

Technical Science

Grade 11

Learner's Book

This book was developed with the participation of the Department of Basic Education of South Africa
and funding by the Sasol Inzalo Foundation

Technical Science Grade 11 Learner's Book

This book was developed with the participation of the Department of Basic Education (DBE) of South Africa, Magic Moments Consulting & Services and ACP Project Management & Publishing Services; and funded as an ongoing project by Sasol Inzalo Foundation.

© 2017. Copyright in the work is vested in publisher. Copyright in the text remains with the contributors.

© Illustrations and design ACP Project Management and Publishing Services, 2017

First published in 2017

Contributors from Magic Moments Consulting & Services

Dr. Samuel Khoza, Dr. Kgadi Mathabathe, Mokhulu Matshika, Sandile Vilane

Contributors from the Department of basic Education

Jayanthi SK Maharaj, Morungwa Masemola, Mmaphaseka Stephen, Modiba Phosa, Mosala Leburu, Khiba Tshiu Stephen

Cover design by Sasol Inzalo Foundation

Cover image by Kim Stevens

Illustrations by Will Alves

Layout and typesetting by Damian Gibbs and Nazley Samsodien in ITC Stone Serif 9pt on 13.5pt

Editing, Proofreading and Project Management by ACP Project Management and Publishing Services

ISBN: 978-0-620-74313-6

Your freedom to legally copy this book

This work is published under a Creative Commons Attribution-Non Commercial 4.0 Unported License (CCBY-NC 4.0)

<http://creativecommons.org/licenses/by-nc/4.0/>

You are allowed to freely copy this book subject to the following criteria:

You can photocopy, print and distribute it as you like.

You may download it onto any electronic device, distribute it via email, and upload it to your website at no charge.

You may adapt the text and illustrations.

Attribution

When doing any of the above, you should provide clear acknowledgement of the license/copyright holders. This attribution should include the name(s) of the original book(s) and the publisher, as well as acknowledgement of SalF and the Department of Basic Education of South Africa. You should also provide the Creative Commons web address (<http://creativecommons.org/licenses/by-nc/4.0/>), which explains this type of license.

If you have made any changes to the material, you must indicate what changes you made. You may not in any way suggest that the licensor endorses you, or uses any of your materials or your changes to the material.

Restrictions

You may not make copies of this book in part or in full – in printed or electronic or audio or video or whatever form – for a profit seeking purpose.

Rights of other copyright holders

All reasonable efforts have been made to ensure that materials included are not already copyrighted to other entities, or in a small number of cases, to seek permission from and acknowledge copyright holders.

In some cases, this may not have been possible. The publishers welcome the opportunity to redress this with any unacknowledged copyright holders.

Contents

Chapter 1:	Mechanics	1
1.1	Introduction	2
1.1.1	Sign convention: The Cartesian plane	3
1.1.2	Sign convention: Compass directions	5
1.1.3	Sign convention: Bearing	5
1.1.4	Graphs and relationships between variables	7
1.2	The theorem of Pythagoras and perpendicular forces	11
1.3	Practical application of the Pythagoras' theorem	13
1.3.1	The 3-4-5 technique for squaring corners	13
1.3.2	Using Pythagoras' Theorem to determine immeasurable lengths	14
1.3.3	Further applications for using Pythagoras' Theorem	15
1.4	Resultant of collinear forces	16
1.5	Resultant of forces in 2-D	18
1.5.1	Head-to-tail method	18
1.5.2	Parallelogram of forces	20
1.6	Resolving vectors	25
1.7	Friction	28
1.7.1	Importance of friction	28
1.7.2	So what is friction?	29
1.7.3	Types of frictional forces	29
	Review exercises	34
	Chapter summary	36
Chapter 2:	Magnetism	39
2.1	Introduction	40
2.2	Magnet	41
2.2.1	Geographic North and South	41
2.2.2	Magnetic north and south	41
2.3	Magnets	42
2.3.1	What magnets are	42
2.3.2	A dipole magnet	42
2.3.3	Technological applications of magnetism	44
2.4	Magnetic domains	46

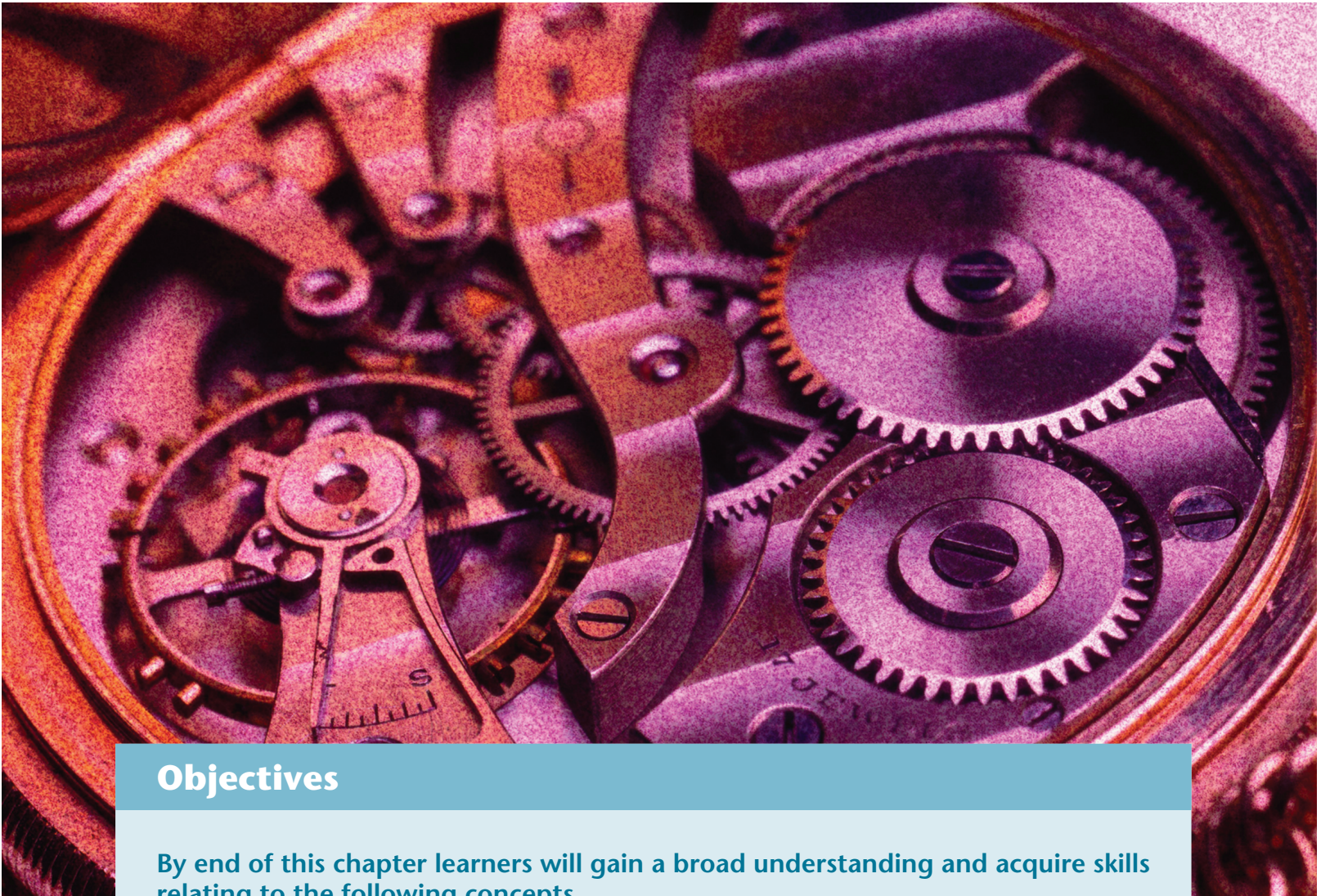
2.5	Inducing unmagnetised iron (Fe)	47
2.6	Magnetic field	48
2.7.1	Magnetic field between two bar magnets	48
2.7.2	Properties of magnetic field lines	51
2.7	Earth's magnetic field	52
2.7.1	Geographic North vs Magnetic North Pole	53
2.7.2	The importance of the magnetic field to life on Earth	53
2.7.3	Aurora borealis aurorae (pronounced or-roar-ee)	54
	Review exercises	56

Chapter 3:	Waves and sound	59
-------------------	------------------------	-----------

3.1	Introduction	60
3.2	Pulses	61
3.2.1	Transverse pulse	61
3.2.2	Longitudinal pulse	62
3.3	Waves	62
3.3.1	Medium	63
3.3.2	Transverse wave	63
3.3.3	Longitudinal wave	64
3.4	Wave terminology	66
3.4.1	Frequency and period	66
3.4.2	Difference between frequency and period	67
3.4.3	Wave velocity	68
3.5	Speed of sound in different media	70
3.6	Formal experiment: Determine the speed of sound in air	70
3.6.1	Speed of light versus speed of sound	71
3.7	Superposition of waves	77
3.8	Interference	77
3.8.1	What happens when waves come together?	77
3.8.2	Constructive interference	77
3.8.3	Destructive interference	78
3.9	Sound waves	80
3.9.1	Some applications of ultrasound and infrasound	81
3.9.2	Pitch and loudness	83
3.9.3	Pitch and loudness on oscilloscope	84
3.9.4	Echo	84
	Review exercises	85

