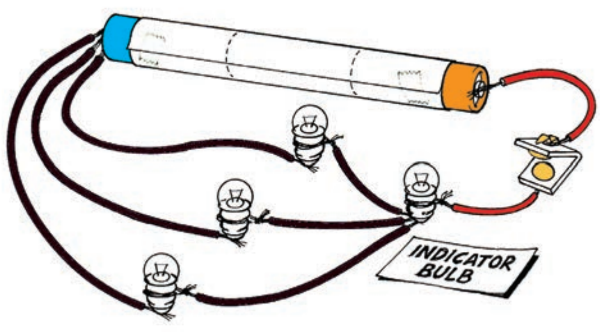
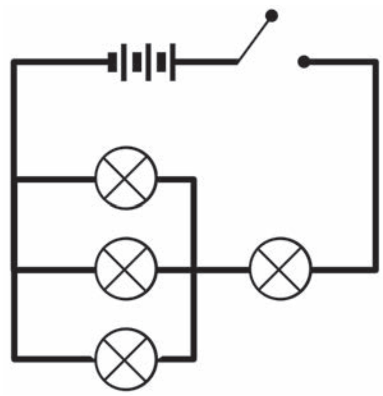


Figure 15.11 *The circuit diagram of the circuit in Figure 15.10 on the left.*



NOTE: When we make a circuit that has two or more paths for current, we say those paths are "in parallel". In maths, parallel lines never cross each other, but in electricity we just mean there are **two or more paths** for current.

Questions for discussion

1. Will the four bulbs in Figure 15.10 be equally bright? If not, say what differences there will be.

2. Will the indicator bulb in Figure 15.10 be as bright as the indicator bulb in Figure 15.8, or even brighter?

Part Two

Remember that a bulb is a resistor.

Now you test the **predictions** you made in **Questions 1 and 2**.

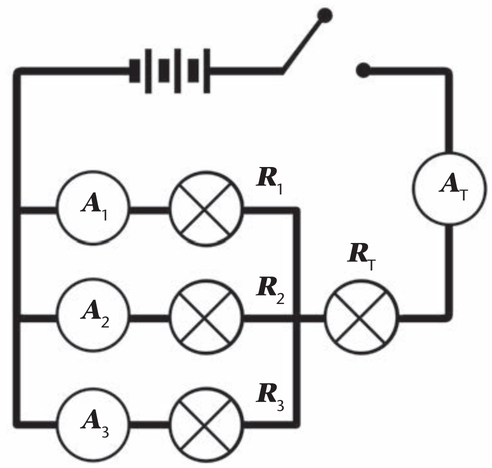
C. Begin to make the circuit that you see in Figure 15.12. First connect resistor R_1 and measure the total current with your ammeter at A_T. The small "T" tells you that the total current flows through this ammeter.

D. Also notice how bright the indicator bulb R_T is. The small "T" again tells you that the total current flows through this resistor.

E. Now add resistor R_2. What is the current A_T? Has the brightness of bulb R_T changed?

F. Finally, add resistor R_3. What is the current A_T? Has the brightness of bulb R_T changed?

Figure 15.12 *Build this circuit, and measure the total current through A_T each time you add another resistor.*



Questions for discussion

3. How does the **total current from the battery** change, as you add resistors in parallel?

4. What would you observe in the circuit if you added another bulb, R_4, in parallel with R_3?

5. Is the **overall resistance** in the circuit increasing or decreasing as you add resistors in parallel? How do you know this?

What we have learned from Activity 3

When you connect bulbs so that the current has two or more paths to go on, you are connecting bulbs **in parallel**. Each extra bulb in parallel is as bright as the one next to it. This means that the battery is giving off its energy faster. The more bulbs you connect in parallel, the quicker the battery will go "flat".

People sometimes say that the current splits up or "divides", so that each parallel path carries some current. But this kind of "dividing" lets the **overall current become bigger**, *not* smaller, because there is more than one path for current.

The overall current becomes bigger, and this tells us that if you add resistors in parallel, you **reduce** the overall resistance in the circuit.

However, there is more to say here. We saw that the bulbs were about equally bright each time we connected another bulb in parallel. Their equal brightness means there was equal **potential difference** across each bulb.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 342 2016/01/05 3:21 PM

Resistors in **parallel** have the **same potential difference** across them.

This is different to the case of resistors in series, where the potential difference is split between the resistors.

Parallel resistors with differing values

We have been using bulbs that are **identical*** in their resistance values. For example, when the bulbs are hot, they each have a resistance value of about 18 ohms.

* **identical** – exactly the same

But what if you had a parallel circuit with differing resistance values?

Activity 4 Currents in parallel branches with differing resistance

A. Connect the circuit you see in Figure 15.13.

B. Answer **Questions 1, 2 and 3**. You must make two predictions.

C. Then test your predictions: connect your ammeter in series in the positions X, Y and Z and measure the currents.

D. Also use a voltmeter and measure the potential difference across the branches.

Figure 15.13 *Connect this circuit.*

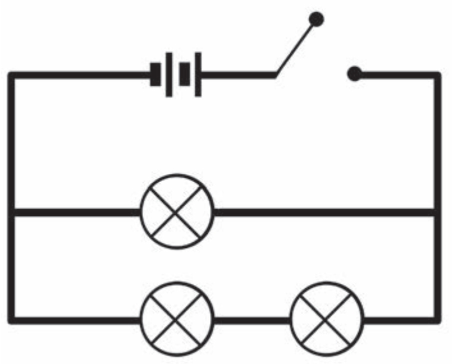
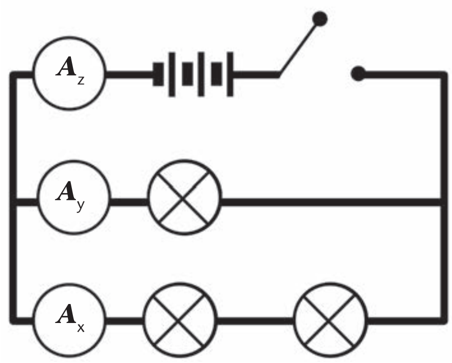


Figure 15.14 *Measure the currents at these places to test your predictions.*



Questions for discussion

1. In what ways are the two parallel branches different? Think of all the differences you can.

2. Are the parallel branches going to get the same current? Make your prediction and give your reason.

3. Will the parallel branches have the same potential difference across them? Give a reason for your answer.

4. What do you find when you test your predictions with an ammeter and a voltmeter? Explain your results to your group partners, and get ready to explain the results to the class.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 343 2016/01/05 3:21 PM

What we have learned about parallel circuits from Activity 4

Key ideas about voltage and current in parallel circuits

- Resistors in parallel have the same potential difference across them.
- The total current "divides" or splits up, and some goes along each branch.
- The branch with the highest resistance gets the smallest current.

A short circuit is a parallel path for current

A short circuit is a conducting path that has almost zero resistance. Look at the parallel circuit in Figure 15.15. Someone has made a mistake in this circuit, and made a zero-resistance path for current.

Find the zero-resistance path in this circuit.

If you close (press) the switch, the battery will "feel" almost no resistance and the current will be as big as it can be. The battery will transfer its energy as fast as it possibly can. It will get hot and it will be "dead" in about 10 minutes. It will do that because it finds a zero-resistance path. We call that path a **short circuit.**

About 99% of that big current will go through the orange wire, and only about 1% of the current will go through the bulb.

Now look at Figure 15.16. Why does the bulb in this figure not glow if you close the switch?

The bulb is glowing, but if you press the switch, the bulb stops glowing. Explain the problem, and draw a picture to show how you would connect the circuit in the correct way. The bulb should glow only when you press the switch.

Figure 15.15 *If you press the switch, the orange wire will complete a short circuit.*

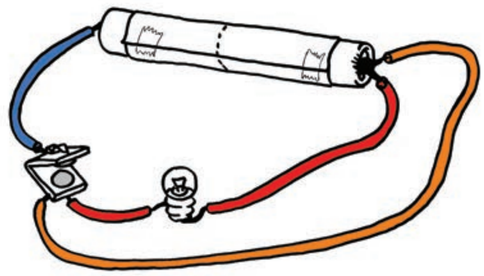
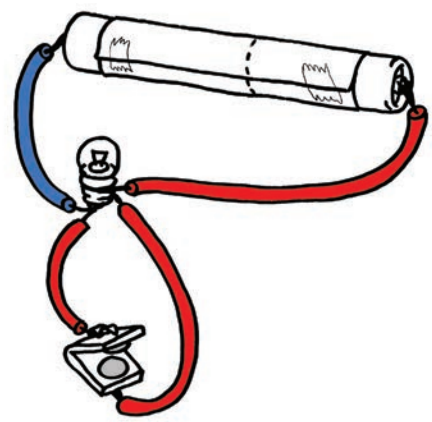


Figure 15.16 *The bulb stops glowing when you press the switch. What is wrong?*



Why short circuits in a house are dangerous

ESKOM supplies energy at 230 volts and this can make a heater red-hot. This is safe in a heater, because only the resistor in the heater gets hot, and not the wires from the plug. But if the insulation is broken on some wires, the wires may touch each other and make a short circuit. The current will not go through the heater but it will take another path along the wires. The current will give off all its energy to the wires. Then the wires may become red-hot and set fire to something in the house.

That is why we have fuses in electronic equipment and circuit-breakers in a house. If the current becomes too big and begins to heat the wires, the fuse melts or the circuit-breaker "trips" and stops the current flow.

Let's compare series and parallel circuits

In Unit 15.1 and Unit 15.2 we've seen that series and parallel circuits behave differently. That can be confusing, but we can summarise the differences like this:

	In series circuits	In parallel circuits
Voltages across resistors	The total voltage splits up across the resistors. The highest value resistor has the greatest voltage across it.	All resistors in parallel have the same voltage across them.
Currents through resistors	The same current flows through all the resistors. The greater the number of resistors in series, the smaller the current.	The current splits up and some of the current goes through each resistor. The lowest value resistor gets the most current. The greater the number of resistors in parallel, the greater the total current.

How to calculate the resistance in a parallel circuit

If you make more parallel paths for current, then the resistance in the circuit becomes less.

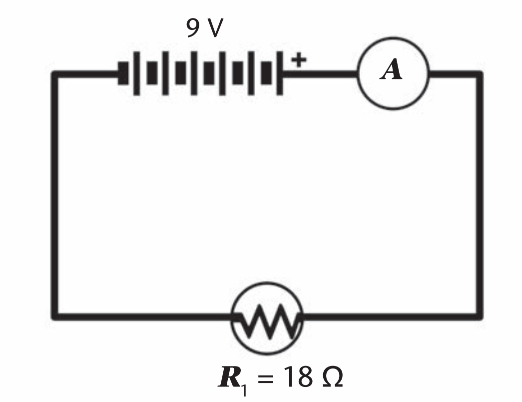
The battery "feels" a smaller resistance as you add more parallel resistors – you are making the **effective resistance** smaller. We write the **effective resistance** as R_{eff}

Look at Figure 15.17. Let's say that the resistance of the hot bulb R_1 is 18 ohms. The ammeter shows a current of 0,5 ampere.

Now in Figure 15.18 we add another identical resistor, R_2, in parallel with R_1. The current increases and it **doubles** to 1 ampere because there are two identical paths for current.

The current has doubled, so this means the **effective** resistance is now only 9 ohms, even though we connected **another 18 ohm resistor** in parallel. We can think of the two parallel resistors as **one effective resistor** of 9 ohms. The orange block around R_1 and R_2 in Figure 15.18 shows you how to see them as one resistor, with an effective resistance of 9 ohms.

Figure 15.17 *The circuit with one resistor – a hot bulb*

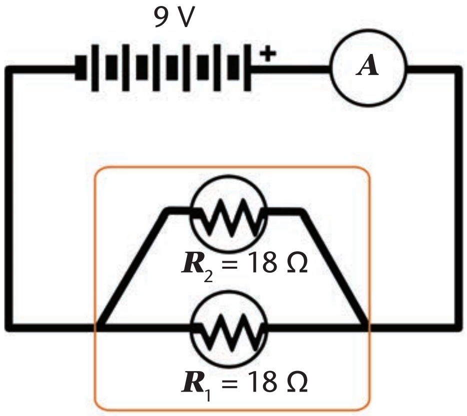


Let's see what would happen if we connected a third resistor of 18 ohms in parallel. Look at Figure 15.19 and notice the brown box around the three 18 ohm resistors. The brown box tells you to see the three resistors as one resistor.

The total current will increase to 1,5 A, and so the **effective resistance** is only 6 ohms.

So if we **double** the number of these resistors in parallel, we **halve** the resistance of the circuit. If we have **three** times the number of resistors in parallel, we get **one-third** the resistance in the circuit.

Figure 15.18 *Add another 18 Ω resistor in parallel. What is the effective resistance now?*



What if the resistors have different values?

Of course, the resistors do not always have the same resistance. Sometimes you have different values of resistor – then the problem is more complicated.

Fortunately, there is a formula for working out the **effective resistance** R_{eff} when you have different value resistors in parallel.

For two resistors:

$$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2}$$

From this we get:

$$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2}$$

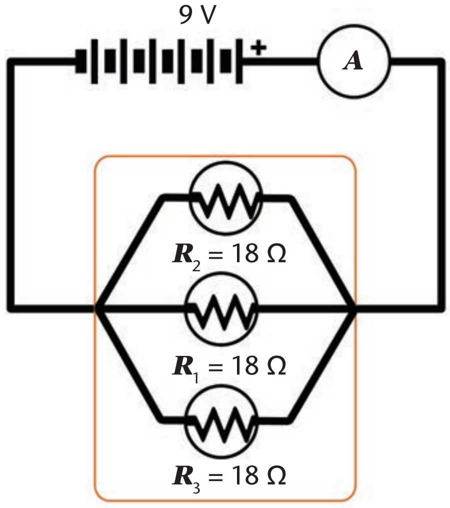
$$= \frac{R_2 + R_1}{R_1 R_2}$$

$$\therefore R_{eff} = \frac{R_1 R_2}{R_2 + R_1}$$

For three resistors, we can use:

$$\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Figure 15.19 *Three 18 Ω resistors are in parallel. What is the effective resistance now?*



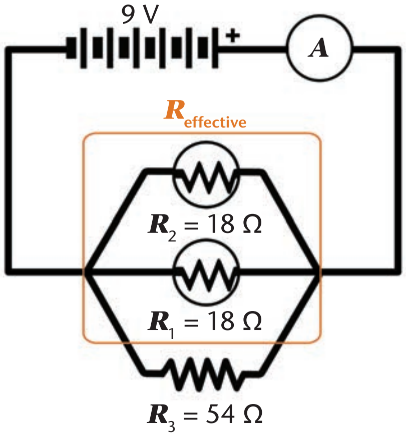
Quick Activity:

Let's practise with the formula for three parallel resistors above. If R_1 is 10 ohms, R_2 is 12 ohms and R_3 is 15 ohms, work out what the **effective resistance** R_{eff} will be.

How to simplify a parallel circuit

Remember that you can always think of **three** parallel resistors as **two** parallel resistors – you just group two of them together. This will immediately simplify your calculations. Look at Figure 15.20, with R_1, R_2 and R_3. The two 18 ohm resistors R_1 and R_2 are like one 9 ohm resistor, called R_{eff} in the orange box, and this is in parallel with R_3, the 54 ohm resistor.

Figure 15.20 *Think of R_1 and R_2 as effectively just one resistor.*



Quick Activity:

Calculate the total current in the circuit you see in Figure 15.20.

Hint to help you: You can apply the formula for two resistors R_1 and R_2 in parallel, and then do it again for R_{eff} and R_3.

Before you calculate, remember what you know and think about this:

a) Will the **current** be bigger when you add resistor R_3?

b) When you add R_3 = 54 ohms, will the **total resistance** in the circuit be bigger or smaller than with R_1 and R_2 in parallel?

Now calculate the current!

Think: Does the formula for R_{eff} still work for the two parallel 18 ohm resistors in Figure 15.18?

Chapter summary

- A series circuit has only one path for current and therefore all the current must go through all the series resistors. The charges in the current transfer some of their energy in each resistor, but the current itself is not used up.
- The voltage we measure across a resistor is really the amount of energy that is transferred from each coulomb of charges as they pass through the resistor. The difference between the energy of charges before and after going through the resistor is called the potential difference across the resistor.
- In a series circuit, the highest resistor has the biggest potential difference across it. The potential differences across all the series resistors are in proportion to the values of the resistors.
- A parallel circuit has two or more paths for current. Currents flow through each resistor, but the lowest value resistor carries the biggest current and the highest value resistor carries the smallest current.
- Adding more resistors in parallel decreases the total resistance in the circuit, and so adding resistors in parallel increases the total current from the battery.
- A path that has no resistance is called a short circuit connection. A short circuit connection allows the maximum current to flow from the battery, and the battery's energy is given off in the short circuit and in the battery itself.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 347 2016/01/05 3:21 PM

Check your understanding of this chapter

1. Describe what happens to the total current if you add more resistors (a) in series and (b) in parallel.
2. Look at Figure 15.21. The bulb is glowing and the switch is open. What will happen if you close the switch? Explain why this will happen.
3. In Figure 15.22, which of the two bulbs will glow when you close the switch? Explain your answer.

Figure 15.21

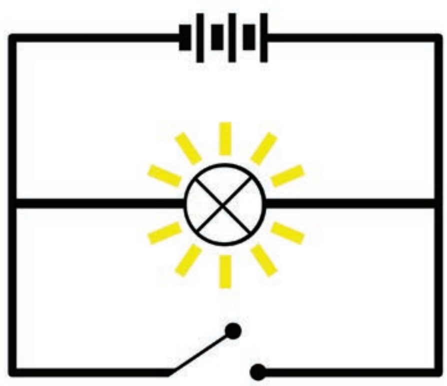
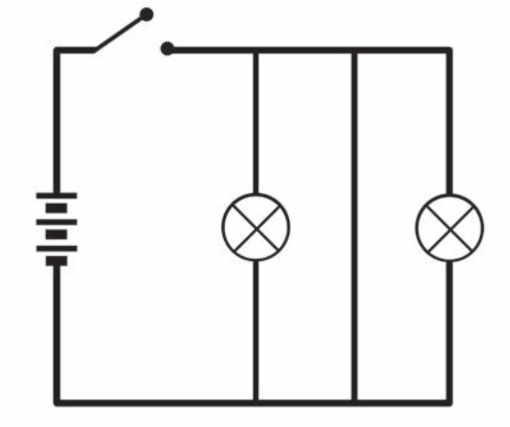


Figure 15.22



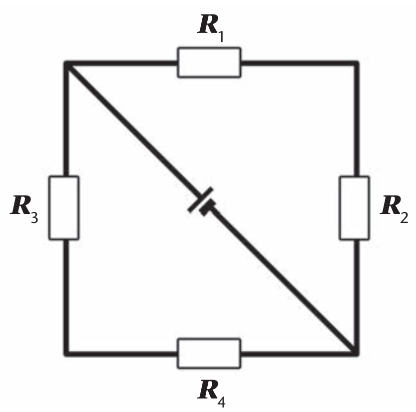
4. You have to build a circuit with a switch, bulb and beeper. When you close the switch, the beeper must make a noise and the bulb must light up. The battery can give only 3 volts, and both the bulb and the beeper need 3 volts to work.
   Draw the circuit that will make them both work.

Challenges and projects

Is this a series or a parallel circuit?

1. Re-draw the circuit in Figure 15.23 so that it looks like the series or parallel circuits in this chapter.
2. Let R_1 = 1 ohm; R_2 = 2 ohms; R_3 = 3 ohms; R_4 = 4 ohms. What is the effective resistance in the circuit?
3. The cell can provide a potential difference of 1,5 volts across the resistance. What is the total current that comes from the cell?

Figure 15.23



Two ways to work out the voltage splits in a series circuit

Remember the rule for voltage splits across resistors in series? If you can't remember it, go back to the chapter summary.

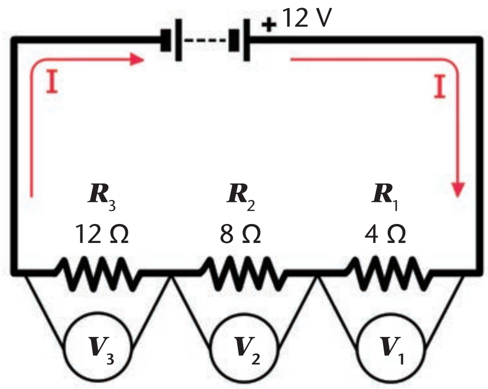
1. Now look at Figure 15.24. If you had three resistors – of 4 ohms, 8 ohms and 12 ohms, with 12 volts across them all – what would be the voltage across each resistor?

a) First work out the three answers by calculating the current and then the voltage across each resistor.

b) Then find a better, quicker way to work out the three answers. Your better method should give you the same answers as the first method.

c) Can you use the second method to work out the voltage splits across **any** set of 3 resistors in series? For example, let R_1 = 1 ohm; R_2 = 5 ohms; and R_3 = 0 ohms.

Figure 15.24 *What is the resistance across each resistor?*



For a voltmeter, why do all points along a good conductor look like the same point?

Look at Figure 15.25. The blue and green lines represent very good conductors.

1. Now, what are the readings on voltmeters V_1 and V_2?

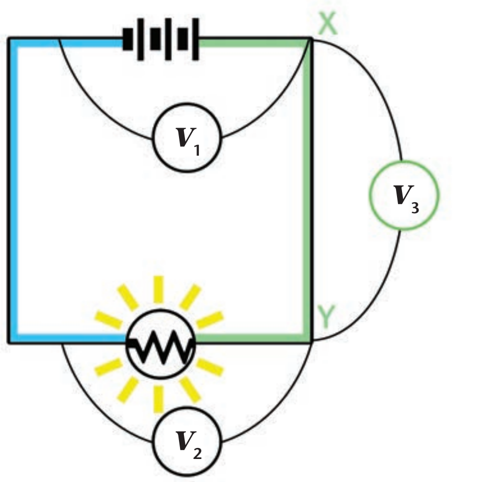
You should see that it does not matter whether you measure V across the battery or across the bulb; the voltage reading is the same.

2. Why is this so? (**Hint**: think what the reading on voltmeter V_3 is.)

3. Is there zero potential difference between the terminal of the battery at X and the terminal of the bulb at Y? Why?

4. If this is a good conductor, does it get hot? Is it transferring any energy? Is this true of the other side of the circuit as well?

Figure 15.25 *Why does the voltmeter "see" X and Y as the same point?*



$V_1 = V_2 = 4{,}3$ V

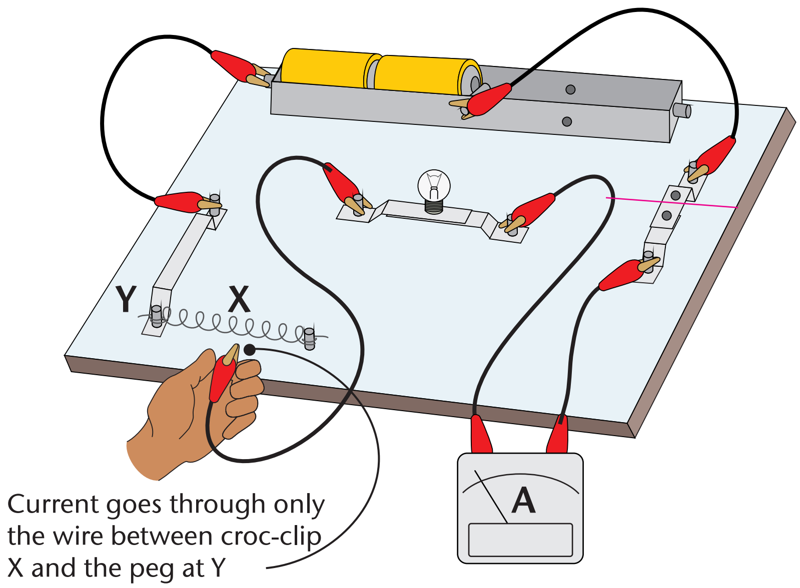
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 349 2016/01/05 3:21 PM

Make a dimmer switch: An application of the voltage divider principle

A. Make the circuit that you see in Figure 15.26. To make the resistor, take 1 metre of nichrome wire and twist it around a pencil or straw, to make a coil.

B. Connect the ends of the coil to two contacts as you see in Figure 15.26.

Figure 15.26 *Slide the croc-clip X along the nichrome wire.*

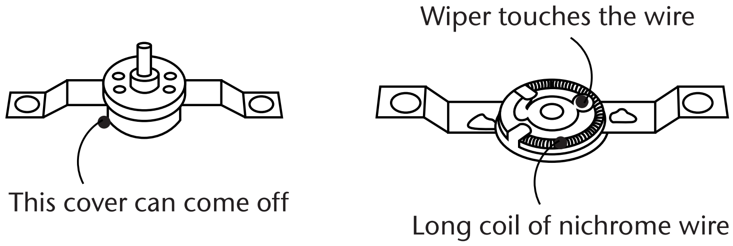


C. Move one croc-clip along the coil and see what happens to the brightness of the bulb. Which end of the coil must you touch to make the bulb brightest, and which end to make it dimmest?

D. Demonstrate your dimmer switch and explain why you can change the brightness of the bulb by moving the lead along the coil.

E. Then open a rheostat like the one you see in Figure 15.27, and explain how it works. Connect it in your circuit and use it to dim the bulb.

Figure 15.27 *A rheostat acts as a dimmer switch.*



F. Think how you could use the graphite resistor in Chapter 14, Figure 14.11 (page 334), as a dimmer switch.

Hint: you can split a pencil along the length, as shown in Figure 14.11, and leave the graphite open.

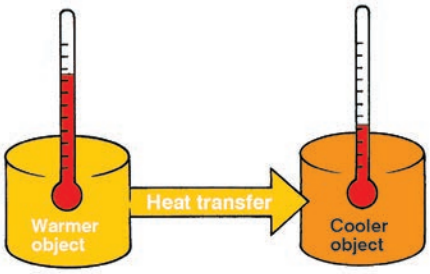
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 350 2016/01/05 3:21 PM

CHAPTER 16 Heat and temperature

In Natural Sciences Grades 7 to 9 you learnt:

- Heat is one of the forms in which energy is transferred.
- Heat energy is transferred from an object that has a higher temperature to an object that has a lower temperature.
- There are three ways in which heat energy is transferred: by conduction, by convection and by radiation.

Figure 16.1 *Heat is energy in transfer.*



In this chapter we focus on:

- how we measure temperature
- how we measure heat energy
- how heat energy is transferred

This work will lead you to understand the factors that affect the power and efficiency of heat engines in Grade 11.

The beginning of the study of thermodynamics

This chapter is the start of our work in thermodynamics, which is a branch of science. It started more than 200 years ago, as the study of the **relationship*** between heat energy, steam and forces caused by heat energy transfers in steam engines.

Steam engines had been invented following the discovery that heat energy can be used to do useful mechanical work. Thermodynamics developed as engineers and scientists worked together to make the machines more **efficient***.

Now we know that the laws of thermodynamics apply to everything in the universe: from molecules, to car engines, to the birth of a new star.

Figure 16.2 *Robert Stephenson built the first steam-driven locomotive in 1829. This photo shows a replica of that locomotive.*

* **relationship** – the way in which quantities are connected
* **efficient** – the ability to do something while wasting a minimum amount of energy

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 351 2016/01/05 3:21 PM

Unit 16.1 Temperature

If we need to know how hot or cold a substance is in the workshop, laboratory or at home, we use a thermometer as the measuring instrument and degrees Celsius (°C) as the unit of measurement.

Definition: Temperature is a measure of how hot a substance is.

Did you know?

The hottest place in our solar system is at the centre of the Sun – about 15 million °C.

When writing a temperature using the Celsius scale, you always write **degrees Celsius or °C** after the number.

The SI unit for temperature is actually the kelvin (K), not the degree Celsius (°C). The Kelvin scale is used mostly by scientists. We will compare the two scales at the end of this unit.

Table 16.1 shows melting and boiling points for some common substances.

Table 16.1 Some melting and boiling points in degrees Celsius

Substance	Melting point in °C	Boiling point in °C
naphthalene	80	218
ethanol (alcohol)	–114	78
nitrogen	–210	–196
mercury	–38	357
iron	1 530 (typical)	
tungsten	3 422	
solder	180 (typical)	
silver solder	220 (typical)	

Activity 1 Think about temperatures

Answer the following questions in pairs and write your answers in your workbooks. You will need to study Table 16.1 and you might need to do some research to answer some of the questions (ask an expert, do experiments, look in books or on the internet).

1. A mother runs water into the basin to wash her baby. She puts her elbow or her hand into the water to test the temperature. If the water feels colder than her elbow or hand, she adds more hot water. If it feels hotter she adds colder water. What is the temperature of the water when it is just right?
2. When the water in the dish-washing bowl is too cold, you add hot water and mix it with the water in the bowl with your hand. At what temperature is the water in the bowl when it is just too hot for your hand?
3. You feel sick and hot. Your granny puts her hand on your forehead and says, “You have a temperature.” What is the temperature in degrees Celsius that she is talking about?
4. Choose one of the above three questions and describe what you could do to test if your answer is correct.

5. Doctors use liquid nitrogen, which they keep in a sealed vacuum flask, to treat warts.
   a) If you look inside the flask what will you see?
   b) When the doctor dips an ear-bud into the liquid nitrogen and touches it onto a wart on a patient's knee, what is the temperature of the ear-bud?
6. Would you choose mercury or alcohol for a bulb thermometer to measure a temperature of about –50 °C?
7. Why did the author of a book for Technology students not include iron in a table that gives the boiling points of substances?
8. As an exercise in soldering, you have to join three strips of 20 mm × 10 mm copper with 5 mm overlaps, all in a row. The first strip is 0,5 mm thick, the middle strip is 1 mm thick and the third strip is 2 mm thick. You can use solder, or silver solder, or both. Which would you choose and how would you do it?

Celsius Temperature Scale

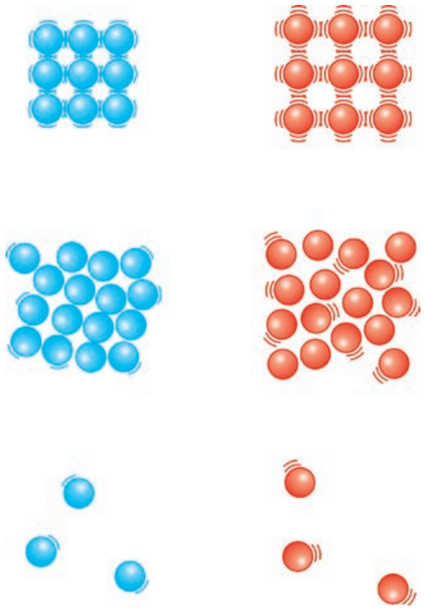
The Celsius temperature scale was created by dividing the **range*** of temperature between the freezing and boiling temperatures of water into 100 equal parts. This scale was developed by Anders Celsius over 250 years ago.

* **range** is the difference between the highest value and the lowest value

You already know a few important temperatures:

- The boiling point of water is 100 °C.
- The freezing point of water is 0 °C.
- Your body's normal temperature is about 37 °C.
- You feel uncomfortable if the air temperature is above 35 °C or below 5 °C, because: "*Thirty is hot, twenty is nice, ten is cool and zero is ice*."

Figure 16.3 *Particles in hotter substances move faster than those in colder substances.*



What is temperature?

To define temperature, we have to think about all substances as being made of microscopic particles.
Have a look at Figure 16.3.

When we measure the temperature of a substance we are actually measuring the average kinetic energy of the particles of the substance:

- The temperature of a fluid (gas or liquid) depends on the kinetic energy of the particles as they move about.
- The temperature of a solid depends on the kinetic energy of the vibrating particles.
- The higher the kinetic energy of the particles, the hotter the substance; the lower the kinetic energy, the colder the substance.

Activity 2 Kinetic energy of particles

1. Describe the relative average kinetic energies of the particles of the steel in Figure 16.4 where the metal is reddish, orange and yellow/white.
2. Describe the relative average kinetic energies of the particles of water in the beakers in Figure 16.5.

Figure 16.4 *The colour of the steel indicates its temperature.*

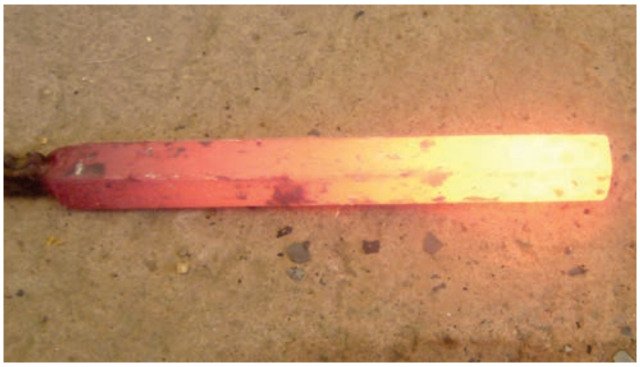
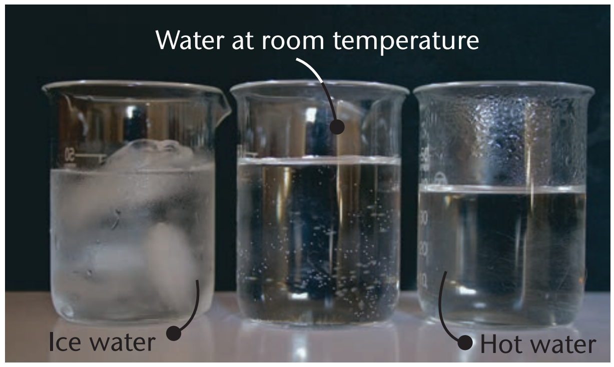


Figure 16.5 *Beakers of water at different temperatures*



Types of thermometers

The four main types of thermometer that we use are:

- bulb thermometers
- thermoelectric thermometers
- bimetallic thermometers
- temperature strips

Figure 16.6 shows an early thermometer called the Galileo thermometer. Read about it in the Resource Pages.

Figure 16.6 *The Galileo thermometer*

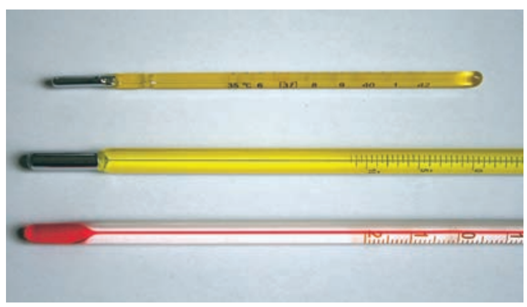
Bulb thermometers

Early thermometers were made of glass and filled with water, but they could not be used to measure temperatures less than the freezing point of water.

The bulb thermometer a nurse might use at a clinic is made of glass and is usually filled with a silver coloured liquid called mercury. But most nurses use thermoelectric thermometers now.

In the science laboratory we use a longer, larger thermometer which is filled with coloured alcohol or ethanol – usually red or blue. We no longer use mercury thermometers in schools.

Figure 16.7 *Mercury-filled and alcohol-filled thermometers*



At one end of the thermometer is a large liquid-filled bulb. It is connected to a glass rod inside which is a long, thin hole sealed at the top. We no longer use mercury thermometres in schools.

When the bulb is placed in a hotter environment, heat energy is transferred from the environment, through the glass and into the liquid in the bulb, and the liquid's temperature increases. When the bulb is placed in a colder environment, the liquid's temperature decreases.

All bulb thermometers work on the same **principle***:

- The volume of the liquid in the bulb changes as its temperature changes – it increases when temperature increases and decreases when temperature decreases.
- As the volume changes, the liquid is seen moving up or down the scale on the thermometer.

Thermometers are carefully **calibrated*** so that the scale shows the correct temperatures. It takes practice to read a bulb thermometer correctly.