Chapter 4:	Electricity	89
4.1	Electrostatics	90
4.1.1	Introduction	90
4.1.2	Coulomb's law	91
4.2	Electric field	95
4.2.1	Electric field lines	97
4.2.2	The electric field between two parallel plates	98
4.2.3	Applications of electrostatics in technology	100
4.3	Electric circuits	102
4.3.1	Introduction	102
4.3.2	Resistance	105
4.3.3	Ohm's law	105
4.3.4	Series and parallel network	110
4.4	Internal resistance and emf (electromotive force)	118
	Review exercises	121
Chapter 5:	Heat and thermodynamics	127
5.1	Introduction	128
5.1.1	Units for measuring heat	130
5.2	Specific heat capacity	131
5.3	Heat capacity	121
5.3.1	Practical applications of heat capacity in technology	133
5.4	Law of conservation of energy	135
5.4.1	Calorimetry	137
5.5	Thermodynamics	139
5.5.1	Thermodynamics system	140
5.5.2	Thermodynamic variables	140
5.5.3	Internal energy	140
5.5.4	Heat engine	144
5.6	Efficiency of a heat engine	145
5.7	Second law of thermodynamics	146
5.8	Refrigerators	146
5.8.1	Evaporative cooling	147
	Review exercises	148
	Chapter summary	149

Chapter 6:	Chemical change	151
6.1	Introduction	152
6.2	Using rules to assign oxidation numbers	153
6.2.1	Using oxidation number to identify redox reaction	154
6.2.2	Oxidation occurs when valence electrons are lost in a chemical reaction	156
6.2.3	Reduction occurs when valence electrons are gained in a chemical reaction	156
6.2.4	Oxidation and reduction are paired reactions	156
6.3	Application of redox reaction	158
6.4	Nonspontaneous reactions redox reactions occur in electrolytic cells	160
6.4.1	Electroplating	161
6.4.2	Electrolysis	162
	Chapter summary	163
	Selected answers	165



Objectives

By end of this chapter learners will gain a broad understanding and acquire skills relating to the following concepts

- sign convention
- drawing and interpreting graphs
- applying the Theorem of Pythagoras
- determining the resultant force in two dimension
- resolving forces into components.



Why the study of Mechanics matters

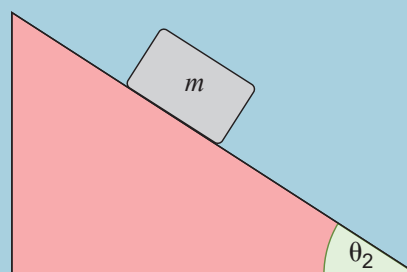
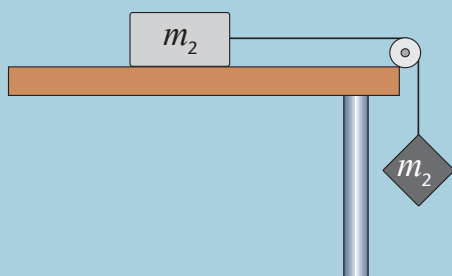
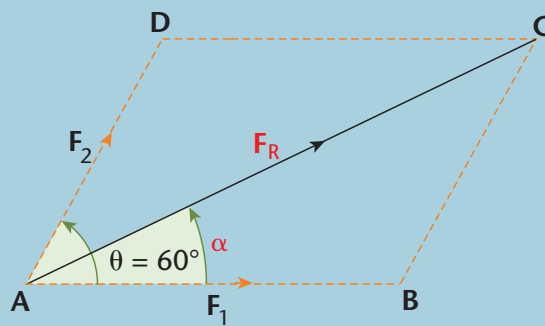
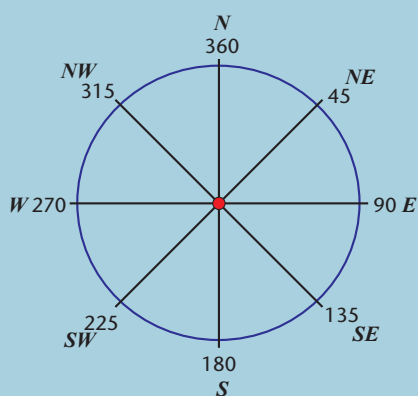
Mechanics is the study of the relationships between energy, motion and force.

Mechanics is a large field and its study is essential to the understanding of physics. It also gives us an understanding of 'how the universe works'.

There are many applications of Mechanics in our daily lives. Have you ever wondered why a car would skid across a wet road? To successfully answer that question, you will need to know about force and motion; and that is part of what we will learn about in this chapter.

Note:

Motion is the action of changing location or position. The study of motion without regard to the forces or energies that may be involved is called kinematics.



1.1 Introduction

In Grade 10 we learnt that physical quantities can be classified as either vector or scalar quantities.

A **scalar quantity** has magnitude only.

Speed is an example of a scalar quantity. For example, we can say that an object moves at 12 m.s^{-1} . This quantity only tells us about the magnitude (size) of the movement. It does not tell us about the direction in which the object is moving. In Physical Sciences, speed is a scalar quantity, or physical quantity with a magnitude only.

A **vector quantity** is a physical quantity that has both magnitude and direction and thus can be represented using an arrow-tipped line segment known as a vector, as shown in Figure 1.1 below.



Figure 1.1 A vector

If we had to, for example, say that a man is running at 10 m.s^{-1} in a westward direction, this would be classified as a vector quantity. 10 m.s^{-1} in a westward direction not only gives us the magnitude (size) of the movement, but it also gives us the direction.

The magnitude of a vector quantity is represented by the length of the line segment and the direction is shown by the arrowhead.

Note:

Vectors can sometimes act at an angle. For example, to specify directions, pilots and air traffic controllers use bearings. Bearing is an angle measured clockwise from the North pole of the compass. The concept of bearing will be discussed later in this chapter.

1.1.1 Sign convention: The Cartesian Plane

A Cartesian Plane is the set of two perpendicular axes (x - and y -axes), with the horizontal axis being the x -axis and the vertical axis being the y -axis. This is the very useful tool for graphical representation of vectors.

The point where the two axes intersect is called the origin and is indicated by the points $(0; 0)$ as shown in Figure 1.2. This is the point against which everything is measured.

Cartesian coordinates are numbers that indicate the location of a point relative to a fixed reference point (the origin), being its shortest (perpendicular) distance from two fixed axes (or three planes defined by three fixed axes) that intersect at right angles at the origin.

Cartesian coordinates are expressed as $(x; y)$, where x is the horizontal displacement from the origin (positive if to the right; negative if to the left), and y is the vertical displacement from the origin (positive if upwards; and negative if downwards). The x -coordinate is referred to as abscissa and the y -coordinate is called the ordinate.

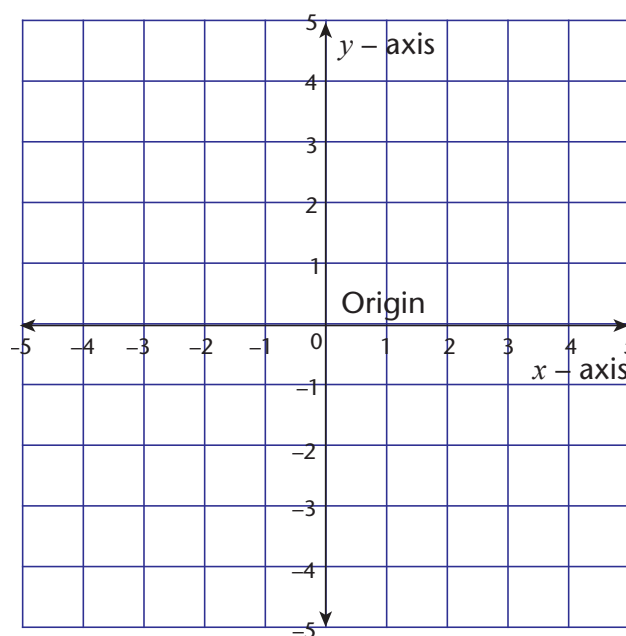


Figure 1.2 A Cartesian Plane

This is shown in Figure 1.3.

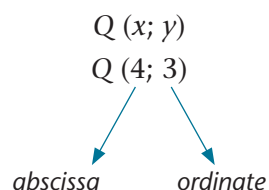
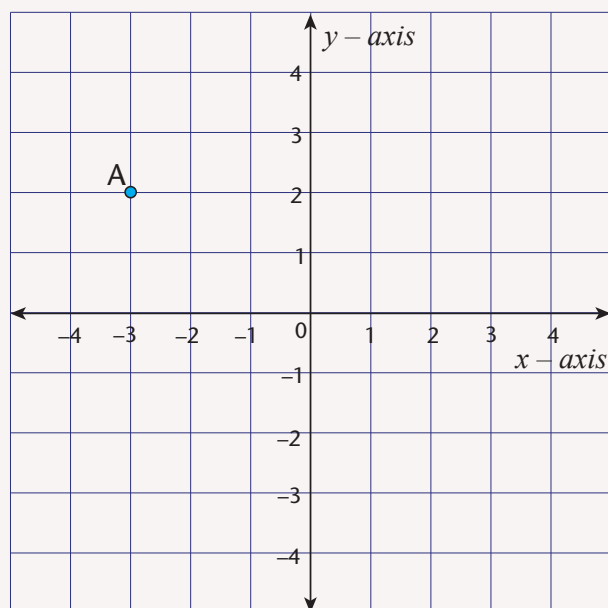


Figure 1.3 The Cartesian coordinates

Example 1.1 THE CARTESIAN PLANE

Consider the Cartesian Plane shown below:



- By how many units and in what direction has the point A been displaced along the x -axis?
- By how many units and in what direction has the point A been displaced along the y -axis?
- Write down the coordinates of point A.