> ✻ **principle** – a law that explains why something happens
> ✻ **calibrate** – to set or correct a measuring instrument to match known measurements

Figure 16.8 *As the temperature of the liquid in the bulb increases, the liquid expands and moves up the narrow glass tube.*

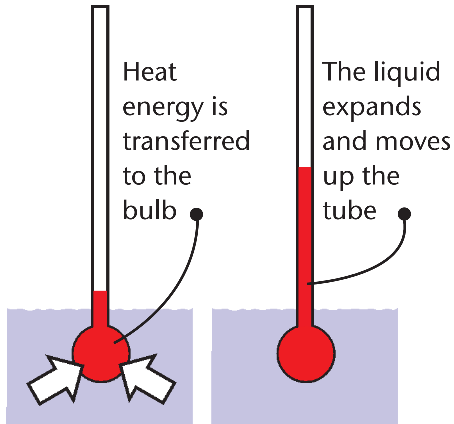
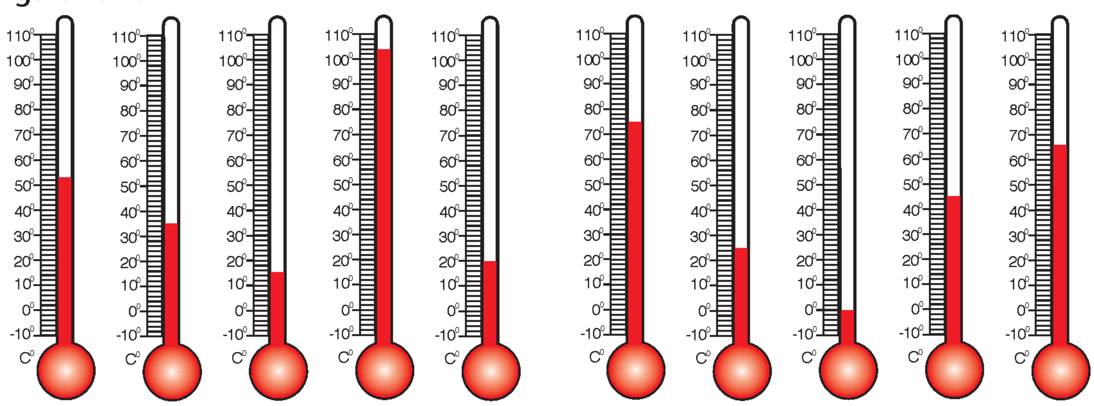


Figure 16.9 *The temperature is 20 °C.*

Activity 3 Read the temperatures

Write the temperatures on the thermometers in Figure 16.10 in your notebook.

Figure 16.10



NOTE: The thermometers we use measure temperatures in degrees Celsius. Most countries of the world use the Celsius scale. The Fahrenheit scale is used in the United States. The Kelvin scale is used mostly by scientists and learners in science, like us.

Thermoelectric thermometers

Thermoelectric thermometers are electronic devices that are built into home appliances and industrial machines to show operating temperatures. It is more common in industry to measure temperature with an electronic device than with a glass thermometer.

The most common thermoelectric sensors are:

Thermocouple: A thermocouple consists of two different conductors that connect to each other at one end. The other ends are free to be connected into a circuit. When the temperature of the joined ends differs from that of the two free ends, a voltage is created across the free ends. A simple circuit measures the voltage and converts it to a temperature which is then displayed or used to control the circuit.

Figure 16.11a *How a thermocouple works*

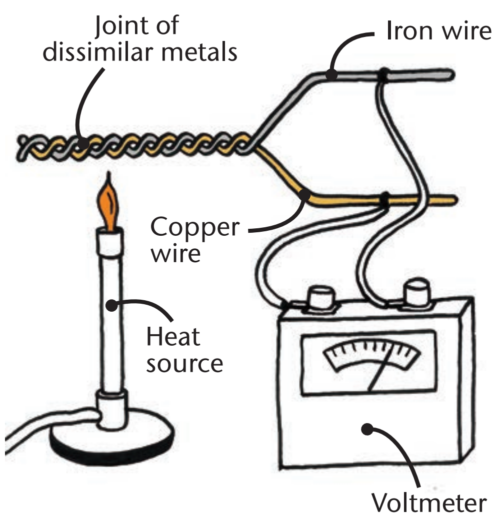


Figure 16.11b *A thermocouple for a gas cooker*

Figure 16.11c A *thermistor*

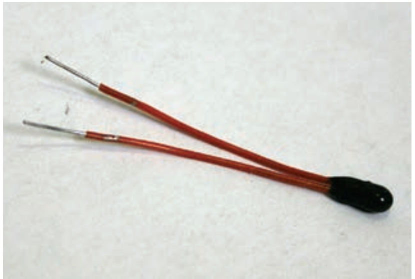
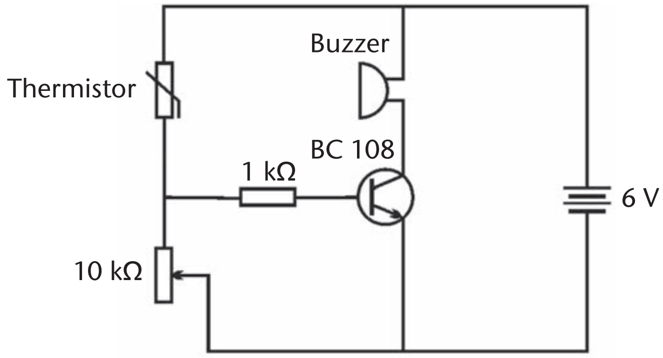


Figure 16.11d *A digital thermometer that uses a circuit containing a thermistor*

Figure 16.11e *A temperature sensor containing a thermistor*

Thermistor: The electrical resistance of a thermistor changes with temperature. A simple circuit measures the change in voltage across the resistance and converts it to a temperature which is then shown on a digital screen. Hand-held thermoelectric thermometers are rapidly replacing bulb thermometers because they are cheaper, they work faster and are easier to read. Thermistors are mostly more accurate than thermocouples.

Figure 16.12 *A circuit with a thermistor and buzzer*



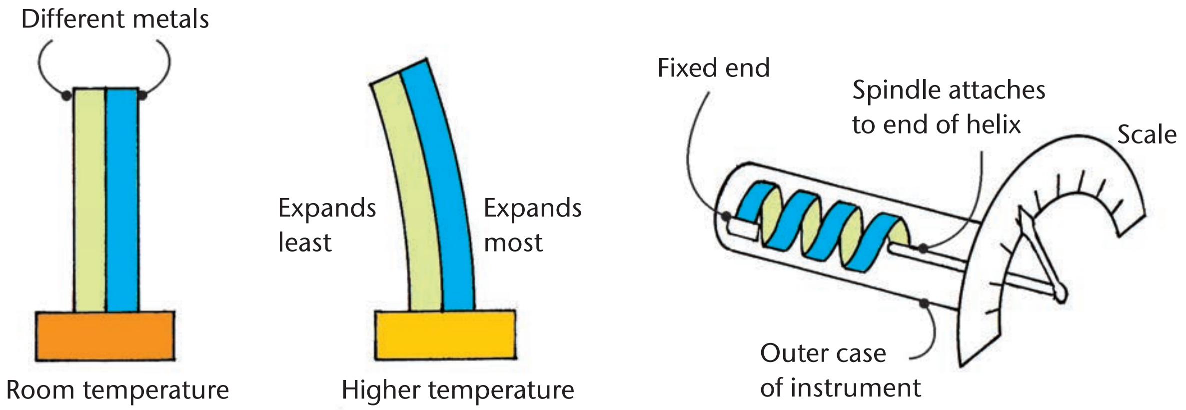
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 356 2016/01/05 3:21 PM

Bimetallic thermometers

Bimetallic thermometers are made by joining together strips of two different metals which expand at different rates when heated. When the strip is heated it bends because the one metal expands more than the other. The mechanical movement of the strip can be used to:

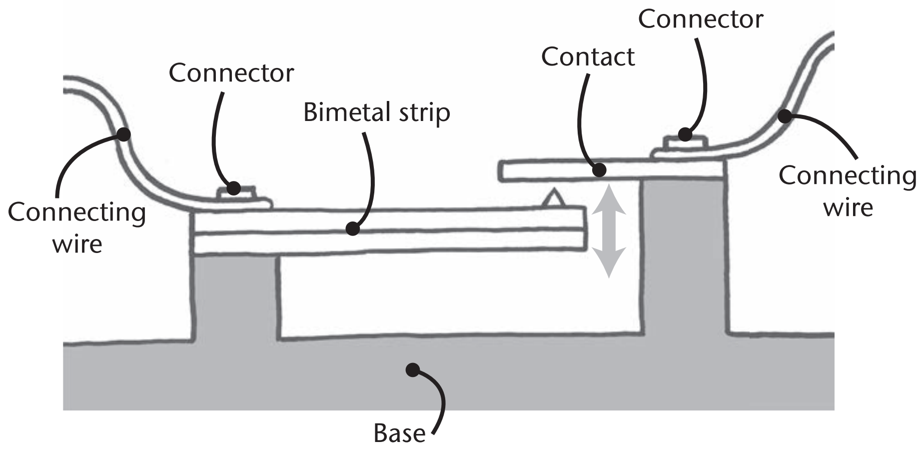
- move the pointer on a dial thermometer
- switch an electric circuit on or off

Figure 16.13 *Bimetallic strip and bimetallic thermometer*



Bimetallic strips have been used for a long time in **thermostats**. A thermostat is a device that switches a circuit on or off when the temperature of the substance it is monitoring gets too hot or too cold. When used as **thermometers** they are tough and reliable, but not very accurate.

Figure 16.14 *A bimetallic strip is used as a thermostat.*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 357 2016/01/05 3:21 PM

Thermometer strips

Temperature strips use colours to indicate temperature. Theyçare flexible, stick-on pieces of plastic used to measure surface temperature in laboratories, hospitals and homes.

The active part of a temperature strip is a layer of liquid crystals. They work like this:

- Incoming light waves reflect off the crystals.
- As they reflect, the waves **interfere*** with each other.
- The level of interference depends on how close the crystals are together.
- The colour of the reflected light depends on the **level*** of interference. The level of interference depends on how “close” the crystals are together.
- Heating or cooling causes the “closeness” to change; so as the temperature of the strip changes, the colour of the reflected light changes.

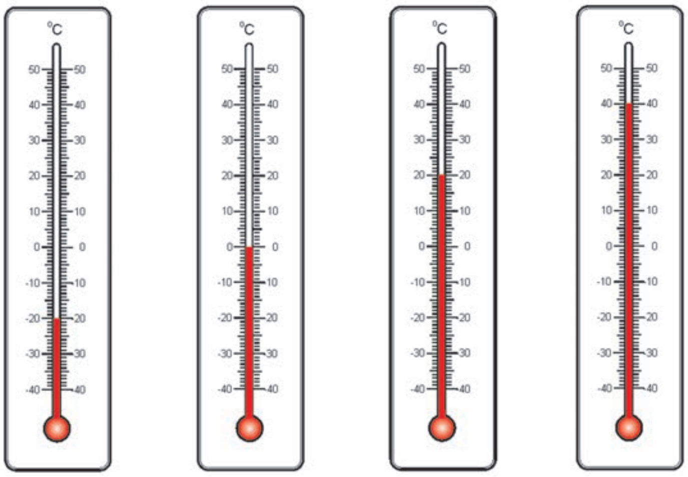
* **interfere** – to prevent something from happening in its usual way

* we use the word **level** to describe interference, rather than “amount” or “quantity”

Figure 16.15 *A strip thermometer*

Activity 4 Interpret temperatures

Figure 16.16



1. In your workbook, write down the temperatures you read on the four thermometers in Figure 16.16.
2. If these temperatures were all recorded on one thermometer at different times, what would the thermometer be measuring? Body temperature, weather, temperature in a room or temperature of an oven? Explain your answer.

Kelvin temperature scale

Two hundred years ago, scientists found that all molecules stop moving at a temperature of –273 °C. William Thomson used –273 °C as the lower **limit*** of his temperature scale. He called that temperature **absolute*** zero. Thomson received the title Lord Kelvin for his work and his scale became known as the Kelvin scale.

* **limit** – the limit of a scale is a point past which the scale does not go

* **absolute** means precise or certain

The Kelvin scale uses the same size units as the Celsius scale – one degree Celsius is the same as one kelvin. The Kelvin scale is really just an extension of the Celsius scale, down to –273 °C.

When you use the Kelvin scale you do not use or write the word "degrees" after the number. For example, the melting point of ice is 273 K and the boiling point of water is 373 K.

Convert between degrees Celsius and kelvin

In Technical Science we study thermodynamics, so you must be able to convert from the Celsius temperature scale to kelvin and from kelvin to Celsius.

To convert from Celsius to kelvin, use the formula:

$T = (t + 273)$ K

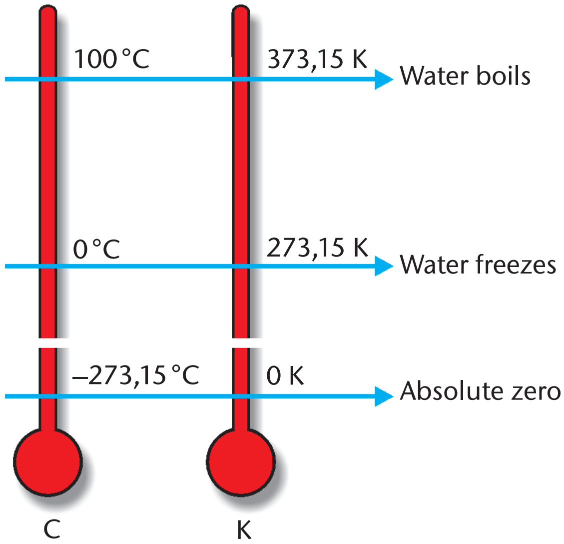
To convert from kelvin to Celsius, use the formula:

$t = (T - 273)$ °C

where:

- t is the symbol for temperature in degrees Celsius (°C)
- T is the symbol for temperature in kelvin (K)

Figure 16.17 *The temperatures on the Kelvin scale and the Celsius scale*



Worked examples: Convert between degrees Celsius and kelvin

1. Convert 100 °C to kelvin.

Solution

Given temperature = 100 °C

Unknown T

Formula $T = t + 273$

$= 100 + 273$ (substitute)

$= 373$ K

2. Convert 100 K to degrees Celsius

Solution

Given temperature = 100 K

Unknown t

Formula $t = T - 273$

$= 100 - 273$ (substitute)

$= -173$ °C

Activity 5 Convert between Celsius and Kelvin scales

1. Convert the following temperatures from degrees Celsius to kelvin:
   - **a)** 0 °C
   - **b)** 100 °C
   - **c)** 1 538 °C (the melting point of iron)
   - **d)** 1 668 °C
   - **e)** –101 °C
   - **f)** –273 °C
2. Convert the following temperatures from kelvin to degrees Celsius:
   - **a)** 0 K
   - **b)** 15 000 000 K (the temperature in the middle of the sun)
   - **c)** 273 K
   - **d)** –273 K
   - **e)** 58,5 K
   - **f)** –47,5 K
3. If the temperature of an object on the space station increases by 5 °C, what is this increase in kelvin?

Fahrenheit temperature scale (Enrichment)

Three hundred years ago a physicist called Daniel Fahrenheit proposed a scale of temperature defined by two fixed points: the temperature at which water freezes at 32 degrees (32 °F), and the boiling point of water at 212 degrees (100 °F).

To revise how to convert from Celsius to Fahrenheit, refer to Unit 1.1 in Chapter 1.

Unit 16.1 Summary Activity

1. The unit for measuring heat energy is the...
2. Correct the following statements:
   - **a)** If we want to measure how hot an object is, we use a thermostat.
   - **b)** In thermodynamics, we measure the temperature in °K.
   - **c)** If a nurse takes your temperature and reads 37 degrees on the thermometer, she should write it down as 37 C°.
   - **d)** 0 K is the same as 273 °C.
3. Complete the sentences:
   - **a)** When we measure the temperature of a substance, we are actually measuring...
   - **b)** The temperature of a fluid (gas or liquid) depends on the speed at which...
   - **c)** The temperature of a solid depends on the speed at which the particles are...
4. Complete the sentence: All bulb thermometers work on the same principle: ...

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 360 2016/01/05 3:21 PM

5. Fill in the missing words:
The two most common thermoelectric sensors are the _____ and the _____

6. Write down the formula for:

a) the conversion of temperature in degrees Celsius to kelvin

b) the conversion of temperature in kelvin to degrees Celsius

7. Convert the following temperatures:

a) –95 °C to kelvin **b)** 95 K to degrees Celsius

Unit 16.2 Heat is Energy in transfer

If you are cold and want to get warm you can sit near a fire. But you will get warm only if the heat energy of the fire reaches you. This unit is about the way heat energy gets from one object to another – from an object at a higher temperature to an object at a lower temperature. It is about the transfer of energy.

Definition: Heat is energy in transfer.

Quick Activity:

What do the words "conduction", "convection" and "radiation" mean?

Spend only two minutes on each word. First write each word. Then use it in a written sentence that shows that you understand its meaning. Your sentence must be only two lines long. Be prepared to share your explanations with the class.

Activity 6 Demonstration of conduction, convection and radiation

Apparatus

- ❑ 2 litre kitchen pot
- ❑ water
- ❑ tripod
- ❑ Bunsen burner
- ❑ plastic straw
- ❑ potassium permanganate crystals (5 g)
- ❑ a dry cloth
- ❑ a home-made paper funnel
- ❑ gloves and an apron
- ❑ matches

Procedure

A. The apparatus must not be near another source of heat.

B. Set up the apparatus as in Figure 16.18.

C. Wait for 5 minutes for the water to become motionless (still).

D. Use the straw to place a few crystals of potassium permanganate at the bottom of the pot, right above the burner, without disturbing the water. You must practise this.

E. Light the burner and turn it on low.

F. Watch what happens in the water. Say what you see.

G. After five minutes do what the hands are doing in Figure 16.19 – feel the heat energy in three ways.

H. Record your observations in your workbook using the words "conduction", "convection" and "radiation" in three full sentences.

Figure 16.18 *Conduction, convection and radiation*

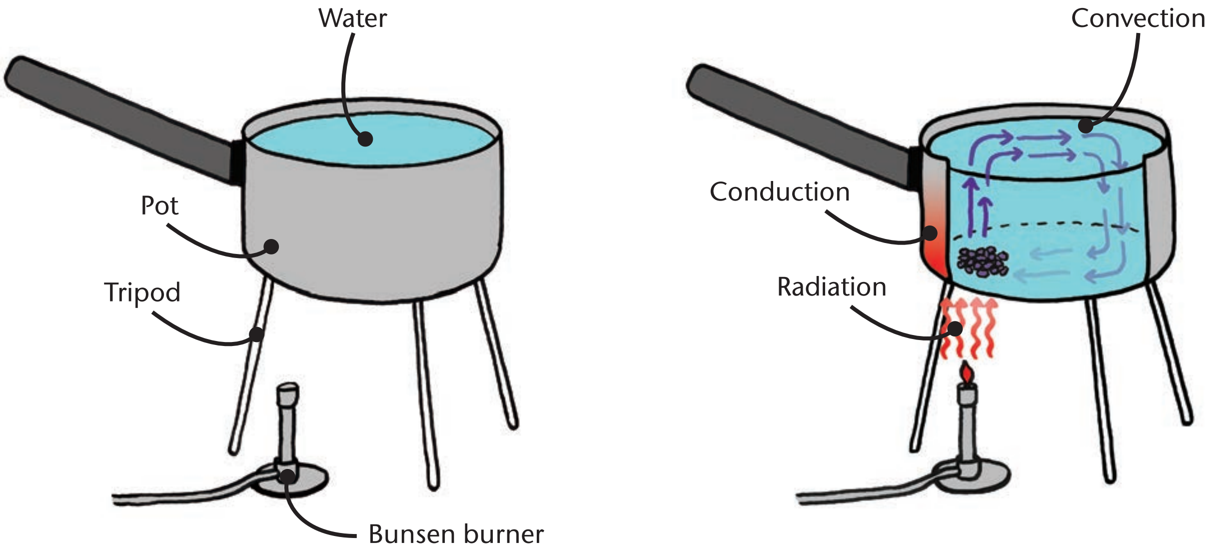
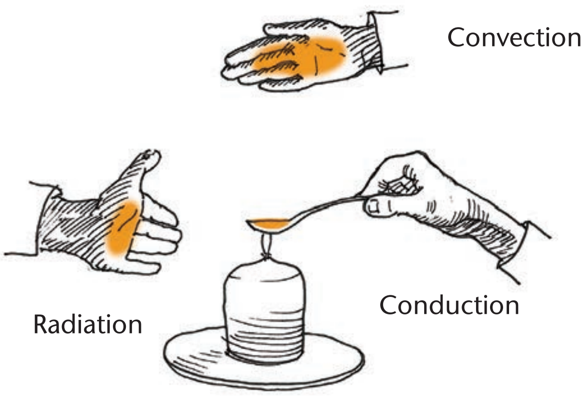


Figure 16.19 *Heat transfer by conduction, radiation and convection*



> **Safety box**
> - Feel the heat one at a time – only one person may be near the apparatus.
> - Except when touching the handle, your hands must be at least 5 cm away from the apparatus.
> - The handle of a conventional pot will get warm. If the pot boils dry, it will be dangerous to hold the handle.

What we have learned from Activity 6

- When the pot was heated at the bottom, the handle of the pot became warm too. This is conduction.
- You felt heat energy around the pot. This is radiation.
- The patterns made by the dissolved purple fluid showed that there was a visible movement of the fluid as a result of the heating of the bottom of the pot. This is convection.

Energy is transferred in the form of heat in three ways

1. **Conduction** is the way heat energy is transferred in a solid. The transfer of heat energy occurs between particles when a rapidly vibrating particle transfers some of its kinetic energy to a neighbouring particle that is vibrating slower. The transfer happens when particles collide with each other. As a result of the collisions, neighbouring particles vibrate faster. In this way, energy is transferred from particle to particle through the solid object.

2. **Convection** happens in fluids (liquids and gases). Fluids expand when they are heated, so the particles are further apart and the liquid becomes less dense. Hotter, less dense parts of the fluid start to rise through the surrounding colder, denser fluid. This transfer of energy through the motion of hotter parts of the fluid is called a convection current.
3. **Radiation*** (or thermal radiation) is the transfer of energy by means of electromagnetic waves. All objects emit radiation, and hotter objects emit more radiation than colder objects. Radiation does not involve particles touching each other. Radiation is the only method of energy transfer that does not rely upon any contact between the heat source and the heated object. So radiation is the way that energy can be transferred through a vacuum or a gas.

> ✻ **radiate** – to send out or spread from a central place

Ways in which we use heat energy transfer

Study Figures 16.20, 16.21, and 16.22. They all show examples of heat energy transfers and how we use them.

Figure 16.20 *A thermal imaging camera detects thermal radiation. The hotter parts show up as orange and the cooler parts show up as blue. The image is formed by energy being radiated, rather than by light being reflected as in an ordinary camera.*

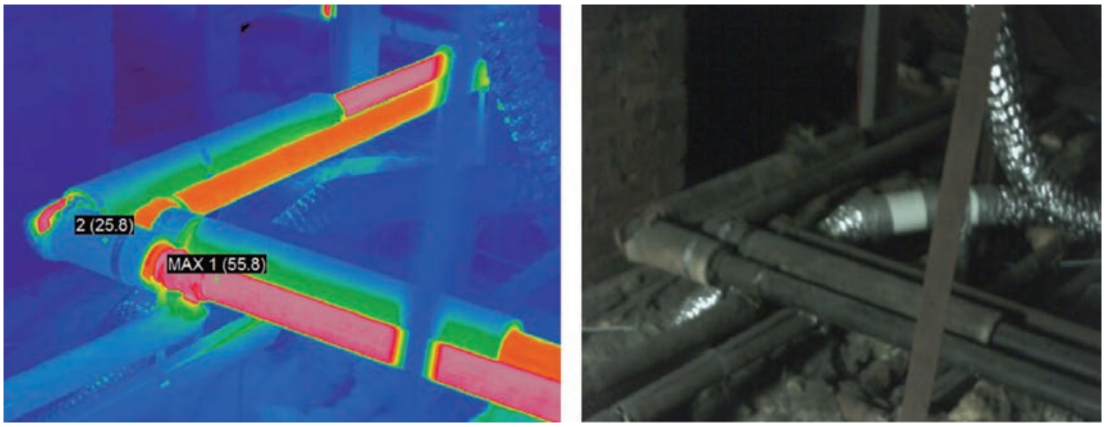


Figure 16.21 *How does all the water in the pot become evenly heated?*

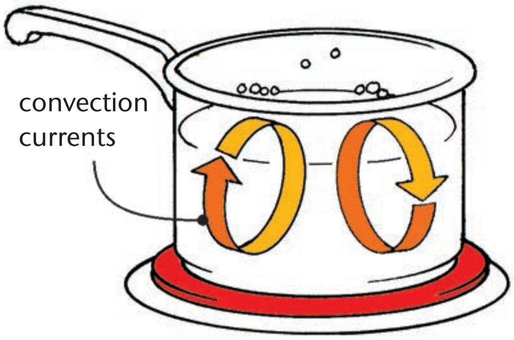
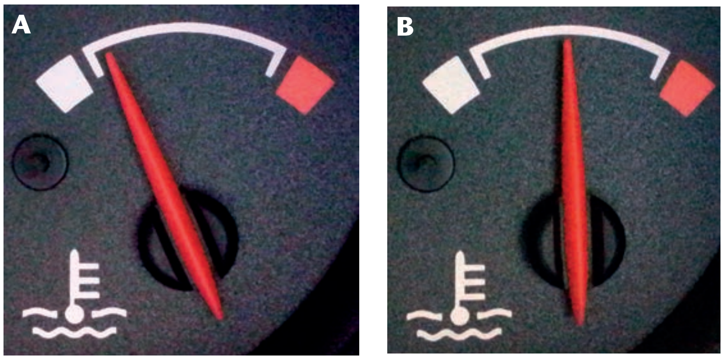


Figure 16.22 *If you are driving a car and the car's water temperature gauge shows either A or B, what is it telling you?*



TechSci_G10-LB-Eng-DBE3_9781431522842.indb 363 2016/01/05 3:21 PM

Table 16.2 describes the heat energy transfers that result in Figures 16.20 to 16.22.

Table 16.2			
1. Source of heat energy	2. What is being heated?	3. Material through which heat energy is transferred	4. Way in which heat energy is transferred
Hot water in pipes in a house	The air in the area around the pipes	Steel pipes and air	Conduction, convection and thermal radiation
Gas burning in air	Water in the pot	Metal and water	Conduction and convection
Combustion of petrol with air in the engine	Water in the radiator	Metal of the engine block; oil in the engine; water in the cooling system	Conduction and convection

Activity 7 Your own examples of heat energy transfer

1. Copy Table 16.2 into your notebook.
2. Copy the information in Column 4 into your table.
3. Fill in columns 1, 2 and 3. Describe examples from your own experience of heat energy transfer by:
   - conduction through metal
   - thermal radiation through the air
   - convection in water

Unit 16.2 Summary Activity

1. Fill in the missing words: Heat energy is one of the _______ in which _______ is _______ . Heat energy is transferred from an object that has a _______ to an object that has a _______ .
2. "Heat energy cannot transfer from a hotter object to a colder object." Is this statement true or false?
3. Write down three headings: "Conduction", "Convection" and "Thermal radiation". Now write paragraphs under each heading, by using the sentences below and putting them in the correct order. There are four or five sentences in each paragraph.
   - The transfer happens when particles collide with each other.
   - So radiation is the way in which heat energy can be transferred through a vacuum or a gas.
   - As a result of the collision, neighbouring particles vibrate faster.
   - **Convection** happens in fluids (liquids and gases).
   - **Conduction** is the way in which heat energy is transferred in a solid.
   - Fluids expand when they are heated, so the particles are further apart and the liquid becomes less dense.

- Radiation is the only method of heat transfer that does not rely upon any contact between the heat source and the heated object.
- Hotter, less dense parts of the fluid start to rise through the surrounding colder, denser fluid.
- **Radiation** is the transfer of heat energy by means of electromagnetic waves.
- The transfer of heat energy occurs between particles when a rapidly vibrating particle transfers some of its kinetic energy to a neighbouring particle that is vibrating slower.
- This transfer of heat energy through the motion of hotter parts of the fluid is called a convection current.
- All objects emit radiation, and hotter objects emit more radiation than colder objects.
- In this way, heat energy is transferred from particle to particle through the solid object.
- Radiation does not involve particles touching each other.

Unit 16.3 Heat energy

Think about these situations:

- If you make a wood fire to cook 10 potatoes, how many pieces of wood do you need?
- A family travels by car from Durban to Johannesburg and back. How many tanks of petrol are needed? How many litres of fuel will be needed? What will that cost?

Figure 16.23 *You need a certain number of pieces of wood to cook and a certain volume of petrol to travel.*

So, you know something about the quantities of different fuels or energy sources that you use.

But you don't yet know how to calculate how much energy is involved. This unit is about the measurement of heat energy.

The unit of measurement of energy is the **joule (J)**. So, because heat is a form of energy, heat energy must be measured in Joules.

How many joules are needed?

Scientists know that it takes 4,184 J of heat energy to raise the temperature of 1 ml of water by one degree Celsius.

Worked example: How many joules are needed?

Figure 16.24 *A mug of hot black coffee*

Calculate how much energy is required (to the nearest 10 000 J) to heat the water to make a mug of black instant coffee.

We make the following assumptions:

- A mug of coffee contains 250 ml of liquid.
- Tap water is at room temperature or 20 °C.
- A cup of black coffee should be served at about 50 °C (a little too hot to drink).

The problem:

- We need to heat 250 ml of water.
- We must raise the temperature by: 50 – 20 = 30 °C.

The calculation:

We do not have a formula but we can work it out.

- Heat energy to raise 1 ml of water by 1 °C = 4,183 J
- Heat energy to raise 250 ml of water by 1 °C
  = 4,184 × 250
  = 1 046 J (this is a simple ratio)
- Heat energy to raise 250 ml by 30 °C
  = 1 046 × 30
  = 31 380 J (this is a simple ratio)
- Answer: 30 000 J is required.

Activity 8 How many joules are needed?

Use the way of thinking and the calculations we did in the Worked Example to calculate the following:

a) Calculate the quantity of energy needed to melt an ice cube. To change one gram of ice to water, without even changing the temperature, it takes a massive 334 J.

b) Calculate the quantity of energy needed to cook a medium-sized soft boiled egg.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 366 2016/01/05 3:21 PM

Activity 9 The use and control of heat energy in Technology

To answer the following questions you need to do some research regarding heat energy.

1. If a concrete structure is being built when it is very cold, with temperatures near freezing, and the temperature drops below freezing shortly after the concrete is cast, the strength of the concrete will be reduced.
   What can the designer do to avoid this problem (other than building in hotter weather)?
2. The hardening of concrete involves a chemical process called hydration. Heat energy is released during hydration. When a large concrete dam is built, the heat of hydration can cause the volume of the concrete to increase so much that cracks form in the hardened concrete when it cools down again.
   What can the designer do to avoid this problem?
3. When you use the soldering process to join wires or objects made of thin metal plate together, the soldering equipment that you use must match the type and form of the materials that you join.
   Discuss this statement with regard to the heat required for soldering.
4. Brazing and gas-welding are similar process used for joining metal objects. What are the differences between the two processes regarding temperature and heat energy?

Experiment 15: Measure the temperature at which paraffin wax melts and solidifies

This is the last of ten experiments that will be assessed informally.

Work in groups of four to fulfill the aim of the experiment:

- Base your work on what you have done in this chapter.
- Use the apparatus that your teacher gives you.
- Carefully follow the process described below.
- Record, in your notebook, all that you do and your interpretation of what happens.

Safety box

There are three substances with the name “paraffin”, which are completely different:

- **Paraffin wax** is the substance that most candles are made of. SASOL makes paraffin wax from natural gas, but it can also be made from oil and coal.
- **Liquid paraffin** is a product you can buy at a pharmacy as a medicine to relieve constipation.
- Many families use a liquid called **illuminating paraffin**, or kerosene, as a fuel for cooking, lighting and heating. If you drink illuminating paraffin you will be very sick.

Description of the experiment

In this experiment we aim to determine the temperatures at which paraffin wax melts and solidifies. In addition, we aim to gather enough data to be able to describe how paraffin cools down from its **molten*** state to room temperature, and how it heats up from room temperature to its molten state.

> * **molten** – melted, usually runny; for example, molten rock flows from a volcano after it has erupted

1. A test tube containing solid wax will be heated until the wax melts.
2. The hot molten wax will be cooled and the temperature recorded at regular intervals.
3. The solid wax will then be reheated and the temperature recorded at regular intervals until it melts again.

This experiment should be done as a demonstration by one group under the supervision of the teacher.

Safety box: It is hazardous to heat wax

- Heat the wax using the double-boiler method. Do not heat it directly.
- A fire-extinguisher suitable for an oil-fire must be in the room.

Plan the experiment

First draw a table with the headings shown below. Allow room for at least 30 lines of data in your table.

Time (minutes)	Cooling cycle		Heating cycle	
	Temp (°C)	Observation	Temp (°C)	Observation
1				
1,5				
2				

Do the experiment

Read all the instructions before starting. Share the tasks amongst the members of the group.

Apparatus

- ❑ a steady table, retort stand with boss-head and clamp, tripod and 2 × gauze
- ❑ Bunsen burner and matches
- ❑ 2 × 250 ml beakers, beaker tongs, 24 mm × 150 mm test tube
- ❑ a sharp knife
- ❑ 20 g paraffin wax
- ❑ 2 × thermometers
- ❑ a skewer
- ❑ a styrofoam cup of crushed ice
- ❑ goggles and apron for all experimenters
- ❑ a timer
- ❑ a dry cloth

Part 1: Melt the wax

Some members of the group must start **Part 2** when the other members start **Part 1**.

A. Chop the wax into small pieces and put them into the test tube.

B. Put about 150 ml of tap water into the beaker.

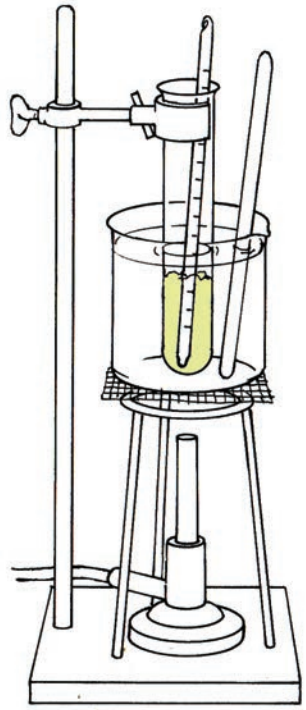
TechSci_G10-LB-Eng-DBE3_9781431522842.indb 368 2016/01/05 3:21 PM

C. Set up the apparatus to heat the wax as in Figure 16.25.

D. Heat and stir the water gently with the skewer until all the wax melts. Continue heating for another 2 minutes.

E. Leave the thermometer in the wax and move on to Part 2B.

Figure 16.25 *Apparatus to heat the wax*



Part 2: Cool the molten wax

A. Put 150 ml of tap water and a little crushed ice into a beaker. When the temperature is 10 °C, remove most of the ice. Keep the water at 10 °C until Step 1E is complete.

B. Work quickly but carefully:

- **i.** Loosen the boss-head and raise the test tube gently.
- **ii.** Remove the beaker of hot water using the beaker tongs and empty the beaker. Remove the tripod and gauze – take care, they are hot.
- **iii.** Put the beaker with cold water on the retort stand base.
- **iv.** Dry the test-tube and lower it gently into the cold water as in Figure 16.26.
- **v.** Start the timer, read the temperature of the wax, observe the wax and record the reading and observation.