SOLUTION

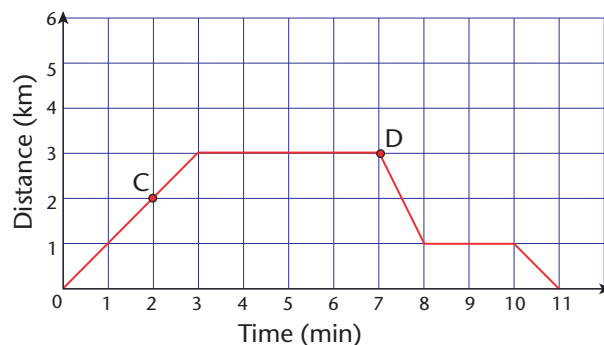
- Trace a line that goes vertically downwards (perpendicular) to the x -axis. Read the value where your line intersects with the x -axis. In this case the values of, which is a displacement of the point A along the x -axis is 3 units, and it is directed to the left of the origin.
This is a negative x direction
- If you trace a horizontal line from the point A that goes (perpendicular) to the y -axis, you will notice that the line intersects the y -axis at $y = 2$ units above the origin.
Mathematically, this is the positive y direction.
- The coordinates of A are: $A = (-3; 2)$.



Activity 1.1

- Thabiso decides to take his bicycle to go to the shop. He rides his bicycle from his home to the shop and back home. Thabiso then records the distance he travelled from home every minute and plots a graph of the results.

Refer to the graph alongside and answer the questions that follows:



- How far is the shop from Thabiso's home?
- How far was Thabiso away from home?
- How long was Thabiso in the shop? Motivate your answer by referring to the graph.
- How far from home was Thabiso after 3 minutes?
- How far from home was Thabiso after 10 minutes?
- Explain the meaning of the flatness of the graph between the 8th and 10th minute.
- Write down the coordinates of the points C and D.

Example 1.2

SIGN CONVENTIONS

COMPASS DIRECTIONS

The compass method is commonly used to determine the direction of a vector quantity.

A compass has four cardinal points, namely, North, South, East, and West. All other directions can be derived from these cardinal points.

If a vector does not point exactly in one of the cardinal points of a compass, we use an angle. For example, in Figure 1.3 below, the vector (the solid arrow), is pointing 70° North of West.

COMPASS DIRECTIONS

The direction of this vector can be described as: $W\ 70^\circ\ N$ (West 70° North); or $N\ 20^\circ\ W$ (North 20° West). To determine the direction accurately it is necessary to start with the vector pointing along the West direction, then to rotate the vector towards the North point of the compass.

BEARING

Depending on the context, bearing is used to refer to either the direction of motion; the direction of a distant object relative to the current course (or the 'change' in course needed to get to a distant object); or the degrees away from North of a distant point relative to the current point.

In navigation, absolute bearing refers to the angle between the magnetic North (magnetic bearing) or true North (true bearing) and an object. For example, an object that lies to the East has an absolute bearing of 90° . Relative bearing refers to the angle between the object's forward direction, and the location of another object. For example, an object's relative bearing of 0° would be dead ahead; an object's relative bearing of 180° would be behind.

Bearings are measured in degrees and are always written as a three-digit number, for example 275° or 080° (for 80°).

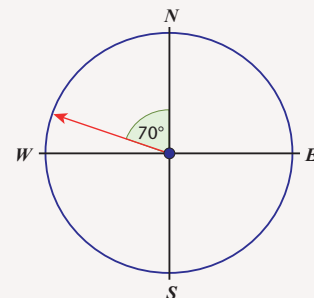


Figure 1.3 The graphical representation of a vector using a compass

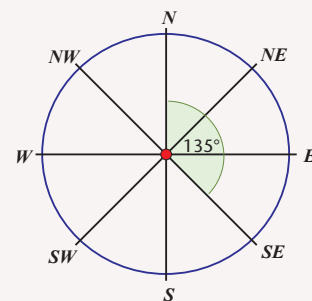


Figure 1.4 Bearing as a measure of vector direction

A bearing is a direction relative to a fixed point. Given just an angle, the convention is to define the angle clockwise with respect to North. So, a vector with a direction of 135° has been rotated clockwise 135° relative to North as shown in Figure 1.4.

MEASURING BEARING

Bearing is an angle measured clockwise from the North pole of the compass. For example, in the morning there was a strong Easterly wind, refer to Figure 1.5a, but later it swung around to N 147° S (North 147° South), refer to Figure 1.5b.

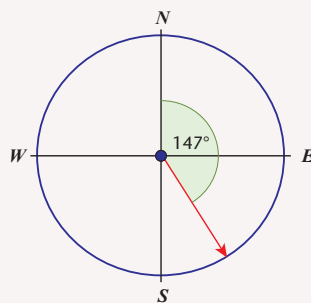
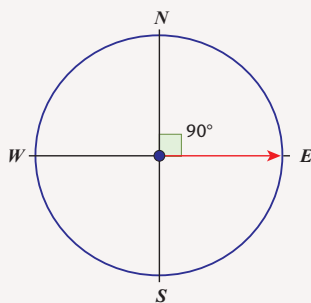


Figure 1.5a Compass direction Figure 1.5b Bearing

DRAWING VECTORS

Draw the following vectors:

- 20 km due North
- $15 \text{ m}\cdot\text{s}^{-1}$ 060°
- $120 \text{ km}\cdot\text{h}^{-1}$ 225°

1 ANALYSE

Given: Magnitudes and directions

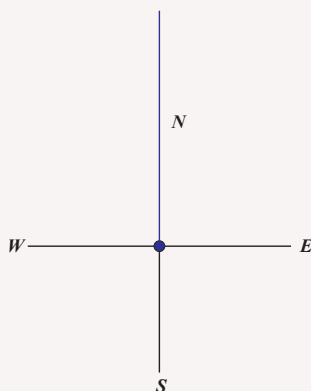
Unknown: Graphical representation of the given information

2 SOLVE

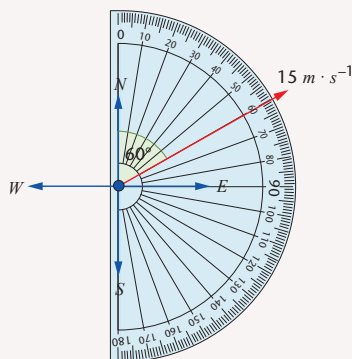
Most of these vectors cannot just be drawn without the use of a suitable conversion scale.

When choosing your scale, make sure that your representation of the vector will not be too too small or too big.

- Let $1 \text{ cm} : 20 \text{ km}$
20 km of due North

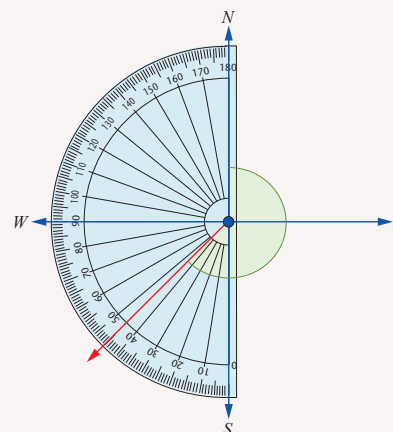


- Let $1 \text{ cm} : 3 \text{ m}\cdot\text{s}^{-1}$, so that $5 \text{ cm} : 15 \text{ m}\cdot\text{s}^{-1}$



c) Let $1 \text{ cm} : 24 \text{ km.h}^{-1}$, so that $5 \text{ cm} : 120 \text{ km.h}^{-1}$

Note: A bearing of 225° is more than 180° , which is a maximum angle a protractor can measure. Note that $225^\circ = 180^\circ + 45^\circ$, so rotate your protractor such that 0° points South, and then measure the 45° that will be added to 180° to make 225° .



Activity 1.2

- Define the following terms:
 - vector quantity
 - scalar quantity
 - bearing
- Draw the following vectors to scale:
 - $10 \text{ cm N } 45^\circ \text{ W}$
 - $25 \text{ m.s}^{-1} 22^\circ \text{ South of East}$
 - $100 \text{ km } 075^\circ$
 - $205 \text{ mm } 300^\circ$
 - $125 \text{ N } 080^\circ$

Example 1.3

GRAPHS AND RELATIONSHIPS BETWEEN VARIABLES

In mathematics we learned that a function (for example, a straight line) can be represented using a graph. Different graphs are used for different purposes. So, for example, when you are conducting an investigation that requires numerical data collection, a graph may be drawn to represent the information collected, and variables under investigation may show how they relate to each other.

Graphs can be plotted on a Cartesian plane using points. The location of a point on a Cartesian plane is found by indexing numerical values (coordinates) along numbered grid lines. This is shown in Figure 1.6 below.

So, to locate point Q (4; 3) on a Cartesian Plane, we need to position the point on the horizontal line at and a vertical line (intersecting the y-axis) at 3; and drawing the horizontal line (intersecting the y-axis) at 4. These are called the x-axis and y-axis respectively.

Point Q will be located at the intersection of the two lines.

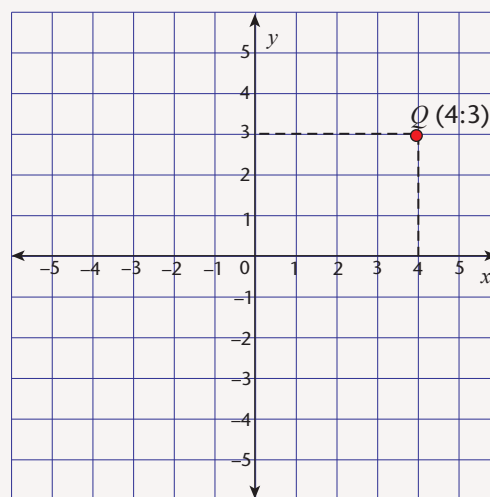


Figure 1.6 Plotting points on a Cartesian Plane

IDENTIFYING VARIABLES

When investigating how two variables relate to one another (under controlled conditions) we need to be able to identify the variables. Generally, there is a dependent variable, independent variable and a controlled (or constant) variable.