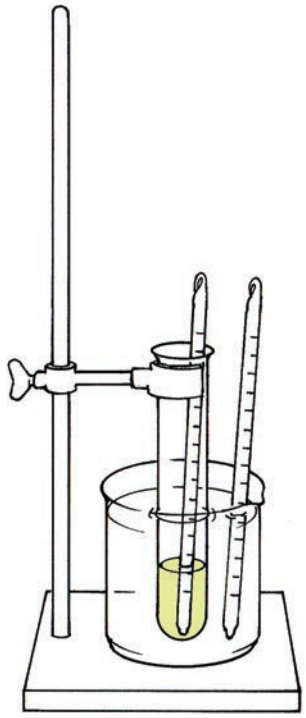
C. At half-minute intervals, read the temperature of the wax, observe the wax and record your reading and observation.

D. Stir the water gently between readings. By gently lifting the thermometer in the wax about 1 cm between each reading, you will "feel" the start of the solidification.

E. Use the second thermometer to monitor the temperature of the cold water. Keep the water at about 10 °C by adding little bits of ice. This will speed up the cooling.

F. Take careful observations as the wax solidifies. Continue recording temperatures until the temperature has dropped to about 25 °C, when you can remove the cold water.

Figure 16.26 *Apparatus to cool the wax*



Part 3: Reheat the wax

A. Put 150 ml of tap water into the empty beaker.

B. Set up the apparatus as in Figure 16.25 again.

C. Light the Bunsen burner and start the timer.

D. At half-minute intervals, read the temperature of the wax, observe the wax, and record your reading and observation. Stir the water gently between readings.

E. By gently trying to lift the thermometer between each reading, you will "feel" the start of the melting. Take careful observations as the wax melts. Continue recording temperatures for at least 2 minutes after you are sure that all the wax has melted.

F. Switch off the gas and allow the apparatus to cool before dismantling it.

Use the data to create information

1. Prepare two sheets of A4 graph paper, with time on the horizontal axis and temperature on the vertical axis. Write the heading "Cooling of paraffin wax" on one sheet and "Heating of paraffin wax" on the other sheet.
2. Use the data in your table to plot a set of points on each sheet.
3. Join **successive** points with light, ruled lines. Then draw the curve of best fit.
4. In your groups, discuss the answers to the following questions:
   - **a)** Why did we use the indirect method of heating the wax? What was the name of the method?
   - **b)** At what temperature did the solid wax melt? What is the shape of the line at that temperature?
   - **c)** At what temperature did the molten wax become solid? What is the shape of the line at that temperature?
   - **d)** What are the similarities and differences between the two lines you have plotted?
   - **e)** Do the lines you have drawn have any unexpected twists or turns? Are these features the result of experimental error? Or is there another reason for them?

Draw a conclusion

Describe, in full sentences, how the information that you have created fulfils or does not fulfil the aims of the experiment described in the section under the heading **Description of the experiment**.

Recommend improvements

Think about the experiment and write down suggestions on how to do it better.

Chapter summary

- Temperature is a measure of how hot something is. To measure temperature we use a thermometer. We use degrees Celsius (°C) as the unit of measurement.
- When we measure the temperature of a substance, we are measuring the average kinetic energy of the particles of the substance.
- A few important temperatures:
  - The boiling point of water is 100 °C.
  - The freezing point of water is 0 °C.
  - Your body's normal temperature is about 37 °C.
- Types of thermometers:
  - bulb thermometers
  - thermoelectric thermometers
  - bimetallic thermometers
  - temperature strips

- Kelvin temperature scale: The lower limit of the scale is –273 K.
- Conversions:
  - To convert from Celsius to kelvin, use the formula: $T = (t + 273)$ K
  - To convert from kelvin to Celsius, use the formula: $t = (T - 273)$ °C

    where: t is the symbol for temperature in degrees Celsius (°C)

    T is the symbol for temperature in kelvin (K)
- Energy is transferred in the form of heat in three ways:
  - Conduction is the way heat energy is transferred in a solid. The transfer occurs when particles collide. A rapidly vibrating particle transfers some of its kinetic energy to a neighbouring particle that is vibrating slower.
  - Convection happens in fluids. The transfer of energy through the motion of hotter parts of the fluid is called convection.
  - Radiation is the way that energy can be transferred through a vacuum or a gas. It is the transfer of energy by means of electromagnetic waves.
- Heat is a form of energy. It is measured in joules (J).

Challenges and projects

Investigate the ability of blocks of different metals to transfer energy from one environment to another

This experiment requires co-operation between three groups of learners to be successful.

Aim: Investigate and compare the ability of blocks made of three different metals to transfer energy by receiving energy from one environment, and then releasing it to another environment.

Figure 16.27 *Cubes of different metals*

Describe the scientific problem

1. Discuss the problem you have been given, with the learners in your group.
2. Describe the problem in writing, using a full sentence.
3. Write a focus question:
   - Discuss the one question that will help your group to solve the problem.
   - Write down the question using a full sentence. This is called the focus question.
4. Write your expected answer to the focus question:
   - Discuss what you expect to discover at the end of the investigation.
   - Describe your expected answer to the focus question in writing, using a full sentence. This is your **hypothesis.**
5. Plan how to work together to find an answer to the focus question.

Plan and carry out the experiment

Apparatus

- ❑ 3 thermometers
- ❑ 3 insulated cups
- ❑ 3 kebab sticks for stirring
- ❑ hot plate with pot of boiling water
- ❑ blocks of 3 different metals of exactly the same dimensions, kept in the same container
- ❑ cotton thread
- ❑ large jug of water at room temperature
- ❑ 200 ml measuring cylinder

A. Tie each of the metal blocks to a piece of thread about 1 m long and put them back in their container together.

B. Use the measuring cylinder to put the same amount of the room temperature water into each of the cups – enough to cover a metal block with at least 10 mm of water.

C. Put a thermometer and kebab stick into each cup. Take care not to spill any water. Start the experiment again if water is spilt.

D. Draw a table to record the time, temperature and a comment for at least 30 observations.

E. Start timing and at the same moment place the blocks of metal into the boiling water.

F. Record the temperature of the water in each cup every 20 seconds for about the next 10 minutes.

G. At 2 minutes, pull the blocks out of the boiling water and place them as quickly as possible into the water in the cups.

H. Keep reading and recording the temperatures. Stir the water gently before each reading (leave the kebab stick in the water). The temperature will rise, then stay constant, and then start to fall.

I. Stop recording when the temperature stays constant for three readings, or starts to fall.

J. Plot you data on graph paper and determine the value of the water temperature before the block was put into the water and the temperature at the end of the process.

K. Subtract the temperature before the block was put into the water from the temperature at the end of the process. Do this for each of the blocks.

Use your data to create information

L. Study the data (the results). Compare the numbers you got in degrees Celsius for each block.

M. Use the data as you had planned, to create information. You might, for example, draw a graph using numbers you have produced, or just write a sentence.

Draw a conclusion

Write a sentence (or more) that describes how the information that you have created answers or does not answer the focus question.

Recommend improvements

Think about the investigation you have just completed and suggest (in writing) how it could be improved if it were repeated.

RESOURCE PAGES

Contents

How these Resource Pages are like a little library

- In these Resource Pages, you will find some articles (short pieces of information). Use the table of contents on the previous page to find articles that may help you. The articles are similar to articles that you may find in encyclopaedias and other reference books in a library.
- You will also find an article similar to one from the Internet.
- You may find two articles in these pages that give you some of the information that you want. Then you must read both articles and make your own notes that summarise the information. This is what could happen if you went to a real library.
- Most of the time, you will find more information than you need in each article. Then you must choose the parts that you need for the task. This is also what could happen if you went to a real library.
- You are not only learning science; you are also learning how to learn.
- You will also find help in developing skills in the "How To" pages.

Practise reading thermometers

The diagrams show you laboratory thermometers that are measuring temperatures of different things.

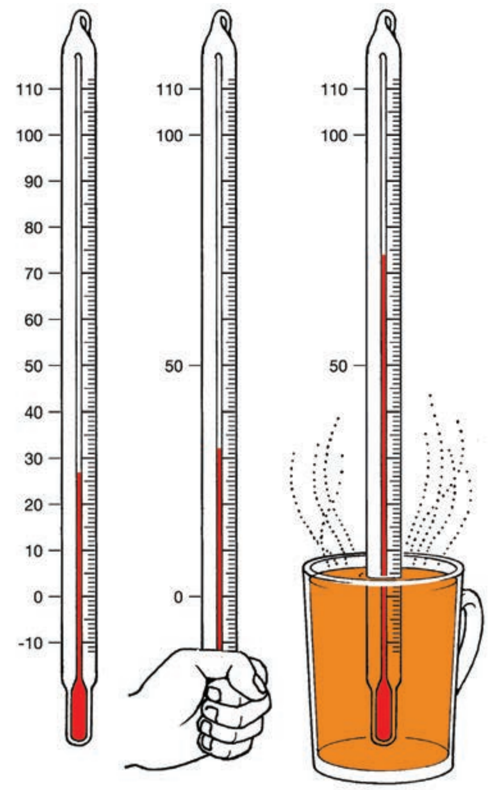
1. What is the temperature of the air?

2. What is the temperature on the skin of the hand?

3. What is the temperature of the tea?

When you really measure the temperature of a liquid, you must keep the thermometer bulb in the liquid. If you take it out, you will measure the temperature of the air!

Practise reading the scales of these thermometers



The Galileo thermometer

The Galileo thermometer is an early type of thermometer. It is made of a tube containing a liquid and several hollow glass capsules filled with coloured liquid and a little air. The levels of the various capsules respond differently to a change in the temperature of the liquid in the tube. This is because the density of a capsule decreases when the liquid gets hotter and increases when the liquid gets colder. This all happens because liquids expand when they get hotter and contract when they get colder.

The Galileo thermometer

A table of melting points of pure metals and alloys

Pure metal or alloy	Melting point (°C)	Boiling point (°C)
Aluminium, pure	658	2 467
Brass, depending on % copper, zinc and other metals	900–940	data not available
Bronze, depending on % copper, tin and other metals	about 950	data not available
Copper	1 085	2 575
Iron, cast and malleable	1 260	2 870
Lead, pure	327	1 750
Magnesium	671	1 090
Nickel	1 452	2 800
Platinum	1 772	3 827
Solder for electronics: 63% tin, 37% lead	183	data not available
Solder for sheet metal work: 50% tin, 50% lead	183–212	data not available
Solder for metals that touch food: 96% tin, 4% silver	221–229	data not available
Silver, pure	961	2 212
Stainless steel: 18% chromium, 8% nickel	1 399	similar to iron
Steel, high-carbon: 0,40% to 0,70% carbon	1 371	similar to iron
Steel, medium carbon: 0,15% to 0,40% carbon	1 427	similar to iron
Steel, low carbon: less than 0,15%	1 482	similar to iron
Tin	232	2 603
Titanium	1 799	3 287
Tungsten	3 400	5 550
Zinc	419	910

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 375 2016/01/05 3:21 PM

Benjamin Franklin's lightning rod

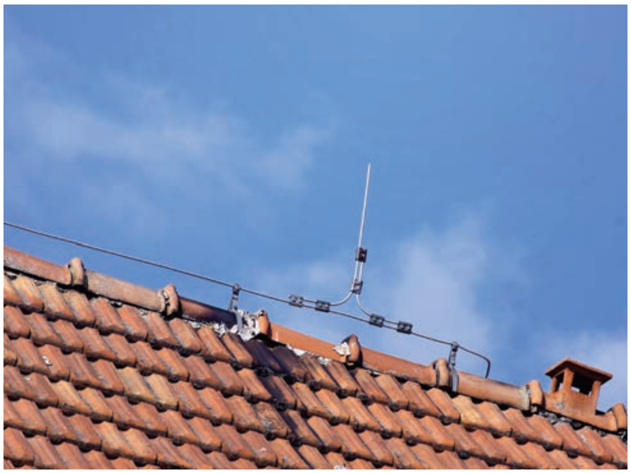
What would you think if you saw a man chasing a thunder and lightning storm on horseback? You would probably wonder what on Earth he was trying to do. Well, if you lived in the 1700s and knew Benjamin Franklin, this is just what you might see during a terrible storm. Ben was **fascinated** by storms; he loved to study them. If he were alive today, we could probably add "storm-chaser" to his long list of titles.

It was in Boston, Massachusetts, in the United States in 1746 that Franklin first found out about other scientists' electrical experiments. He quickly turned his home into a little laboratory, using machines made out of objects he found around the house. During one experiment, Ben accidentally shocked himself. In one of his letters, he described the shock as:

"...a universal blow throughout my whole body from head to foot, which seemed within as well as without; after which the first thing I took notice of was a violent quick shaking of my body..." (He also had a feeling of numbness in his arms and the back of his neck that gradually wore off.)

Franklin spent the summer of 1747 conducting a series of groundbreaking experiments with electricity. He wrote down all of his results and ideas for future experiments in letters to Peter Collinson, a fellow scientist and friend in London. Later the same year, he explained what he believed were similarities between electricity and lightning, such as the colour of the light, its crooked direction, crackling noise, and other things. There were other scientists who believed that lightning was electricity, but Franklin was determined to find a method of proving it.

Lightning rod wire on a roof of clay tiles



By 1750, in addition to wanting to prove that lightning was electricity, Franklin began to think about protecting people, buildings, and other structures from lightning. This grew into his idea for the lightning rod. Franklin described an iron rod about 3 metres long that was sharpened to a point at the end. He wrote, "the electrical fire would, I think, be drawn out of a cloud silently, before it could come near enough to strike...". Two years later, Franklin decided to try his own lightning experiment. Surprisingly, he never wrote letters about the famous kite experiment; someone else wrote the only account 15 years after it took place. Some people even think that this was a "thought" experiment.

In June of 1752, Franklin was in Philadelphia, waiting for the steeple (tower) on top of Christ Church to be completed for his experiment – the steeple would act as the "lightning rod". He became impatient, and decided that a kite would be able to get close to the storm clouds just as well. Franklin needed to work out what he would use to attract an electrical charge; he decided on a metal key, and attached it to the kite. Then he tied the kite string to an insulating silk ribbon for the knuckles on his hand. This was a very dangerous experiment! Some people believe that Benjamin wasn't injured because he didn't conduct his test during the worst part of the storm. At the first sign of the key receiving an electrical charge from the air, Franklin knew that lightning was a form of electricity. His 21-year-old son William was the only witness to this event.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 376 2016/01/05 3:21 PM

This is what Ben wrote afterwards to people who wanted to repeat the experiment:

"When rain has wet the kite twine so that it can conduct the electric fire freely, you will find it streams out plentifully from the key at the approach of your knuckle, and with this key a phial, or Leyden jar, may be charged: and from electric fire thus obtained spirits may be kindled, and all other electric experiments [may be] performed which are usually done by the help of a rubber glass globe or tube; and therefore the sameness of the electrical matter with that of lightening completely demonstrated."

Two years before the kite and key experiment, Ben had observed that a sharp iron needle would conduct electricity away from a charged metal sphere. He first theorised that lightning might be prevented by using a high iron rod connected to earth to empty static electricity from a cloud. This is what he thought:

"May not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix, on the highest parts of those structures, upright rods of iron, made sharp as a needle ... and from the foot of those rods a wire outside the building into the ground. Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came near enough to strike, and thereby save us from that most sudden and terrible injury!"

Soon people began to use Franklin's lightning rods to protect many buildings and homes. The lightning rods in the United State had a pointed end. The lightning rod constructed on the dome of the State House in Maryland was the largest "Franklin" lightning rod ever attached to a public or private building in Ben's lifetime. It was built according to his recommendations and has had only one recorded instance of lightning damage.

Adapted from https://www.fi.edu/history-lightning-rod

Questions

1. How do you know that Ben Franklin was serious about experimenting with electricity?
2. For how many years can we be certain that he conducted these experiments?
3. What were the similarities he noticed between electricity and lightning?
4. Why do you think he built a steeple on a church?
5. What three things did he use for his kite experiment?
6. Could he use the lightning to charge a Leyden jar? Explain what this proved.
7. How does a lightning rod on a house protect the house as well as the people who live there? Explain what he thought in your own words.

Information on how to improve your Leyden jar

- Make sure that the inner and outer foils have no sharp corners or folds. The charging knob must be smooth and round, because charge leaks off sharp points.
- The plastic of the bottle, between the inner and outer foil, must be thin.
- The negative charge on the inner foil will try to push the negative electrons away from the outer foil. So ask a friend to touch the jar between fingers and thumb. The fingers give a path for electrons to escape from the outer foil.
- Try making the spark gap bigger or smaller.
- Charge up your Leyden Jar in a dark place to see the sparks. Also try to make a neon tube flash. Put your finger on one pin of the neon tube and bring a pin at the other end near to your Leyden jar.
- Try connecting a wire from the charging knob to a sheet of aluminium foil on the glass screen of a TV set. The TV screen collects a lot of charge when you switch it on and also when you switch it off.
- All electrostatic experiments work best in very dry weather. Water molecules in moist air attract electrons and so electrons escape into the air.
- You can make a larger Leyden jar but you might need a van de Graaff generator to charge it. Big Leyden jars can be dangerous and give you a severe shock.

Joseph Priestley's discovery of oxygen

What people believed about air in the 1700s

At the start of the Industrial Revolution (in the mid-1700s) people were still puzzled about elements. In particular, scientists then were very puzzled about how *air* fitted into the system. Nobody understood what it was, and they really needed to know what was happening when things burn. This is what they thought then: materials that could be burned gave off an element called "phlogiston" (say FLA-jis-ton) which came from the Greek word for "burn". When a candle burnt it let off phlogiston, and when the air became saturated with it, the candle went out. When they put a mouse in a container and the mouse died, they thought it was because the air in it wouldn't accept any more phlogiston. The poor mice!

However, between 1754 and 1772, scientists from England had got as far as identifying carbon dioxide, hydrogen, and nitrogen. However, they didn't use the names for these gases yet.