The independent variable is the one that is being manipulated and changed at constant intervals. It is plotted on the x -axis on a Cartesian plane.

The dependent variable responds to the manipulated variable. It is dependent on the changes made to the independent variable and is plotted on the y -axis of the Cartesian plane.

The controlled (or constant) variables are the ones that will be fixed and kept constant throughout the investigation in order to get unbiased (fair) results.

GRAPHS WITH A DIRECT RELATIONSHIP

Two variables are directly proportional if (and only if) they increase or decrease at the same rate. y is directly proportional to x , if (and only if) the ratio $y : x$ is constant.

Consider the table below:

x	y	$y : x$
1	1	1
2	2	1
3	3	1
4	4	1
5	5	1
6	6	1

Because the ratio $y : x$ is constant throughout, it can be concluded that y is directly proportional to x .

Plotting the graph of $y : x$ will give the graph shown in Figure 1.6.

The graph produced by variables that are directly proportional is a straight line graph. If the graph is extended so that it cuts the axes, it will pass through the origin. So, y is directly proportional to x , if:

- x and y increases by the same factor
- the graph of y versus x is a straight line passing through the origin.

Mathematically this is written as: $y \propto x$

Whenever you have a direct proportion as stated above you can change it into an equation by using a proportionality constant: $y = kx$

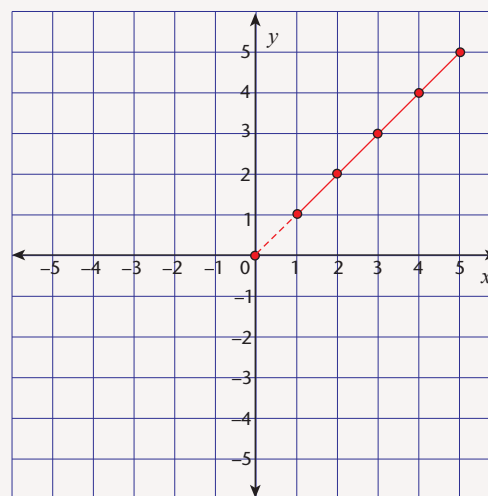


Figure 1.6 Plotting a graph to predict the relationship between variables that are directly proportional

k in this equation is a constant (sometimes referred to as the proportionality constant). In this case it is also the slope of the graph of y versus x . The general equation we derive from this relationship is shown by the equation: $\frac{y_1}{x_1} = \frac{y_2}{x_2}$

Thus, if we graph data for two related quantities, and that graph yields a straight line through the origin, we know that the two quantities are in direct proportion. A straight line graph has a constant gradient, and the general equation $y = mx + c$, where m is the gradient (or slope) of the graph. To calculate the gradient of the graph, we use the following formula: $m = \frac{\Delta y}{\Delta x}$, where c is the y -intercept of the graph.

INVERSE PROPORTIONALITY AND THE HYPERBOLA

Generally, y is said to be inversely proportional to x if x increases and y decreases. There has to be the pattern at which the two variables change: y must be decreasing by the same rate at which x is increasing, such that the product of x and y is constant.

Consider the table below:

x	y	xy
1	1	1
2	0.5	1
3	0.33	$0.99 \approx 1$
4	0.25	1
5	0.2	1

From the table we can see that the product, xy , is constant. Thus, y is inversely proportional to x .

When we plot the points on the Cartesian Plane, the graph shown in Figure 1.7 is produced. This type of a graph is called hyperbola, and it does not intersect with the axes.

It has a general equation $xy = k$, where k is a proportionality constant or even more general, $x_1 y_1 = x_2 y_2$:

This relationship between x and y is written mathematically as: $y \propto \frac{1}{x}$, which reads: y is inversely proportional to x .

In conclusion, we can say that two variables are inversely proportional if:

- the values of y must decrease by the same factor at which the values of x are increasing
- the graph of y versus x must be a hyperbola, that does not intersect with the axes.

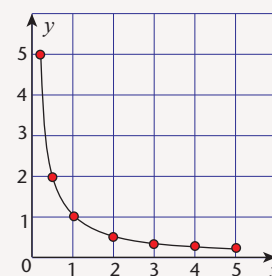


Figure 1.7 hyperbola graph

Example 1.3

DIRECT AND INVERSE PROPORTIONALITY

Find the general formula and draw graphs for the relationships described below:

- a is directly proportional to F , and the proportionality constant is 5
- the distance, D , travelled by an object is directly proportional to time, t , and the proportionality constant is 10
- V is inversely proportional to P , and the proportionality constant is 2
- F is inversely proportional to r^2 , and the proportionality constant is 6

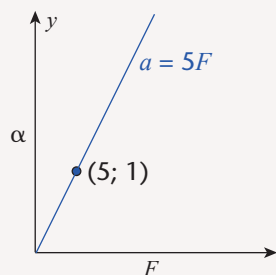
1 ANALYSE

For two variables directly proportional to one another, the general formula has the format $y = kx$ and the graph representing the relationship is a straight line passing through the origin.

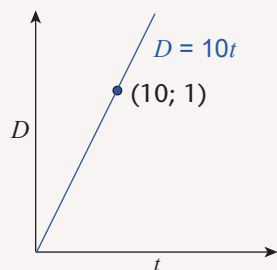
For two variables inversely proportional to one another, the general formula is $xy = k$, and the graph representing the relationship is a hyperbola.

2 SOLVE

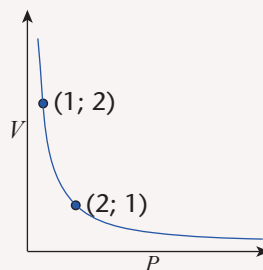
a) General formula: $a = 5F$



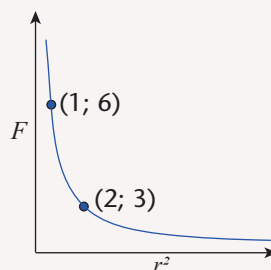
b) General formula: $D = 10t$



c) The general formula: $PV = 2$



d) Following the same reasoning as in c) we find that $Fr^2 = 6$



Activity 1.3

1. State the condition(s) required for two variables to be directly proportional to one another.
2. State the condition(s) required for two variables to be inversely proportional to one another.
3. The following information is supplied to prepare concrete with the required strength to build a house: every one bag of cement requires four full wheel barrows of sand.

a) Use the above information to complete this table:

Number of cement bags	Number of level-full wheel barrows with sand	Ratio Sand : Cement
1	4	4
2		
3		
4		
5		

- b) From the information in the table, identify the dependent and independent variable.
 - c) Use the information in the table to plot the graph.
Correctly label the axes and use a suitable scale.
 - d) From the graph and the information in the table, determine what the relationship between the number of cement bags and the number of wheel barrows filled with sand is.
 - e) Express the relationship between the variables as a mathematical equation.
4. Learners in a class were divided into groups and each group was asked to make a 24 cm^2 rectangular chart. Each group was given one dimension of the rectangle and had to find the other dimension, such that the area of their charts equaled 24 cm^2 .

Group Number	Length (cm)	Width (cm)	Area (cm^2)
A	1	24	24
B	2		24
C	3		24
D	4		24
E	5		24

- a) Complete the table:
- b) Use the information in your completed table to plot the graph, Width versus Length
- c) What is the relationship between the width and the length of rectangles with the same area?
- d) Use your results to two different mathematical equations that can be used to express the relationship between the length and the width for rectangles with a fixed area.
- e) If one group was given a length of 10 cm, use the equation obtained in d) to find the width they would have to use.

1.2 The theorem of Pythagoras and perpendicular forces

The theorem of Pythagoras states that the area of a square on the hypotenuse is equal to the sum of the squares on the other two sides. It is used to calculate the dimension of one side of the right-angled triangle if two sides are given.

Pythagoras' theorem can be represented graphically, as shown in Figure 1.8.

In a right-angled triangle, the longest side (the one opposite the interior angle of 90°) is called the hypotenuse. The side opposite the given angle is called the opposite and adjacent side, and are named relative to the given angle, as shown in Figure 1.8 below.

When two or more forces act on an object, their resultant force can be calculated. If these forces are perpendicular to one another, Pythagoras' Theorem becomes a very useful technique in finding their resultant force.

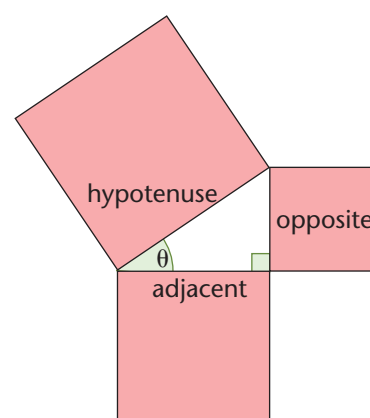


Figure 1.8 A graphical representation of Pythagoras' Theorem

Example 1.4**APPLICATION OF PYTHAGORAS' THEOREM**

Determine the magnitude of the resultant of two forces: $\vec{F}_1 = 3 \text{ N}$ to the right and $\vec{F}_2 = 4 \text{ N}$ up.

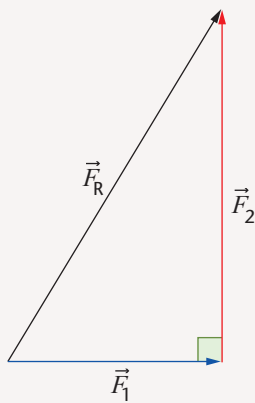
1 ANALYSE

Given: $\vec{F}_1$ and $\vec{F}_2$

Unknown: Resultant force $\vec{F}_R$

2 SOLVE

Start by representing the given information graphically and use Pythagoras' Theorem to determine the magnitude of $\vec{F}_R$.



$$F_R^2 = F_1^2 + F_2^2$$

$$F_R^2 = (3)^2 + (4)^2$$

$$F_R^2 = 25$$

$$\therefore F_R = 5$$

Example 1.5**APPLICATION OF PYTHAGORAS' THEOREM**

Calculate the magnitude and direction of the resultant force for the forces 4 N to the left and 4 N downwards:

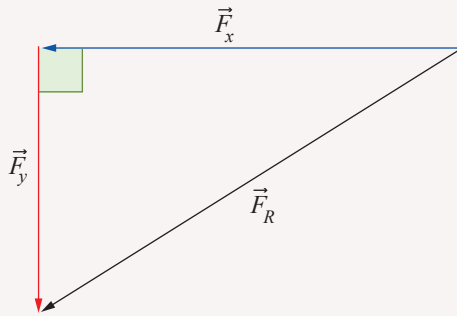
1 ANALYSE

Given: $\vec{F}_1$ and $\vec{F}_2$

Unknown: Resultant force $\vec{F}_R$

2 SOLVE

Start by representing the given information graphically and use Pythagoras' Theorem to determine the magnitude of $\vec{F}_R$.



The magnitude of the resultant force can be calculated using Pythagoras' Theorem:

$$F_R^2 = F_1^2 + F_2^2$$

$$F_R^2 = (-4)^2 + (-4)^2$$

$$F_R^2 = 32$$

$$\therefore F_R = 5,66$$

The direction of the resultant force can be found using the tan function:

$$\tan\theta = \frac{F_2}{F_1}$$

$$\tan\theta = \frac{4}{4} = 1$$

$$\theta = 45^\circ \text{ anticlockwise from the negative } x\text{-direction}$$

$$\vec{F}_R = 5,66 \text{ N at } 45^\circ \text{ anticlockwise from the negative } x\text{-direction}$$

1.3 Practical application of Pythagoras' Theorem

1.3.1 The 3-4-5 technique for squaring corners

One of the challenges in carpentry and construction is making sure that corners are 'square'. If they are not, any other fittings such as tiles, carpets and even roofing, will noticeably be 'off' from one side of the room to the other.

The 3-4-5 technique can be used to get an accurate 90° angle. It will also ensure that all parts of the construction fits together as planned, as shown in Figure 1.9 below.

This technique simply requires a builder to create a triangle using any suitable material such as wooden beams, that has sides that are 3 m, 4 m and 5 m long. Such a triangle will have a 90° angle opposite the 5 m side.



Figure 1.9 Using the 3-4-5 technique

Note: You can use any other measurement, but they need to be in the same proportion.

The beauty and simplicity of this technique is that if the builder needs to increase the accuracy on larger walls and structures, he can use any multiple of the 3-4-5 set of numbers, and it will still produce accurate results.



Activity 1.4

Use Pythagoras' Theorem to validate whether these sets of numbers will give you a right-angled triangle.

3-4-5	6-8-10	9-12-15	12-16-20	15-20-25
-------	--------	---------	----------	----------

The above practical application is only one example of how Pythagoras' Theorem can be used in real life situations. There are many other real life situations where using Pythagoras' Theorem can be quite useful. Here are a few examples:

1.3.2 Using Pythagoras' Theorem to determine 'immeasurable length'

'Immeasurable length' can be defined as the length that you cannot measure directly using a measuring device.

So, for example, how would you go about using Pythagoras' Theorem if you need to design and construct a zip line over a water pond as shown in the diagram below. A zip line is an aerial runway between two points of different heights.

First you will need measure the horizontal distance of the zip line and the maximum height at the start using a measuring tape. Then you can use Pythagoras' Theorem to determine the length of the zip line you need.

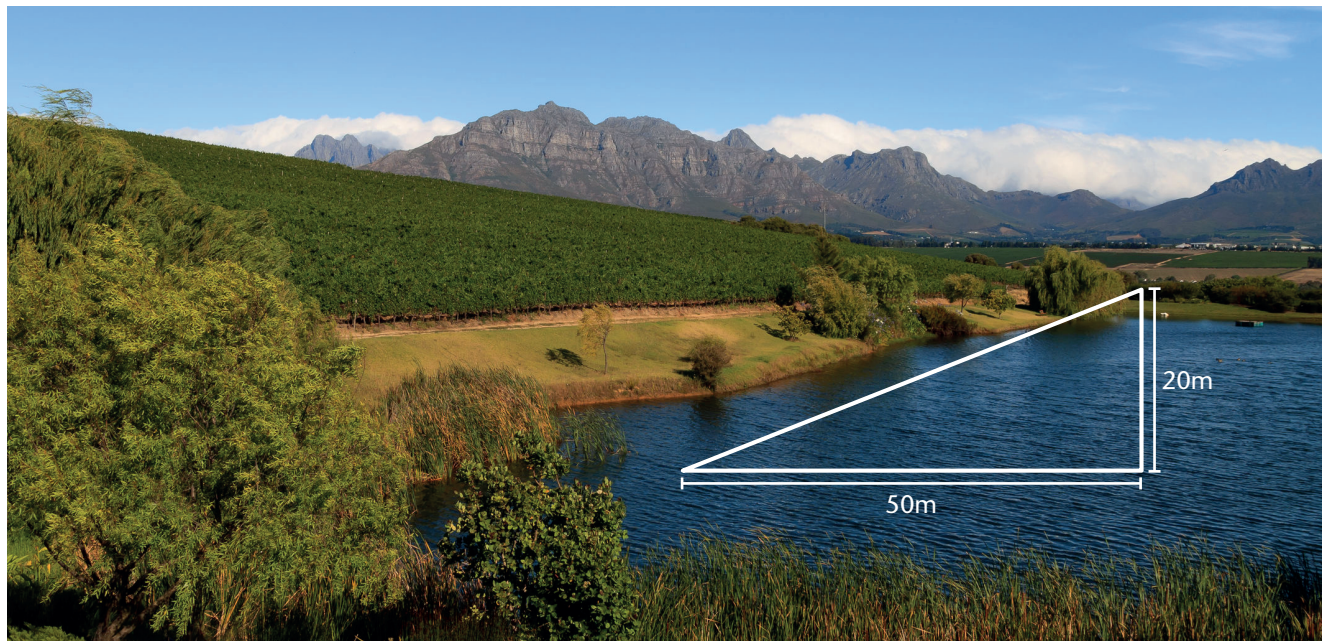


Figure 1.10 Using Pythagoras' Theorem to determine 'immeasurable length'

Note: You will need to assume that the ground is perfectly horizontal.

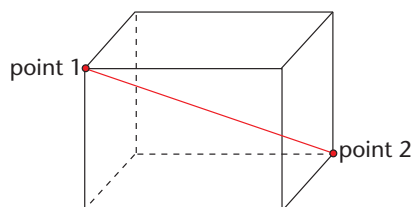


Activity 1.5

1. Determine the length of the zip line using the horizontal and vertical lengths given in Figure 1.10.
2. What practical consideration would you need to take regarding the length of the zip line needed? Hint: think about the effect of gravity on the zip line.

1.3.3 Further applications for using Pythagoras' Theorem

Consider a solid cuboid. It is easy to measure the length, width and height of the cuboid using a measuring tape.



But how can the length of the diagonal running from one corner to the opposite corner of the cuboid be measured without breaking it apart?

We can use Pythagoras' Theorem to help us. Let's look at an example to see how it works.

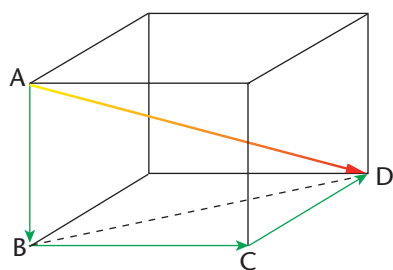


Activity 1.6 Application of Pythagoras' Theorem

All three sides of the cuboid form a right triangle.

Using horizontal diagonal BD and the vertical edge AB, the length of diagonal AD is then found by a second application of Pythagoras' Theorem as:

$$BD^2 = BC^2 + CD^2 \text{ and } AD^2 = AB^2 + BD^2$$



Therefore:

$$AD^2 = AB^2 + BC^2 + CD^2$$

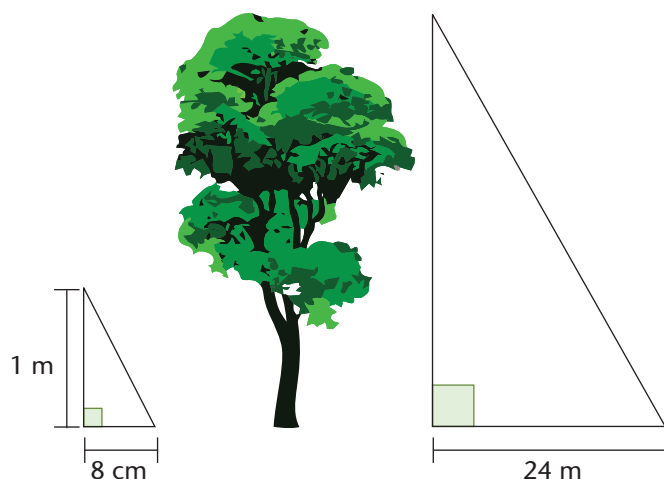
Determine the length of the diagonal AD, if the dimensions of the cuboid are as follows:

AB = 4 cm; BC = 5 cm; CD = 6 cm

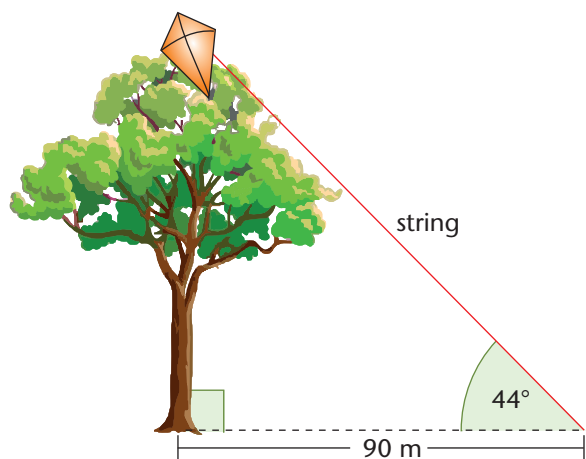


Activity 1.7

1. The shadow cast by a 1 m ruler held perpendicular to the ground is 8 cm long. At the same time, the shadow cast by a pine tree is 24 m long. What is the height of the pine tree?