Joseph Priestley

Joseph Priestly comes into the picture

The next key discovery came from Joseph Priestley. Priestley was a priest from England, a very clever man, who was also a friend of Benjamin Franklin. Priestley scientifically analysed the properties of different "airs" using the apparatus that scientists at that time preferred to use. This was a container on a raised platform placed on a pool of water or mercury, which sealed it. Mercury is very dense and won't absorb gases. Priestly floated materials on top of the mercury. He then heated the lump of yellow powder through a 30 cm magnifying glass. Mercuric oxide was going to give off something.

The gas that came from the orange powder pushed the mercury down. The gas molecules were free to move around and so they created a pressure in the tube. The colourless, odourless, and tasteless gas produced from the lump caused a flame to burn intensely. It also kept a mouse alive about four times as long as a similar quantity of normal air. Whatever the gas was called, its effects were extraordinary.

He said that his lungs felt as if they had air, but his chest felt light and easy. He thought it might be a luxury in times to come. At that stage only he and two mice "had the privilege of breathing it", he said. He wrote all about it in his notebook.

He had discovered oxygen; he didn't use that word yet, though. He decided to call it "dephlogisticated air", because it supported the burning process so well. The reason it felt so good was that it was quite pure oxygen, the kind we give to people in hospital to help support their breathing, when they are struggling for breath.

The Chemical Revolution

Shortly after this, Priestley visited France and met Antoine Lavoisier, another scientist who was also investigating gases. Lavoisier called the gas "oxygen" from the Greek word for acid-maker, because it combines with non-metals to produce acids. This was a big leap forward towards modern chemistry.

The colour codes for resistors

4 Band Resistor Colour codes

The colours of the bands, from left to right, are yellow, violet, orange and silver.

	First 2 Bands	Third band (the Multiplier)	Fourth band (Resistor Tolerance)
Black	0	1	Gold 5%
Brown	1	10	Silver 10%
Red	2	100	None 20%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7	10,000,000	
Grey	8	Gold 0.10	
White	9	Silver 0.01	

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 379 2016/01/05 3:21 PM

The “How To” pages

How to do research on the Internet

1. On your internet browser, type in *google.co.za* or *www.bing.com* or *https://za.yahoo.com/*
2. Type in your search terms, for example the word *gravitation,* and press Enter.
3. Your search engine will find a large number of hits. Click one or two at the top of the list to see if it explains the science meaning that you are looking for.
4. You can Copy and Paste important information into a Word file. Remember, if you are going to use the information exactly as it is, then use quotation marks. However, it is better to try and rewrite the information in your own words.
5. Remember you must reference the site in your writing. Here is an example: *http://en.wikipedia.org/wiki/Gravity as downloaded on 18th April 2015*

How to have a useful group discussion

Roles

There are different roles in group discussions. Take turns to have the following roles:

- The group leader: You are the person who makes sure everybody has turns.
- The one who makes notes: Make sure other members give you time to write.
- The one who summarises the discussion
- The one who presents your group’s report at the end

Speaking

- Speak in English as far as possible; use your home language if you are really stuck.
- Have respect and give everyone a chance to say something.

Listening

- Listen to what everyone says.
- Don’t interrupt.
- If you don’t understand what someone is saying, ask them to explain. You can also ask the teacher.

Writing

- Write a list of the things you all agree on and the things you don’t agree on.

Presenting

- You will be tempted to give this job to your best speaker. However, everyone must have a turn to present a report to the class. That way, everybody develops confidence.

How to read a table

- Find the title of the table: what does it show/tell/give us? What do you expect to learn from it?
- Read the column headings.
- Run your eye *down* each column to check that you can relate the contents of the column to the heading of it.
- Run your eye *along* a few rows to check that you can relate the contents of each cell to the content of the other cells in the row.
- Take note of the units that are used in the table.
- You are now ready to understand and use the table.

Practise your skills on the table below:

Table E: Table of conversion factors for measurements of time

Factors to use in conversion			Examples
From	**To**	**Factor**	
seconds	minutes	$\frac{1}{60}$	300 s = 30 ÷ 60 = 5 min
seconds	hours	$\frac{1}{3\,600}$	300 s = 300 ÷ 3 600 = $\frac{1}{12}$ h
minutes	seconds	60	5 min = 5 × 60 = 300 s
minutes	hours	$\frac{1}{60}$	5 min = 5 ÷ 60 = $\frac{1}{12}$ h
hours	seconds	3 600	12 h = 12 × 3 600 = 43 200 s
hours	minutes	60	12 h = 12 × 60 = 720 min

Test your understanding:

1. How many hours are 1 440 minutes?
2. How many minutes are 900 seconds?
3. How many seconds are there in 7 hours?

How to do Practical Activities

In Technical Sciences you will do at least 16 practical activities, including:

- Practical Investigations
- Experiments
- A Project

Your teacher will give you Practical Investigations and Experiments to do regularly through the year. Some activities will be done in groups and will be assessed informally: not for marks. Some activities will be for individuals and will be assessed formally: for marks.

You will get your Project in the first term. You will do it on your own. In the third term you must present your project and hand it in for formal assessment (for marks).

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 381 2016/01/05 3:21 PM

A. How to do a Practical Investigation

You do a Practical Investigation when you have a scientific problem to solve. Any investigation in Technical Sciences must follow a **Scientific Process**. Here is an example of a Scientific Process for an investigation.

The Scientific Process

1. **Describe the scientific problem**
   - **Discuss** the problem you have been given with the learners in your group.
   - **Describe** the problem in writing using a **full sentence**.

2. **Write a focus question**
   - The problem might have raised a number of questions. **Discuss** the one question that will help your group to solve the problem.
   - **Write** down the question using a **full sentence**. This is called the **focus question**.

3. **Write your expected answer to the focus question**
   - **Discuss** what you expect to discover at the end of the investigation.
   - Describe your expected answer to the focus question **in writing** using a full sentence. This is called the **hypothesis**.

4. **Plan an investigation to find an answer to the focus question**
   - Write **a list** of the materials, equipment or other resources that you will need.
     - **Write down** what you intend to do – the steps you need to take. This is called the **method**.
     - **Write** the steps in the order that you will do them, and number the steps.
     - Use **short phrases** to describe the steps.
   - Each member of the group must have the same number of tasks to do.
   - Before you start doing the investigation:
     - **Draw up a table** for the results. You will write your results in this table. The results of the investigation are called **data**.
     - Decide how you will use the data to create **useful information**. You might, for example, just need to compare the colours you have produced, or draw a graph using the numbers you have produced, or sketch a diagram, or write a sentence.

5. **Do the investigation**
   - Do the investigation in the way you planned it.
   - Record the results **in writing**.

6. **Use the data to create information**
   - Study the data (the results) and use it in the way you had planned to create information.

7. **Draw a conclusion**
   - **Write a sentence** or more that describes how the information that you have created answers, or does *not* answer, the focus question.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 382 2016/01/05 3:21 PM

8. **Recommend improvements**
   - Think about the focus question and **write down** a new question for another investigation.

B. How to do an Experiment

Every Experiment you do in Technical Sciences must follow a **Scientific Process**. Here is an example of a Scientific Process for an Experiment:

The Scientific Process

1. **Describe the experiment**
   - **Discuss** the experiment with the learners in your small group.
   - Give the experiment **a name** and write it down.
   - **Describe, in a full written sentence**, the known theory that you intend to prove.
   - Describe, in general terms, what you need to do to prove the theory and **write it down**.

2. **Plan the experiment**
   - **List** the materials, equipment or other resources that you will need.
   - **Write down** what you intend to do – the steps you need to take (this is called the **method**).
   - Write the steps in the correct order and **number them**.
   - Use **short phrases**.
   - Each member of the group must have the same number of tasks to do.
   - Before you start doing the experiment:
     - **Draw up a table** for the results. You will write your results in this table. The results of the investigation are called **data**.
     - Decide how you will use the data to create **useful information**. You might, for example, just need to compare the colours you have produced, or draw a graph using the numbers you have produced, or sketch a diagram, or write a sentence.

3. **Do the experiment**
   - Do the experiment just as you planned it.
   - **Write down** the results.

4. **Use the data to create information**
   - Study the data (the results) and **use it in the way you had planned**, to create information.

5. **Draw a conclusion**
   - **Describe, in a written sentence,** how the information that you have created confirms the theory that you set out to prove, or does not prove it.

6. **Recommendation**
   - Think about the experiment and **write down** suggestions on how to do it better.

C. How to do a Project

In Technical Science a Project is described as an integrated task. The integrated task occurs within a scientific, technological, environmental or everyday context. It focuses on process skills, critical thinking, scientific reasoning, and strategies to investigate and solve problems.

You will be using process skills throughout the year in Technical Science. Process skills include planning, observing, recording, comprehending, inferring, synthesising, generalising, hypothesising, and communicating results and conclusions. Your teacher will explain these skills as you learn to use them.

You will follow the Scientific Method in your Project. You have three possibilities for your Project. You will choose one of the following:

- Construct a **device**.
- Build a **physical model** to solve a challenge you have identified.
- Do a **practical investigation**.

Projects are set in the same situations as your Experiments and Practical Investigations. They also require the same group of skills as Experiments and Practical Investigations. However there are two differences between a Project and an Experiment/Practical Investigation. A project:

- will be more complex, involve more work and take more time
- must produce a device, or a model, or consist of a Practical Investigation

The Project will be given to you in the first term. In the third term you must present your Project and hand it in. You have the option of including a poster as part of the presentation of the Project.

If you choose to construct a device or a build a physical model you will still use the Scientific Method, but there is one more part. This is the Design Process. You studied this process in Technology in Grades 4–9. Use the Design Process to design and make the device or physical model. The Design Process includes these steps: investigating, designing, making, evaluating and communicating.

How to write a report

A report describes something that has happened. It shows how you carefully went about your investigation or project.

A report organises facts so that they are easy for a reader to understand. So, do your work on a computer to make it easy to check, edit, polish and print out.

How to go about writing a report

1. Collect the information you need.
2. Write a draft report: this will help you to get a good idea of what is needed.
3. Put it aside for a few days, because that helps you to get a bit of distance from what you wrote. Then edit it.
4. Write out or type the final version.

1. **Compile (put together) the information**
   - Observe, listen and read around the topic.
   - Make notes or record facts.
   - Then organise the notes/facts.

2. **Write a draft report**

   Beginning: Use the 5 *wh* formula:
   - *Who* did it?
   - *What* happened?
   - *Where* did it take place?
   - *When* did it take place?
   - *Why* did it happen?
   - *How* did it happen?

   NOTE: You don't have to use all of the above points every time.

   Middle:
   - Aim – what was the focus question?
   - Hypothesis – what did you expect to find?
   - Apparatus – what did you use?
   - Procedure – how did you go about carrying out the task?
   - Safety – what precautions did you take?
   - Results – what were your findings?
   - Discussion
   - Conclusion

   NOTE: It is not necessary to use all of these sections in every report.

   End:
   - Summarise the main issues.

   Language style
   - Write in the past tense.
   - Use the second person: "we did..." and so on.
   - Be factual and not emotional.
   - Be formal in your writing style.
   - Avoid using "awesome", "amazing" sort of adjectives – they belong in the English essay.

3. **Edit the draft report**
   - Ask someone who you trust to check the draft report. Then edit it.

4. **Write the final report**
   - Write the final version of the report, print it and hand the final document in.

How to design a poster

Headings	Big and bold headings make the poster eye-catching.
Text	*The simpler and shorter the message, the clearer the message will be.* The text should be readable from 2 metres away.
Picture	Pictures and drawings should be used to help other people to understand the text: don't simply fill a space.
Border	A poster must have a border, which might be a frame, a pattern, the poster background, or just blank space.
Balance	There should be about equal areas of text, blank space and pictures.
Colour	Use colour to help other people to understand, not to make a multi-coloured display. So, not too many colours.
Flow	The poster must invite you to read it from left to right and top to bottom. Use both headings and subheadings if you need to.
References	Give the reader your contact details or guidance regarding where to go for more information.

Some internet resources to help you with revision

NOTE: in the first instance, revise from your textbook. If you still have time, you could try one or two of these.

Electricity

This is the most entertaining general series on the Story of Electricity. But you must only watch it if your family or school have uncapped ADSL or wifi – this is because it is three hours long, and will cost thousands of rand in data otherwise.

https://www.youtube.com/watch?v=Gtp51eZkwoI

Shock and Awe: The story of electricity (BBC documentary): three hours with Prof Jim Khalili

Websites for static electricity

http://www.ducksters.com/science/static_electricity.php

A page with good explanations: on the second page; there is also a section called Easy Reading

http://www.sciencemadesimple.com/static.html

Projects

http://www.sciencemadesimple.com/static_electricity_projects.html

A good basic source of information in readable English

http://www.school-for-champions.com/science/static_electricity.htm#.VguJTPmqqko

Here's a 20 minute video made in Canada in 1986 with good animations of the electroscope, induced charge, electric thunderstorms, net charge, and grounding.

It looks old fashioned but it has good animations that show what happens in a similar way to the textbook.

https://www.youtube.com/watch?v=6_Hl1g_lnK0

Electrostatic induction, conduction and friction

Perhaps for Grade 11. Great visuals. You could try viewing it in Grade 10 and get more from it in Grade 11.

Bozeman Science with Paul Anderson

https://www.youtube.com/watch?v=dwJ-MM7yu4E

Bozeman Science: *Positive and negative charge*

Introduces the term polarisation, but otherwise good for revision Grade 10, or viewing for Grade 11. Great visuals always.

https://www.youtube.com/watch?v=zHJkJGBdvwE

Voltaic Piles: here is a simple project for you. This explains the very important invention of the Italian scientist Volta, on which the history of electricity began to take off.

https://www.youtube.com/watch?v=edMN7P5oCaY&list=PLCFDAEF5166DD1473&index=7

Websites for Circuits

Voltage, resistance and current.

https://www.youtube.com/watch?v=J4Vq-xHqUo8

Careful explanation of the difference between the two: series and parallel

https://www.youtube.com/watch?v=x2EuYqj_0Uk

Electrical potential and potential energy as a preparation for understanding voltage

In two parts: be sure to watch the both, as you will go "aha" at the end of the second part.

Part 1

Physics 12.4.1a – Electric Potential and Potential Difference:

https://www.youtube.com/watch?v=wT9AsY79f1k

Part 2

Physics 12.4.1b – Electric Potential and Potential Difference, continued:

https://www.youtube.com/watch?v=Aq31mjWYdJ8

GLOSSARY

In this book you will find words in bold or that are marked with *, an "asterisk". This glossary will explain what those words mean. Of course, one word may have other meanings too! You should use a dictionary to find the other meanings.

Remember that there are many words people use in everyday talk which have special meanings in science. For example, you hear people talk of "mass meeting"; here "mass" means "great numbers of people". In science, the word "mass" means "the amount of substance" in a thing, that gives the thing its weight or heaviness. "Mass" in science does not have anything to do with "great numbers of people".

So when you hear a word in your science lesson that sounds familiar, remember that the word may have a special science meaning and you must find out what that meaning is.

The first letters of the words are in **alphabetical order**. The alphabet is printed at the top of each page to remind you of the order. Lots of information books, like telephone directories, are in alphabetical order and you should memorise the alphabet.

(n.) means "this word is a noun, the name of a thing", ***(v.)*** means "this word is a verb that tells what you do" and ***(adj.)*** means "this word is an adjective, it tells you more about a noun".

You practise **skills** until you can use them easily. Find the meaning of each skill-word in the glossary.

These are words for skills:

- observing and comparing
- measuring
- recording information
- sorting and classifying
- interpreting information
- use a model to explain why something happens
- predicting what will happen if something changes
- hypothesizing
- raising questions to investigate
- planning investigations. Your investigation needs to be a fair test.
- doing an investigation
- communicating science information

Pronouncing new words. Some words have a pronouncing guide. In the word "anaesthetic" **(AN-is-THET-tik)**, you say the "AN" and "THET" parts more loudly than the other parts, so they are in capital letters. "-uh-" sounds like the -o- in "person", like a sound between "u" and "i" sounds. The sound in "high" and "my" we show with the letter "y".

A

absolute *(adj.)* **(AB-suh-loot)** complete. An object's temperature is a measure of how much its atoms move – the colder an object is, the slower the atoms are. At the physically impossible-to-reach temperature of zero kelvin (minus 273,15 degrees Celsius), atoms would stop moving. So, nothing can be colder than absolute zero on the Kelvin scale.

acceleration *(n.)* **(ak-sele-RAY-shun)** This change of speed is called acceleration. When the velocity of an object changes, we say that it accelerates. If velocity is constant, there is no acceleration, even if an object is moving very fast.

acid *(n.)* **(A-sed)** a substance which reacts with a carbonate to produce CO_2, and which turns bromothymol blue to yellow, and which reacts with most metals to produce hydrogen, and which has a sharp sour taste.

adjacent *(adj.)* **(uh-JAY-sint)** next to, or in line with.

affect *(v.)* **(A-fekt)** to have an effect on something, to cause a change in something.

air resistance *(n.)* air resistance, also known as drag, is a force that is caused by air. The force acts in the opposite direction to an object moving through the air. It is where air particles hit the front of the object, slowing it down.

algebraic sum *(n.)* the term algebraic sum is used when the numbers you are adding include both positive and negative numbers. Ordinary sums are done with positive numbers only.

alloy *(n.)* **(A-loi)** a mixture of metals. You can mix metals by heating and melting them. When the mixture has cooled you have a new metal which may have different properties from any of the original metals.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 388 2016/01/05 3:21 PM

amber *(n.)* **(AM-buh)** a hardened tree gum, which has been valued for its colour and natural beauty as a gemstone since earliest times.

appropriate *(adj.)* suitable, proper, right, correct.

area *(n.)* the size of a surface. The amount of space inside the boundary of a flat (2-dimensional) object such as a triangle or circle.

attraction *(n.)* force of pull. The process between objects being drawn towards each other. The opposite of **repulsion***.

average speed *(n.)* the **average speed** is calculated by the distance that an object travelled over a given interval of time.