2. Thabiso's kite gets caught at the top of a tree as shown in the diagram below. If the string makes a 44° angle with the ground, and the string holder pinned to the ground is 90 m from the base of the tree, how tall is the tree?



1.4 The resultant of collinear forces

Collinear forces (or vectors, in general) are forces (or vectors) that lie in the same line of action. These vectors are parallel but not necessarily pointing in the same direction.

By sticking to the sign conventions discussed earlier in the chapter, collinear vectors can be added.

Example 1.7**DETERMINE THE RESULTANT FORCE**

Find the resultant of four forces acting on an object:

$\vec{F}_1 = 2 \text{ N}$ in the positive y-direction

$\vec{F}_2 = 1,5 \text{ N}$ in the negative y-direction

$\vec{F}_3 = 2,5 \text{ N}$ in the negative x-direction

$\vec{F}_4 = 6 \text{ N}$ in the positive x-direction

1 ANALYSE

Identify collinear forces $\vec{F}_x$ and $\vec{F}_y$ assign directions conventionally.

In our case there are forces acting in the x-direction and in the y-direction.

2 SOLVE

Add all collinear forces.

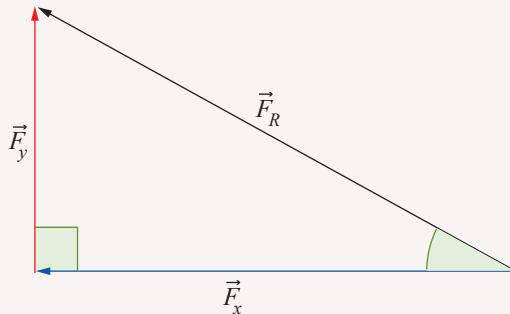
Call these resultants forces $\vec{F}_x$ and $\vec{F}_y$: Take the direction to the right as positive, and the direction up as positive.

$$\vec{F}_x = +2,5 \text{ N} + (-6 \text{ N}) = -3,5 \text{ N}$$

This means it's 3,5N in the negative x-direction

$$\vec{F}_y = +2,5 \text{ N} + (-1,5 \text{ N}) = 0,5 \text{ N}$$

This means 0,5N in the positive y-direction

3 NOW DRAW

$$F_R^2 = F_x^2 + F_y^2$$

$$F_R^2 = (-3,5)^2 + (0,5)^2$$

$$F_R^2 = 12,5$$

$$\therefore F_R = 3,45 \text{ N}$$

The sketch represents the $\vec{F}_x$ and $\vec{F}_y$, and calculation the resultant of $\vec{F}_x$ and $\vec{F}_y$. This is the same as the resultant of the four forces.



Activity 1.8

1. Define the term resultant force.
2. Define the term collinear vector.
3. Calculate the resultant of the following forces:
 - a) A force of 23,7 N in the negative x -direction acts simultaneously to a force of 9 N in the positive y -direction.
 - b) A force of 17 N in the positive x -direction acts simultaneously to a force of 23 N in the positive y -direction.
 - c) A force of 23,7 N in the negative x -direction acts simultaneously to a force of 9 N in the positive y -direction.
4. Four forces act simultaneously at a point, find the resultant if the forces are:
 $\vec{F}_1 = 2,3$ N in the positive x -direction
 $\vec{F}_2 = 4$ N in the positive y -direction
 $\vec{F}_3 = 3,3$ N in the negative y -direction
 $\vec{F}_4 = 2,1$ N in the negative x -direction
 - a) Find the resultant of forces in the x -direction, $\vec{F}_x$.
 - b) Find the resultant of the forces in the y -direction, $\vec{F}_y$.
 - c) Calculate the resultant of the four forces.
5. Four forces act simultaneously at a point, find their resultant if the forces are:
 $\vec{F}_1 = 2,3$ N in the negative x -direction
 $\vec{F}_2 = 4$ N in the positive y -direction
 $\vec{F}_3 = 3,3$ N in the positive x -direction
 $\vec{F}_4 = 2,1$ N in the positive x -direction

1.5 Resultant of forces in 2-D

Finding the resultant of two-dimensional forces that are not necessarily perpendicular to one another can be done by using accurate scale drawings. There are two techniques that can be used to do this. These are:

- head-to-tail method
- parallelogram of forces

1.5.1 Head-to-tail method

Remember that a vector quantity is a physical quantity having both magnitude and direction. A vector quantity is represented by a ray, which is an arrow tipped segment, as shown in Figure 1.10 below.

Tail  Head

Figure 1.10 A diagrammatic representation of a vector

The drawing above is the general representation of a vector. The length of the line represents the magnitude of the vector, and the arrow shows the direction of the vector.

To add vectors using the head-to-tail method, move the vectors such that the head of one vector is attached to the tail of the other. The resultant vector ($\vec{R}$) is the single vector leading from the tail of the first vector to the head of the last when the vectors are placed tail to head in any order, as shown in Figure 1.11 below.

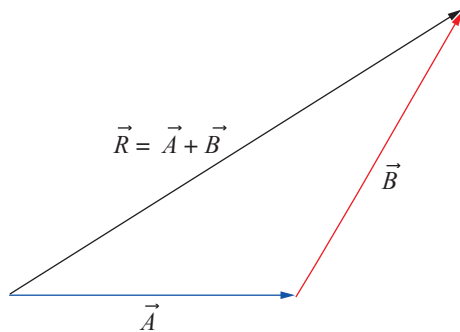


Figure 1.11 Graphical representation of the resultant vector ($\vec{R}$)

Example 1.6

HEAD-TO-TAIL METHOD

Determine the resultant of the forces $\vec{F}_1 = 30\text{N}$ to the right and $\vec{F}_2 = 40\text{N}$ upwards using the head-to-tail method.

1 ANALYSE

Given: $\vec{F}_1$ and $\vec{F}_2$

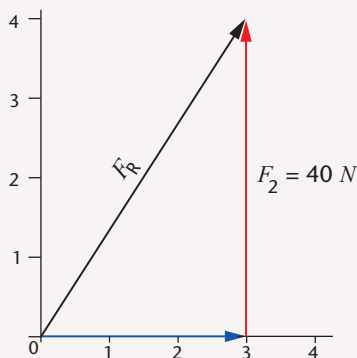
Unknown: Resultant force $\vec{F}$

Note: Newton's measure can't be drawn. As a result, we should find a suitable conversion scale that will help us sketch the vector and find their resultant.

2 SOLVE

Check the accuracy of the drawing. We could use Pythagoras' Theorem to find the magnitude of the resultant force.

Scale: 1 cm : 10 N



By measuring with a ruler, we will find that the magnitude of $\vec{F}_R$ is 5 cm, which is an equivalent of 50 N according to the scale described above.



Activity 1.9

- Use the head-to-tail method to find the resultant of the following forces:
 - $\vec{F}_1 = 12 \text{ N}$ to the right and $\vec{F}_2 = 5 \text{ N}$ downwards
 - $\vec{F}_1 = 16 \text{ N}$ to the right and $\vec{F}_2 = 12 \text{ N}$ downwards
 - $\vec{F}_1 = 8 \text{ N}$ to the left and $\vec{F}_2 = 6 \text{ N}$ upwards
 - $\vec{F}_1 = 15 \text{ N}$ to the right and $\vec{F}_2 = 20 \text{ N}$ upwards
- Use Pythagoras' Theorem to verify your answers.
- Use the head-to-tail method to determine the magnitude and direction of the resultant of the forces 12 N at 0° and 20 N at 35° .
- Use the head-to-tail method to determine the magnitude and direction of the resultant of the forces 13 N at 45° and 30 N at 30° .

1.5.2 The Parallelogram Law of Forces

A parallelogram is a quadrilateral with two pairs of opposite sides equal and parallel, and two pair of interior opposite angles equal. Figure 1.12 shows an example of a parallelogram.

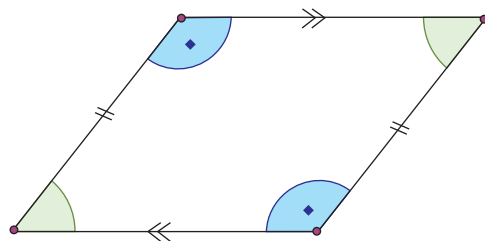


Figure 1.12 A parallelogram

For any two simultaneous forces acting at a point and separated by an angle, we can use a technique called a parallelogram of forces to find their resultant. We call this the Parallelogram Law of Forces. This law states that if two forces acting at a point can be represented by the adjacent sides of a parallelogram both in magnitude and direction, then the diagonal from the point gives the resultant of the two forces.

This is depicted in Figure 1.13 below.

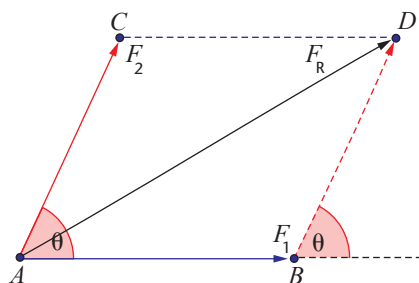


Figure 1.13 The Parallelogram Law of Forces

Example 1.8

THE PARALLELOGRAM LAW OF FORCES

Use the Parallelogram Law of Forces to find the resultant of two forces $\vec{F}_1 = 60 \text{ N}$ and $\vec{F}_2 = 45 \text{ N}$ acting simultaneously at a point, and separated by the angle of 60° .

1 ANALYSE

Choose a suitable scale that you can use to convert forces to cm or mm.

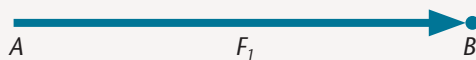
In this case $1 \text{ cm} : 5 \text{ N}$ is a suitable scale.

Thus, $12 \text{ cm} : 60 \text{ N}$ represents $\vec{F}_1$, and $9 \text{ cm} : 45 \text{ N}$ represents $\vec{F}_2$.

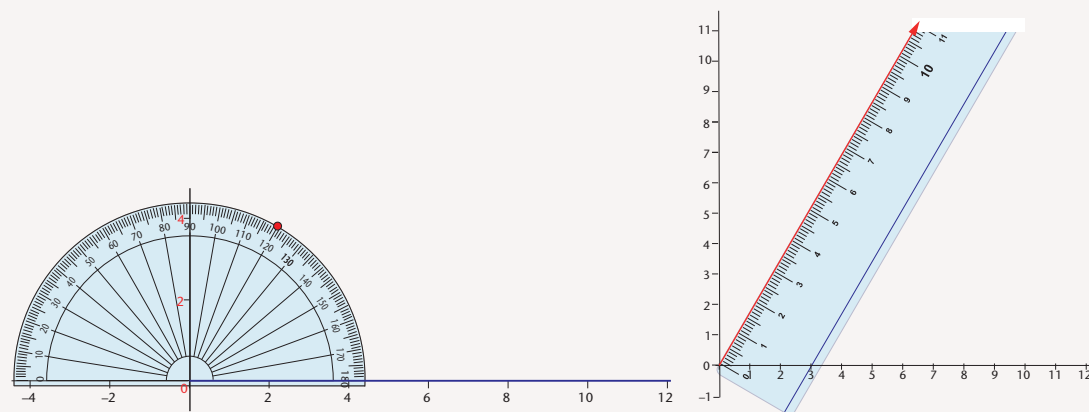
2 SOLVE

Step 1: Draw $\vec{F}_1$, as converted above, represented by the horizontal-arrowed line.

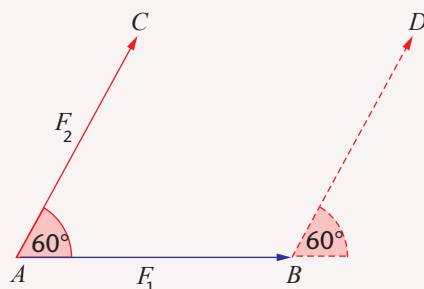
Step 2: Label this line AB.



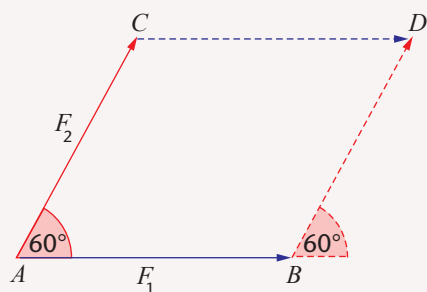
Step 3: From the tail of this force, measure an angle of 60° , and draw the second arrowed-line representing $\vec{F}_2$, as converted above. Label this force AC.



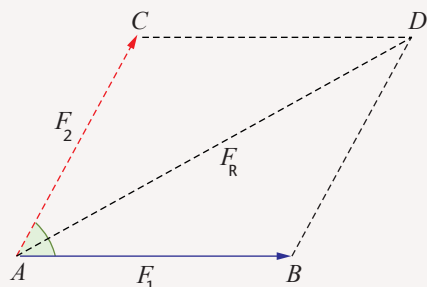
Step 4: From the head of the force AB, measure an angle of 60° and construct a dotted line through that angle. Label that line BD, of the same magnitude as force AC from step 3 above. Notice that BD must be parallel and equal in magnitude to AC.



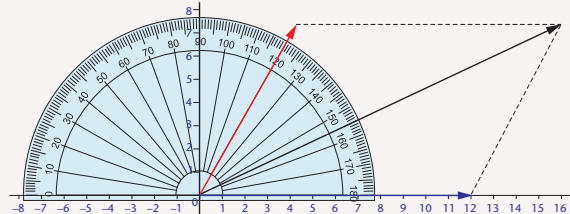
Step 5: Join CD with a dotted line. Note that DC will be automatically equal in magnitude and parallel to AB.



Step 6: Join AD. Notice that, according to the parallelogram of forces theorem, this diagonal is the resultant of the $\vec{F}_1$ and $\vec{F}_2$.



Step 7: Use a ruler to measure the length of the diagonal. Then use the defined conversion scale to convert it to Newton and find the magnitude of the resultant force. Measure the angle made by the resultant with the horizontal, to get its direction.

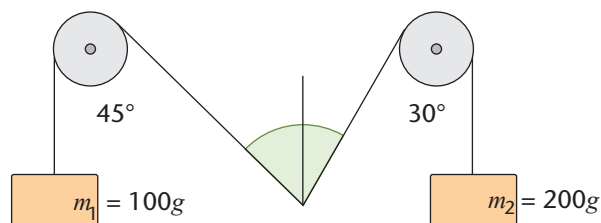


Step 8: In this case, the length of the vector representing the resultant force is about 18,3 cm. Using the defined scale 1 cm : 5 N, we get that the magnitude of the resultant force is approximately: $\vec{F}_R = 91,5 \text{ N}$, and as shown its direction is 25° from the horizontal.



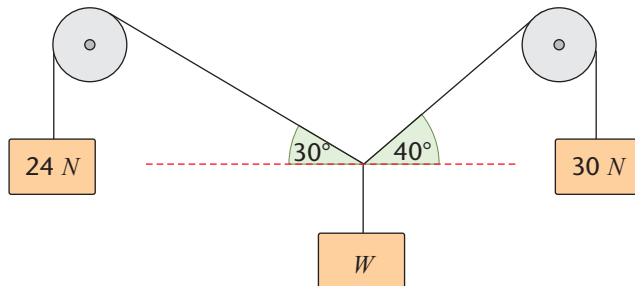
Activity 1.10

1. State the Parallelogram Law of Forces.
2. Use the accurate scale drawing to construct the parallelogram of forces and find the resultant of the forces in each case:
 - a) $\vec{F}_1 = 12 \text{ N}$ and $\vec{F}_2 = 1\% \text{ N}$ separated by the angle of 120° .
 - b) $\vec{F}_1 = 200 \text{ N}$ and $\vec{F}_2 = 120 \text{ N}$ separated by the angle of 80° .
3. Two forces act simultaneously on an object as shown alongside:

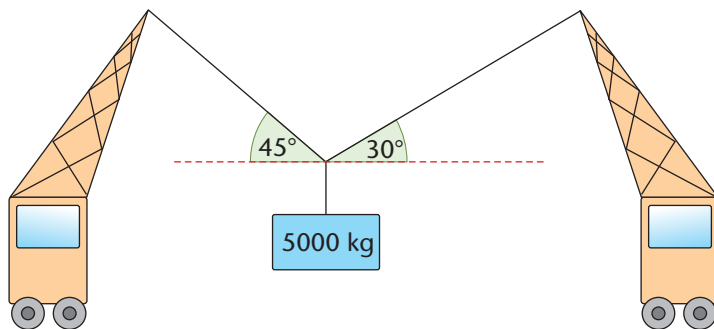


Determine the magnitude and the direction of the resultant force.

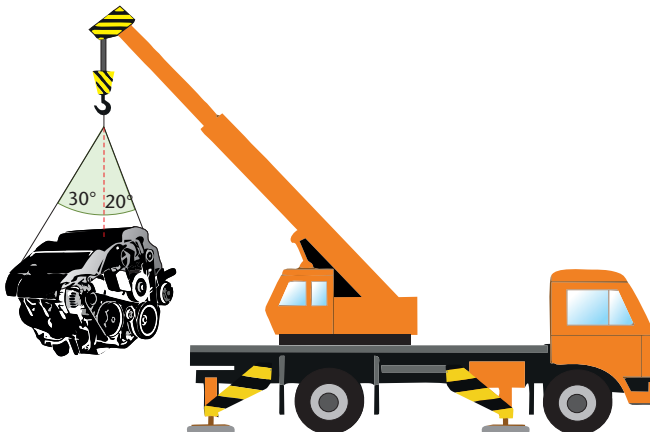
4. Use the parallelogram of forces method to determine the magnitude and direction of the resultant of forces 18 N at 45° and 24 N at 60° .
5. Use the parallelogram of forces method to determine the magnitude and direction of the resultant of the forces 18 N at 125° and 15 N at 225° .
6. Use the parallelogram of forces method to determine the magnitude and direction of the resultant of the force 21 N at 150° and 14 N at 215° .
7. Two weights of 24 N and 30 N are used to balance an object of unknown weight $\vec{w}$ on pulleys as shown in the diagram below. Determine the unknown weight $\vec{w}$ if the strings make angles of 30° and 40° with the horizontal.