B

balanced *(adj.)* stable, secure. When a structure is balanced, it is not going to bend or distort in any way. We can say it is **in equilibrium**.

in **balance** (*adv*.) – in equilibrium *(see above)*.

beam *(n.)* technically a beam is a "horizontal structural member". A member is part of something more complex. Beams are designed to carry loads, which are usually vertical (top-bottom) loads. At the same time as a beam is doing this, its purpose is to resist (fight back) definite forces acting on it.

bending *(adj.)* a **bending** force causes the object on which it acts to tend to bend. This happens when a "turning force" is applied to a structural member (or piece of material) making it bend or sag, and moving it sideways away from its original position. A moment that causes **bending** is called a **bending moment**.

boiling point *(n.)* is the temperature at which the pressure in the vapour under the surface is equal to the pressure of the vapour above the surface.

brittle *(adj.)* **(BRIT-el)** when a substance is brittle, it has hardness and rigidity but little tensile strength; it breaks easily with quite a smooth fracture, like glass. When your nails are brittle, they break easily.

C

calibrate *(v.)* **(KAH-li-brayt)** to set or correct a measuring instrument to measurements that we already know.

cantilever beam *(n.)* this is a beam where one end is fixed and one end is free to move.

capacitor *(n.)* a **capacitor** is a passive electrical component with two terminals; it stores energy in the form of an electrostatic field between its plates. (It was originally called a condenser.).

catastrophic failure *(n.)* **(KAT-a-STROF-ik)** This is a sudden and total failure from which recovery is impossible. This is usually used to refer to an engineering failure, but people also use it in other situations too, for example, to a computer system which fails.

For example, the Tay Rail Bridge (Scotland) disaster happened in 1879, where the centre km of the bridge was completely destroyed while a train was crossing in a storm. The bridge was badly designed and its replacement was built as a new structure in a different place up the river Tay.

cause *(v.)* to make something happen.

cause *(n.)* the reason why something happens.

cell *(n.)* **(SEL)** **(1)** apparatus made of metal plates in a solution, which can give energy to electricity **(2)** an apparatus where **electrolysis*** happens **(3)** the smallest living part of a plant or animal. (There are other meanings of "cell", such as "prison cell".)

characteristic *(n.)* **(KA-ruhk-tuh-RIS-tik)** a mark or feature which is very special about something, for example, spots are a **characteristic** of a leopard. Green or blue colours are characteristic of copper compounds.

chemical *(n.)* **(KE-mi-kuhl)** a substance that has been made pure; not mixed with any other substances.

chemist *(n.)* **(KEM-ist)** **(1)** a person who studies the way substances change and react with each other; **(2)** another name for a person who works with medicines (usually called a pharmacist).

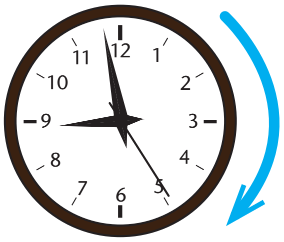
circuit *(n.)* a path of **conductors*** that goes from one end of a cell to the other end. A closed circuit has no breaks, but an open circuit has a break in it, which prevents the charges flowing anywhere in the circuit.

circulate *(n.)* to move round and round a circuit or path.

classify *(v.)* to decide on a rule for putting things into groups. This is like making groups. This is like **sorting*** things.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 389 2016/01/05 3:21 PM

clockwise and **anti-clockwise** *(adj.)* movements related to how an analogue clock's hands move.



communicate *(v.)* to give and receive information.

compare *(v.)* to **observe*** two things and notice what is the same and what is different.

component *(n.)* a part or piece or section.

compound *(n.)* **(1)** a pure substance that is made up from **elements***. The elements have **reacted*** to form the compound. **(2)** a place where people live together. **(3)** a paste for polishing things.

compressed *(adj.)* **(kom-PREST)** pressed together, squeezed into a smaller volume.

compression *(n.)* **(kom-PRESH-en)** in mechanics, **compression** is the application of balanced inward forces to different points on a material or structure. This reduces its size in one or more directions. It is contrasted with **tension*** which is the application of balanced outward forces. *See* **compressed***.

conductor *(n.)* **(kon-DUK-tr)** a substance that will let electric current flow along it. A good conductor of heat will let heat spread through it.

constant *(adj. or n.)* **(KON-stint)** staying the same, unchanging.

contact forces *(n.)* forces that operate on surfaces that touch. Friction is a contact force. The contact may go on, or just work for a moment.

convention *(n.)* **(kon-VEN-shun)** a **convention*** is an agreement between people. For example, we agree that the word kilogram can be shortened to "kg", and the symbol for gold is "au".

conserved *(v.)* stay the same, nothing is lost.

conservation of charge *(n.)* the principle that the nett charge in an isolated system is constant during any physical process. In other words, the total overall charge in a system stays the same even if the parts of the system give charges to each other.

conservation of energy *(n.)* the principle that energy is not destroyed, it just passes from one object to another, becoming more spread out and less useful.

contract *(v.)* **(kon-TRAKT)** **(1)** to get smaller, as when a substance cools it contracts. **(2)** to tense and pull, as when a muscle contracts. **(3)** to sign an agreement to do something, as when a builder contracts to finish a house by a certain date.

contract *(n.)* **(KON-trakt)** an agreement, deal made between people.

co-ordinates *(n.)* **(KOU-OR-di-nayts)** two numbers or letters which tell you a position on a map or on a graph.

cross-section *(n.)* **(KROS-sek-shun)** a diagram of something that shows what it looks like inside. The diagram shows what the thing would look like inside if you cut across it. Here, the word "section" means "cut".

crystal *(n.)* a solid which forms from a liquid. For example, crystals of table salt form from a solution of salt in water. Molten zinc forms crystals on zinc-coated iron. Molten rock forms crystals as it cools. You can see the crystals in the granite rock which is used for gravestones.

current *(n.)* a stream of electric charges **flowing*** around a **circuit***. (To be accurate, we should not say "there is current flowing round the circuit" but instead say "there are charges flowing round the circuit". However, most people talk about current flowing and their meaning is still clear enough.)

D

data *(n.)* information, facts, figures, numbers. The results you get in your experiment is your **data** which you analyse.

deceleration *(n.)* **(DEE-sel-er-EY-shun)** slow down. The words, 'acceleration' and 'deceleration' are understood in everyday language, but in science we use the word **negative acceleration** instead of deceleration.

decrease *(v.)* to become less; the opposite of **increase***.

decimal *(adj.)* based on the number ten; our number system is based on this.

decompose *(v.)* **(DEE-kum-powz)** to break down into the parts which make up something. A compound like mercuric oxide decomposes into oxygen and mercury when you heat it. A dead animal or plant decomposes into the substances which made it up when it was alive.

density *(n.)* **(DEN-sit-ee)** the heaviness-for-size of a substance. A small piece of iron may be lighter than a big piece of wood, but the density of the iron is greater than the wood.

depends on *(v.)* to need something else in order to carry or to survive. For example, passing Grade 10 depends on getting good enough marks on your projects and exams.

derived *(adj.)* **(duh-RAIV-d)** it comes from something else. Derived units come from basic units.

describe *(v.)* to tell the important things that you observed; to tell what happened.

designer *(n.)* **(dee-SIY-nuhz)** a person who makes designs, especially one who creates forms, structures, and patterns, as for works of art or machines.

diagram *(n.)* a picture that shows information. Diagrams show only the parts of a thing you need to learn about, and diagrams have writing on those parts.

diameter *(n.)* the width or distance across. We use "diameter" to refer to the distance across a circle, for example.

diffuse *(v.)* **(dee-FEWZ)** to spread out; one substance spreads out in another substance without anyone blowing or stirring the substances.

displacement *(n.)* **(dis-PLEYS-muhnt)** is the length of the shortest line between two points in a particular direction: it always involves both a distance and a direction.

domain *(n.)* **(doh-MEYN)** **(1)** a field of action, thought, influence, etc., for example, the domain of politics. **(2)** the set of values assigned to the independent variables of a function. The set of values for the dependent variables is called the "range".

ductile *(adj.)* **(DUHK-tiyl)** a **ductile** metal can be stretched out into a thin wire; you could not do this with a cylinder of concrete, because concrete is not ductile; copper and low-carbon steel are **ductile** materials from which wire is made.

E

efficient *(adj.)* **(ee-FISH-ent)** the ability to do something without wasting energy.

electrically neutral *(adj.)* **(NEW-tril)** In any piece of material the number of electrons is equal to the number of protons: this is true most of the time. So the **positive** charges **balance** the **negative** charges. We say that the material is **electrically neutral**. But when two solids touch or rub together, electrons near the surface of one solid can be pulled off and onto the **surface*** of the other solid.

electrode *(n.)* **(eh-LEK-trowd)** the electrical conducting part at the end of a wire. We put electrodes into solutions and the doctor may put electrodes on your skin to observe your heartbeat.

electrolysis *(n.)* **(eh-lek-TROL-i-sis)** breaking up a compound by using an electric current.

electrolyte *(n.)* **(eh-LEK-trow-liyt)** a solution that will conduct an electric current.

electrons *(n.)* **(eh-LEK-tronz)** the small parts of every atom which move around the nucleus. Electrons can drift along from atom to atom in some substances, and we call these substances conductors. Electrons can leave one atom and move around the nucleus of another atom; when this happens the electrons have made a bond between the atoms.

element *(n.)* **(1)** a pure substance that will not break up into other substances. There are only about 104 such substances on Earth. **(2)** a resistance wire in an electrical apparatus that becomes hot when electricity moves through it. A kettle, a heater or a soldering iron have heating elements. (There are still more meanings to this word; look in a dictionary.)

energy *(n.)* **(EN-eh-jee)** the ability of something to cause changes in other things. The changes may be that the other things become hot, or move faster, or move to a new position.

energy transfer *(n.)* **(EN-eh-jee TRANS-fuh)** passing energy from one part of a system to another part.

equilibrant *(n.)* **(EK-wee-lee-brint)** The equilibrant is the force that has the same **magnitude*** as the **resultant*** but it acts in the opposite direction.

equilibrium*(n.)* **(eh-kwi-LIB-rium)** an object is in **equilibrium** when the resultant force acting on it is zero. We call it **equilibrium** because all the forces acting on the object are in balance.

equipment *(n.)* **(ee-KWIP-mint)** apparatus or tools or machinery.

estimate *(v.)* **(EST-ee-meyt)** to guess the amount of something as accurately as you can.

exert *(v.)* **(ig-ZUHT)** **(1)** If you exert a force on something, it means you cause something to feel a force. **(2)** you exert yourself when you exercise hard.

exist *(v.)* to be, to be here on Earth, to be real.

expand *(v.)* to grow bigger, to increase in size.

experimental error *(n.)* when you do an experiment, because the equipment and the conditions are not perfect, and because the person doing the experiment might not be careful enough, experimental errors creep in. So experimenters, such as you, have to develop a judgement about what is acceptable error and what is not.

explain *(v.)* to give reasons why something happened. This is different to **describing*** what happened because you give reasons. When you describe you only tell what happened or say what something is like.

exponent *(n.)* **(iks-POH-nent)** the **exponent** of a number says **how many times** to use the number in a multiplication. $8^2 = 8 \times 8 = 64$. In words: 8^2 could be called “8 to the power 2” or “8 to the second power”, or simply “8 squared”. The 8 is the base and the ^{2} is the index.

extract *(v.)* **(eks-TRAKT)** to remove something. A dentist might extract a tooth. A chemist might extract copper from copper ore.

extruded *(v.)* **(eks-TRUH-did)** **(1)** to force or press out **(2)** to form (metal, plastic, etc.) with a wanted cross section by forcing it through a die.

F

factor *(n.)* **(1)** a factor can change the way something happens. Example: rainfall is a factor when farmers choose what kind of crop to plant. The resistance of a wire is a factor which limits the amount of current that passes through the wire. **(2)** in maths, a factor is a number that you multiply with another number.

familiarise *(v.)* **(fuh-MIL-yuh-rahyz)** to make sure you understand well, and can do something efficiently.

fair test *(n.)* a test of an idea or prediction, in which you make sure that the idea has equal chances of being proved wrong or being proved right. The fair test can also be a comparison of two things, and it is fair because the two things are tested under the same conditions.

fascinated *(adj.)* to cause someone to be very interested in something; to hold all their attention.

fibres *(n.)* **(FAYH-birs)** the string-like parts that make up asbestos, clothing, muscles, rope.

field – *See* **magnetic force-field**.

flex *(v.)* the trunk of a tall tree **flexes*** in a high wind – it bends a bit without breaking.

flexible *(adj.)* **(FLEKS-i-bil)** able to bend without breaking. We also say people are flexible if they can fit in with other people’s arrangements.

flow *(n.)* the movement of things in one direction.

flow *(v.)* to move together in the same direction.

fluid *(n.)* a substance that can flow. Fluid usually means a liquid, but a gas is also a fluid because it can flow.

flux *(n.)* fluctuation or change.

focus question *(n.)* a question which helps you to focus on the lesson or experiment.

forces *(n.)* **(FAWS-iz)** a force is not something you can see or touch, but you can see and feel what it does. Forces are acting all around us. Things are hanging, falling, moving, all as the result of forces. A force can change the motion of an object, make it go faster, slower, start it, stop it and hold it in one place. It can also change the direction of motion and the shape of an object. A force has magnitude and direction, so it is a vector quantity.

force diagram *(n.)* *See* **free body diagram** *below.*

foil *(n.)* very thin metal sheet, for example aluminium foil.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 392 2016/01/05 3:21 PM

free body diagram *(n.)* this is a rough working drawing, used by engineers and physicists to analyse the forces and moments acting on a body. There are four steps. **(1)** Draw a basic version of the object, perhaps just a shape. **(2)** draw the force vectors with arrows. **(3)** draw the arrows from the centre of the body. **(4)** label the forces. These diagrams also help you to understand the forces better.

frictional force *(n.)* if two surfaces are touching and one of them moves, friction is created.

fulcrum *(n.)* **(FOOL-krum)** the support or point of rest on which a lever turns in moving a body.

function *(n.)* **(funk-SHIN)** the work that a thing does. For example, the function of a switch is to open and close a circuit.

fundamental *(adj.)* **(fundah-MEN-til)** basic. A set of **fundamental units** is a set of units for physical quantities from which every other unit can be worked out. In the International System of Units (SI), there are seven fundamental units: kilogram, metre, candela, second, ampere, kelvin, and mole.

fuse *(n.)* a thin wire that will melt if a large current flows through it.

fuse *(v.)* this is a word used in everyday English which means "to melt together".

G, H, I

gauge *(v.)* to mark or measure off, to work out the exact dimensions.

gauge marks *(n.)* **(GEHJ)** marked off in precise or exact quantities.

graphical method *(n.)* in maths we would use pie-charts, and bar and line graphs; in science we also use things like free body diagrams.

graphical representation *(n.)* We use these in order to get better insight and understanding of the problem we are studying – pictures can convey an overall message much better than a list of numbers.

gravitational potential energy *(n.)* because an object has weight, it takes energy to lift it up. As an object is lifted up from one level above the earth, to a higher level, it gains energy. The energy that is used to lift it up is transferred to the object and is stored in the object. The energy is the result of the **gravitational** attraction of the Earth for the object. The word "**potential**" shows that the energy has been stored and can be used later to do work. Gravitational potential energy can be stored and used later to do work.

gravity *(n.)* in everyday terms we talk about gravity as the force that causes objects to fall onto the ground. This is a force that all bodies exert on all other bodies because of their masses. This is true of the whole universe. The sun attracts the Earth and the earth attracts the sun; and even inside an atom, particles attract other particles.

hypothesis *(n.)* is a good guess about a situation, with reasons.

hypothesise *(v.)* to think of a reason why something happens.

identical *(adj.)* exactly the same.

identify *(v.)* to find out what a thing is, or what its name is.

ignore *(v.)* to take no notice of something.

indicator *(n.)* **(IN-dee-KAY-tuh)** a substance which reacts with an acid or an alkali, and changes colour.

IEEE stands for Institute of Electrical and Electronics Engineers and **IEC** stands for International Electro-technical Commission.

increase *(v.)* to become greater

increase *(n.)* a change which makes something bigger than before.

induce *(v.)* means that an electric charge can create another electric charge on an object without touching the object.

infer *(v.)* **(in-FUR)** to think about an **observation*** and decide what this means.

inference *(n.)* **(IN-fuh-rens)** a conclusion you make after thinking about the observation; make an inference *(v.)* means the same as to **infer**.

insulate *(v.)* **(IN-syu-late)** to prevent heat or electric current from passing from one place to another, to cover a conductor with an insulator.

insulation *(n.)* **(IN-su-LEY-shun)** the plastic covering on wire – means the same as **insulator** *(n.)* another name for a non-conductor.

interpret *(v.)* **(in-TUHR-pret)** to say what something means, to make it clearer by telling the information in another way, or to show how it applies.

investigate *(v.)* to design and carry out tests to find out how a system works, or what the truth of a matter is.

J, K, L

jam-tin *(n.)* or tin-can are words we use for containers made of steel, coated with a thin layer of tin.

joule *(n.)* **(JOOL)** the standard unit of energy and work, in electronics and general scientific uses. One joule is defined as the amount of energy exerted when a force of one newton is applied over a displacement of one meter. It is named after the English physicist James Prescott Joule (1818–1889).

kinetic *(adj.)* **(ki-NET-ik)** this word comes from the Greek word *kinesis* which means motion or movement.

kinetic energy *(n.)* is the energy of motion. An object that has motion has energy. It has **kinetic*** energy.

lead *(n.)* **(LEED)** a wire that conducts current in a circuit.

lead *(v.)* **(LEED)** to go in front, or to show the way.

lead metal *(n.)* **(LED, not leed)** lead is a soft metal that is very dense.

like charges *(n.)* can mean negative and negative charges, or it can mean positive and positive charges. They are the same, in either case.

limit *(n.)* the boundary or border or edge of something.

load *(n.)* a weight that is being carried, for example, a bakkie that is carrying a load of bricks. In engineering, a load refers to any force that is **exerted*** on an object, such as weight. This is important for working out the forces the structure can cope with when it is being used. Dead loads are weights of material, equipment or parts that are going to stay when the structure is complete, for example walls, floors, roofs and stairways. Dead loads are permanent. Live loads are loads or forces that the structure will have on it, for example, the pressure of feet on a stairway.

locate *(v.)* **(low-KEYT)** to find the place of something.

longitudinal movement *(n.)* **(long-ge-TYUU-di-nil)** movement running along the length of a beam, rather than across the beam.

M, N

macro-scale *(adj.)* large scale; thinking of a whole system together.

magnetic force *(n.)* a pull or push from a magnet on other magnets or magnetic substances.

malleable *(adj.)* **(MAL-ee-uh-buhl)** something that can be shaped by pressure like a hammer or roller.

magnetic force-field *(n.)* the space around a magnet or a conductor where a piece of iron will feel a magnetic force.

magnify *(v.)* **(MAG-nuh-fahy)** to make something look bigger than it really is.

macroscopic *(adj.)* visible without using a **microscope***.

magnitude *(n.)* **(MAG-nuh-tyuud)** the size or amount of a measurement. It may be positive or negative.

mass *(n.)* the property of matter that gives it heaviness, or weight.

matter *(n.)* **(1)** any substance, which may be a liquid, a solid or a gas. Matter has **mass***, it takes up **volume*** and it is made of **particles*** **(2)** something which needs talking about, for example, "You look worried; what is the matter?"

maximum *(adj.)* the greatest size something reaches.

mechanical advantage *(n.)* mechanical advantage (MA) is the advantage you gain when you use a machine. Mechanical advantage is expressed as a number without a unit. It tells you how much the input force is multiplied when you use the machine.

mechanical energy *(n.)* the total energy possessed by an object because of its motion and its position. If you sum (add together) the energy of motion and the energy of position of an object, you gets its mechanical energy.

metal *(n.)* a substance that is **flexible***, shiny and will conduct heat and electricity.

metric *(adj.)* **(MET-rik)** The **metric system** is an internationally agreed **decimal*** system of measurement. Sometimes the word is used to refer to the SI system.

microscope *(n.)* **(MEY-kruh-skoyp)** (from *mikrós*, "small" and *skopeîn*, "to look" or "see") is an instrument used to see objects that are too small for the naked eye.

microscopic *(adj.)* **(MI-kruh-SKOH-pik)** too small to see with the naked eye so you will need a microscope to see it. We also use it in everyday language to mean very, very small.

mineral *(n.)* a solid substance which you can find in nature and which has a definite **crystal*** structure and is made of a certain set of elements. For example, malachite is a mineral which you can find all over the world; its crystal structure and the elements in it give it a green colour, and it is always made up of copper, carbon, oxygen and hydrogen.

model *(n.)* **(1)** an object which **represents*** the real thing. For example, a model aeroplane. **(2)** an idea or a way to understand something you cannot see e.g. the particle **model** of matter. **(3)** a person who shows off new clothes in order to sell them.

moist *(adj.)* with a little water in it; not dry.

mole *(n.)* **(1)** the mole is the basic SI unit of amount of substance. A mole of atoms is $6{,}022 \times 10^{23}$ atoms. If you have the same number of grams of a substance as its relative atomic mass in the periodic table, then you have a mole of the substance. For example, 12 grams of carbon-12 is one mole of carbon-12. **(2)** a small darker-coloured growth on a person's skin. **(3)** an animal the size of a large mouse or rat that lives underground.

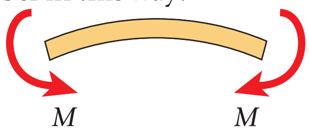
molecule *(n.)* two or more atoms bonded together.

molten *(adj.)* melted, usually runny, for example, molten rock flows from a volcano after it has erupted.

moments *(n.)* **(1)** if a force is applied to an object which is attached to a **fulcrum***, the force will try to rotate (turn) the object around the fulcrum. When this happens we say that the force has a turning effect about the fulcrum. The turning effect is called the **moment** of the **force*** or simply the **moment***. **(2)** in ordinary language, "this moment" means this exact time.

nanoscale *(n.)* "nano" means very, very small. A nanometer is 10^{-9} metres. That is one millionth of a millimetre. That is the kind of measurement we are talking about in nano-scale. It is the sort of measurement we use for atoms.

negative bending moment *(n.)* a moment that bends a member in this way:



Negative moment

negligible *(adj.)* **(NEG-li-GIB-el)** tiny, small, unimportant.

nett *(adj.)* the amount that remains when nothing more has to be added or taken away. **nett charge***. means the charge left over when you added the positive and negative charges together.

nitrate *(n.)* a salt of nitric acid; also a **fertiliser*** which farmers add to soil.

non-conductor *(n.)* a substance that is such a poor conductor that current will not flow along it. Electrons are held tightly in the atoms in the non-conducting substance. It is an **insulator***.

non-contact force *(n.)* forces that are not touching, that operate across a space. **Gravity*** is a non-contact force.

non-metal *(n.)* a substance which does not have the **properties*** of a **metal***. It is not **flexible*** and shiny and is not a good conductor. *See* **metal***.

normal force *(n.)* this is the support force **exerted*** upon an object that is in contact with another stable object. For example, if a book is resting on a table, then the table is exerting an upward force on the book in order to support the weight of the book.

nucleus *(n.)* **(NEW-klee-us)** the part at the centre of an atom. It is positively charged and it is very much smaller than the atom as a whole.

O

object of interest *(n.)* the thing we are thinking or talking about at this moment.

observation *(n.)* the things that you observed or watched, or a measurement you made and recorded.

observe *(v.)* to see, feel, smell, measure all that you think is important about something.

origin *(n.)* **(AW-ruh-gin)** where something started from.

P, Q

parallel connection *(n.)* means that two or more bulbs are connected in such a way that electric current has two or more paths to flow on, because some of the current goes through one bulb and some of the current goes through the other bulb. *Compare to* **series***.

particle *(n.)* **(1)** a very small part **(2)** a tiny piece of matter like a molecule, an atom or an electron.

pattern *(n.)* a regular form, order or arrangement. We see a pattern in the results of our experiment.

perimeter *(n.)* border, edge, outside; a path that surrounds a two-dimensional shape. The term may be used either for the path or its length – it can be thought of as the length of the outline of a shape.

perpendicular *(adj.)* **(puhr-pin-DIK-yuu-luh)** vertical, upright, at right angles to.

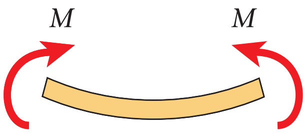
period *(n.)* time, cycle or interval.

phase *(n.)* **(FAIZ)** the form or state of a substance; it can be in the solid phase, the liquid phase or the gas phase.

point load *(n.)* a load that acts at a point on a beam. It is not spread out. If the beam is a plank across a ditch on a building side, then a man with a wheelbarrow of concrete is a point load on the plank.

position *(n.)* **(puh-ZISH-en)** its location or place in relation to the beginning point.

positive bending moment *(n.)* a moment that bends a member in this way:



Positive moment

positive *(adj.)* the kind of electrical charge that we find at the "+" terminal of a battery. Positive charges and negative charges attract each other, and so they move along conducting wires. In everyday language, we say that someone is positive if they look at the bright side of everything.

predict *(v.)* **(pre-DIKT)** to use your knowledge to say what is going to happen, and give reasons.

prevent *(v.)* to stop something from happening.

principle *(n.)* **(PRYN-suh-pil)** a law that explains why something happens.

process *(n.)* a step-by-step way of making progress. Example: going through school from primary to high school is a process.

product *(n.)* **(1)** something which is made. **(2)** the new substances which are formed during a chemical reaction.

property *(n.)* a feature of something which you can use to **identify*** that thing; e.g. properties of copper are hardness, colour, being able to conduct a current.

proportion *(n.)* the size of one part compared to the size of another part.

quantity *(n.)* **(KWAN-ti-tee)** the amount or number of something.

R

radiate *(v.)* to send out or spread from a central place.

radiation *(n.)* **(ray-dee-EY-shin)** **(1)** a method of transferring energy from one place to another place, using the vibrations of electric and magnetic force-fields. The Sun's energy reaches us by radiation, and microwave ovens heat water by radiation. **(2)** the atoms of some "radioactive" elements send out radiation in the form of particles and high-energy waves. This radiation can cause cancers.

range *(n.)* the range is the difference between the lowest value and the highest value. You have to choose the correct **range*** on the multimeter for the **quantity*** you want to measure.

rapid *(adj.)* quick.

rapidly *(adv.)* quickly.

rate *(n.)* the change in a physical quantity per unit time; in everyday language, frequency or how fast something is going or changing. For example, the rate of crime rose by 25% last year.

react *(v.)* **(ree-AKT)** **(1)** in chemistry: two substances react with each other when they each change and together form another substance. A compound can react to heating by **decomposing*** into other substances. **(2)** in human biology: your eye reacts to a change in the light or you react to seeing a falling object by catching it. **(3)** a change which results from another change. For example, a thermometer reacts to a change in temperature.

reaction forces *(n.)* **forces*** that are acting in opposite directions; for example, when something is exerting **force** on the ground, the ground will push back with equal **force** in the opposite direction. We call that reaction force, normal force.

record *(v.)* to make notes or in some other way to capture an event that happened. For example, tape recordings or photographs are also a means of **recording** what happened or what you saw.

refer *(v.)* to look in another place for information; to ask someone else what they think. We refer to a dictionary when we don't know what a word means.

relationship *(n.)* the way one thing depends on another thing; e.g. there is a relationship between bees and plants, because the plants depend on the bees to pollinate the flowers.

relationship, stating a relationship *(v.)* to write the way one thing changes when another thing changes. We often use words like this to state a relationship: "the greater the resistance becomes, the smaller the current becomes" or "the hotter A becomes, the bigger B becomes"

represent *(v.)* to stand for something; e.g. a bulb symbol stands for a real bulb; a model volcano stands for a real volcano.

repulsion *(n.)* **(ree-PUHL-shun)** the force that acts between bodies of like electric charge or like magnetic polarity, which tend to separate them. It is the opposite of **attraction***.

resist *(v.)* to make it difficult for something to pass.

resistor *(n.)* **(ruh-ZIS-tuh)** a substance that is not a very good conductor; e.g. nichrome. Resistors make the current smaller, and the resistors in a circuit take the energy of the current.

respond *(v.)* to **react*** to something; to act in answer to something that happens.

resultant *(n.)* the single force that can produce the same effect as two or more forces; like the sum of two forces, but taking into account their magnitude.

rotational motion *(n.)* movement of turning; the Earth rotates around the Sun.

S

salt *(n.)* a compound that is produced when an acid has reacted with a metal or a metal compound. For example, copper sulphate $CuSO_4$ is a salt.

scientific notation *(n.)* this is the way that scientists easily handle very large numbers or very small numbers. For example, instead of writing 0,000 000 043, we write $4{,}3 \times 10^{-8}$.

series, in series *(adj.)* a number of things which follow each other; connected so that all the current must go through each part; the path for current has no branching paths, there is only one path for the current. But *compare* **parallel***.

shear force *(n.)* when forces on opposite sides of an object act in opposite directions, that object will tend to deform, and might even fail. The object deforms or warps. Forces that act in this manner are called **shearing** or **shear forces**. A pair of tinsnips cuts a sheet of metal with a shearing action. A paper punch also has a shearing action.

short-circuit *(n.)* a conducting path that by-passes **resistors*** and lets the current become very big.

short-circuit *(v.)* to make a path like this *(see above)*.

shrink *(v.)* to become smaller.

signal *(n.)* some change which has meaning for you, such as a flash of light or the sound of the starting gun in a race.

similar *(adj.)* almost the same.

simple machines *(n.)* Things that give **mechanical advantage***. Simple machines are useful because they can make a physical job easier by changing the magnitude or direction of the force needed to do the work.

simply supported beam *(n.)* this is a beam supported at the ends in such a way that the supports allow the beam to bend, deflect or flex when it is loaded.

solder *(n.)* **(SOHL-duh)** a metal that melts easily and then becomes a solid again. Solder is like a conducting glue for joining conductors.

soluble *(adj.)* able to dissolve.

solute *(n.)* the substance which dissolves.

solution *(n.)* **(1)** an even mixture of substances, such as salt in water; "even" means the salt has spread out evenly everywhere in the water. **(2)** the answer to a maths problem. **(3)** the best thing to do in a difficult situation.

solvent *(n.)* the liquid which dissolves a substance; e.g. alcohol is a solvent for grease, water is a solvent for sugar.

sort *(v.)* to put things into groups, using some rule that says which things belong together.

specimen *(n.)* **(SPESSI-min)** a sample, a small piece of the material that is like all the rest of the material.

speed *(n.)* how fast something is travelling; worked out by taking the distance covered over a particular time, for example, 70 kilometres per hour.

spring balance *(n.)* a spring balance is a device used to measure weight or force.

standard notation *(n.)* the way in which we usually write numbers; e.g. 473. The opposite of expanded notation (400 + 70 + 3). *See also* **scientific notation***.

static electricity *(n.)* is made when certain materials are rubbed together. Tiny electric charges gather on the surfaces because of the rubbing: we say the surfaces become **electrostatically charged***.

steel *(n.)* iron which contains a small amount of carbon and is therefore harder than pure iron.

structure *(n.)* a thing that is made up from many parts that fit together. Example: a house is a structure.

substance *(n.)* any kind of solid or liquid or gas. "Substance" and "matter" mean almost the same.

substitute *(n.)* something used in place of something else.

substitute *(v.)* to use in place of something else.

successive *(adj.)* following, one straight after the other, without a break.

symbol *(n.)* a letter we use for a word. For example, m is used for "metre".

summarise *(v.)* to give a short statement about something. We can summarise a book in a paragraph.

surface *(n.)* **(SUH-fis)** means the outside area of something, not deep inside.

survey *(v.)* to collect information from many people or from many observations.

system *(n.)* This word has 3 meanings. **(1)** a mechanical system is a number of objects which are connected so that they exert forces on each other. A bow and an arrow are a mechanical system. An electric circuit is another one. **(2)** a system in your body is the organs that work together; e.g. your breathing system; also an ecosystem. **(3)** a method for doing things;
e.g. the examination system.

T

technology *(n.)* the knowledge of how to find out what people need or want and provide solutions to problems. The solutions may be better equipment, better methods or better ways of organising activities.

tension *(n.)* **(TEN-shin)** the tension force is the force that is spread through a string, rope, cable or wire when it is pulled tight by forces acting from opposite ends. In everyday language we can say it is a stretching force. Related to the adjective **tensile**, stretchy. We use the tensile strength test to show how a material will change when tension force is **exerted*** on it.

test specimen *(n.)* a part that you take out of a whole, but which still keeps all the properties of the whole.

terminal *(n.)* This word has three meanings. **(1)** the ends of a battery. In a cell, the terminals are the ends where you connect wires. **(2)** a train station or bus station **(3)** *(adj.)* deadly, fatal.

torque *(n.)* **(TAWK)** a force produces a **moment*** which produces a rotation. **Torque** is a measure of how much a force acting on an object causes that object to rotate or turn round.

torsion *(n.)* **(TAW-shun)** a twisting effect in an object. An object "feels" torsion when one end of the object is held firmly while the other end is turned. Torsion is not a **force***, it is the effect of a turning action.

track *(n.)* a line or path showing how something moves, or a path that you move along, like an athletics track.

TechSci_G10-LB-Eng-DBE3_9781431522842.indb 398 2016/01/05 3:21 PM

track *(v.)* to follow the course of movement of someone or something.

transmitted *(v.)* passed along to; spread, or conducted or transferred. A radio transmits radio waves, which we hear as music or speech.

transfer *(v.)* to give something away, to pass a thing to another place or person. Energy is transferred from one part of a system to another part.

translational motion *(n.)* when an object moves permanently from one place to another; when an object is displaced. We often think of it as the opposite of **vibrational motion***.

theory *(n.)* an idea about how something happens. Scientists like theories that they can test with experiments.

thermostat *(n.)* a system which **reacts*** to temperature changes by switching a current on or off.

trace *(v.)* to follow the lines or marks.

transmit *(v.)* to send out; a radio transmits radio signals, which we hear as programmes.

U

unit *(n.)* an amount that people have agreed to use for measuring something; e.g. people have agreed to measure petrol in the unit of the litre.

V

variables *(n.)* related to the verb **vary**, which means to change. Scientists use an experiment to search for **cause and effect** relationships in nature. In other words, they design an experiment so that changes to one item cause something else to vary in a predictable way.

These changing quantities are called **variables**. A variable is any factor, trait, or condition that can exist in differing amounts or types. An experiment usually has three kinds of variables: independent, dependent, and controlled.

For example, if you open a tap (the **independent** variable), the quantity of water flowing (**dependent** variable) changes in response – you observe that the water flow increases. The number of dependent variables in an experiment varies, but there is often more than one.

velocity *(n.)* **(vuh-LOSS-uh-tee)** to most people, speed is the same as velocity. Speed and velocity are related but they are not the same. In science, speed and velocity are different quantities. Speed is based on distance, but velocity is based on displacement. The word formula for velocity is: velocity times displacement.

vertical *(adj.)* straight up and down.

vibrate *(v.)* to move back and forth very quickly.

vibrational motion *(n.)* things wiggle. They do the "back and forth". They vibrate; they shake; they oscillate. All this is vibrational motion in nature.

voltage *(n.)* a way of telling how much energy electric charges have.

volume *(n.)* **(1)** the space which an object fills up; the three-dimensional space that an object occupies or takes up. **(2)** the part of a series of books; for example, an encyclopaedia may have 15 volumes.

W

watt *(n.)* the unit of power; that is the unit which measures how fast energy is being taken by an appliance. 1 watt means 1 joule of energy being taken every second. 1 kilowatt means 1 000 joules being taken every second. 1 **kilowatt-hour** means the amount of energy you take if your appliance takes 1 000 joules every second, **for one hour.** (A heater is an example of an appliance).

weight *(n.)* The weight of every object on earth depends on its **mass*** and **gravity***.

X, Y, Z

Zero height position *(n.)* To be able to decide the gravitational potential energy of an object, we must choose a zero height position. We usually take the ground surface as this.