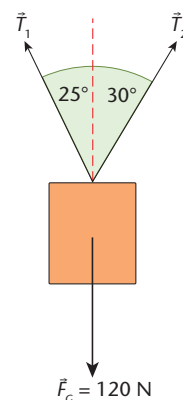
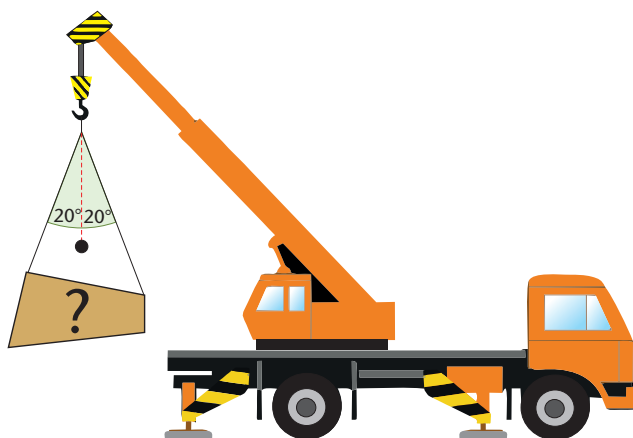
8. In the diagram, a mass of 5 000 kg ($w = 50$ kN) is hanging on the hook of the lifting cable and the arms of the cranes are stationary. The cables make the angles of 45° and 30° with the horizontal. Determine the tensions on the cables.



9. A two-legged sling and hoist chain are used to lift a car engine at constant speed as shown below. Determine the tension on each leg of the sling if the weight of the car engine is 1 500 N.



- 10 A load of 120 N is lifted by two strings connected to the same point on the load, making angles of 25° and 30° on opposite sides of the vertical. Determine the tensions in the string. t
11. If the threshold tension of each of the strings in the hoist below is 4 000 N, what is the maximum load that the crane can carry before the strings snap, if the angle that each string makes with the vertical is 20° ?



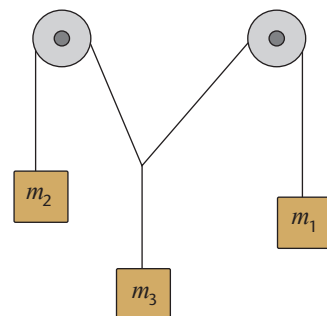
PRACTICAL INVESTIGATION (Informal)

Apparatus

- force board
- mass pieces
- pulleys
- strings
- protractor

Procedure

- Create two stands A and B on each side, and in between the stands, put a board.
- On top of each stand mount a plastic pulley of at least 25 mm in diameter.
- Wound a piece of string along the pulley and have masses m_1 and m_2 on each end of the string, that is, at the end of A and B. Put another mass of m_3 at the centre of the string on the side of the board and represent $\vec{F}_1$ acting at a downwards direction.
- Label a point where m_3 is hung as point O. Name the tension force that acts towards the left-hand side of point O towards m_1 , $\vec{F}_1$ and name the second force that acts towards the right-hand side of point O, $\vec{F}_1$.
- Measure an angle that is formed between point O, $\vec{F}_1$ and $\vec{F}_2$. $\vec{F}_3$ that acts towards m^3 is now the equilibrant force because both $\vec{F}_2$ and $\vec{F}_1$ are in equilibrium and opposite $\vec{F}_3$ above point O. When you have found $\vec{F}_3$, you would have found the resultant force.
- Use a parallelogram of forces diagram to make a graphical representation of your findings.



Results

- Measure the magnitude of the angle between the forces $\vec{F}_2$ and $\vec{F}_1$.
- Calculate the magnitude of the forces $\vec{F}_1$ and $\vec{F}_2$. This is simply the weight of the hanging masses, m_1 and m_2 , respectively.
- Use the parallelogram of forces method to find the magnitude of the resultant of these two forces
- How does your answer compare to the magnitude of $\vec{F}_3$?

1.6 Resolving vectors

In the previous section we learned that the combined effect of two or more forces can be represented by a single force, referred to as the resultant force.

In the same way, a single force that acts at an angle can be considered to have two parts – one part directed along the horizontal axis and the other along the vertical axis. The two parts (called components) of the single force are therefore perpendicular to one another – the horizontal and the vertical components of the force.

Therefore, a single force acting at an angle can be resolved into a vertical and horizontal component. In Figure 1.14, the vertical component represents the influence of the force in the vertical direction, whilst the horizontal component represents the influence of the force in the horizontal direction.

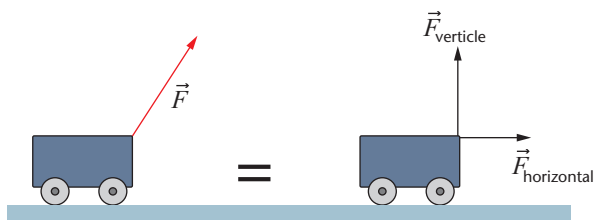


Figure 1.14 resolution of vectors

Any time a force is directed at an angle to the horizontal, the trigonometric functions can be used to determine the components of that force.

This applies not only to forces but to all vectors.

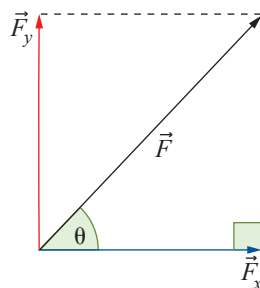
Figure 1.15 shows a force $\vec{F}$ that acts at angle θ from the horizontal axis. It is possible to decompose force $\vec{F}$ into its components as shown in Figure 1.15 alongside.

From the definitions of the trigonometric ratios, it is known that:

$$\sin \theta = \frac{\text{opp}}{\text{hyp}} = \frac{\vec{F}_y}{\vec{F}} \Rightarrow \vec{F}_y = \vec{F} \sin \theta$$

$$\cos \theta = \frac{\text{adj}}{\text{hyp}} = \frac{\vec{F}_x}{\vec{F}} \Rightarrow \vec{F}_x = \vec{F} \cos \theta$$

The formulae above are used to calculate the vertical (F_y) and horizontal (F_x) components of force F making an angle θ with the horizontal axis.



The components of a force $\vec{F}$ acting at an angle θ .

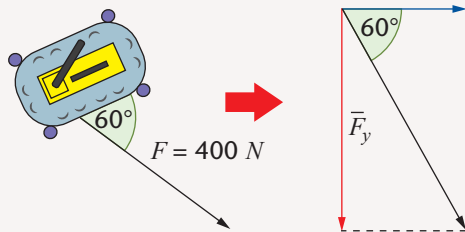
Figure 1.15 Vector decomposition

Example 1.9**RESOLVING A VECTOR**

The diagram below shows a force $\vec{F} = 400 \text{ N}$ acting at an angle 60° with the horizontal. Determine the x and y components of $\vec{F}$.

1 ANALYSE

Draw a right-angled triangle and label all the sides as shown below.

**2 SOLVE**

$$\sin 60^\circ = \frac{\vec{F}_y}{400}$$

$$\vec{F}_y = 400 \sin 60^\circ$$

$\therefore \vec{F}_y = 346$ to the right. In the positive x -direction.

$$\cos 60^\circ = \frac{\vec{F}_x}{400}$$

$$\vec{F}_x = 400 \cos 60^\circ$$

$\therefore \vec{F}_x = 200$ to the right. In the negative y -direction.

Example 1.10**RESOLVING FORCES USING AN ACCURATE SCALE DRAWING**

Determine graphically the horizontal and vertical components of a force of 800 N which acts at 20° below the horizontal to the left.

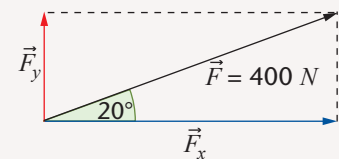
Let $1 \text{ cm} : 100 \text{ N}$ such that $8 \text{ cm} : 800 \text{ N}$

GIVEN

$$\vec{F} = 800 \text{ N}$$

STEPS

1. Draw line $\vec{F} \cos \theta$ of any length on the horizontal and measure 20° anticlockwise using a protractor. Then draw line $\vec{F}$ below the horizontal.
2. From the tail of $\vec{F}$, draw a line going vertically (not measured) up and another line going horizontally to the right.



3. From the head of $\vec{F}$, draw a line going horizontally, to intersect with the vertical line drawn in step 2. Put a point where the two lines intersect.
4. From the tail of $\vec{F}$, draw a line going vertically to intersect with the horizontal line drawn in step 2. Put a point where the two lines intersect.
5. Put arrows to indicate the directions of the horizontal and vertical components of the force $\vec{F}$.
6. Measure the dimensions of the components of $\vec{F}$, and use the defined scale to get the magnitude of the forces.
7. Measuring the dimension of $\vec{F}_x$ and $\vec{F}_y$ we get: 7,5 cm and 2,75 cm. Using the scale, we get:
 $\vec{F}_x = 750 \text{ N}$ in the positive x-direction and $\vec{F}_y = 275 \text{ N}$ in the positive y-direction.

Note: Remember that the quadrant in which a force acts will determine its direction, that is, positive or negative.



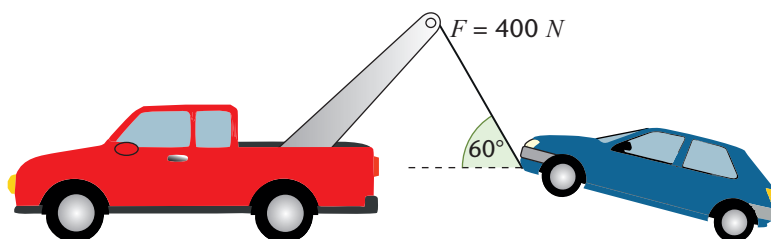
Activity 1.11 resolving vectors

1. Determine the horizontal and vertical components of the forces given below:
 - a) a force of 205 N at 45° below the horizontal to the left
 - b) a force of 8 N at 45° below the horizontal to the right
 - c) a force of 400 N at 15° below the horizontal to the left
 - d) a force of 1 500 N at 30° above the horizontal to the left
 - e) a force of 90 N at 90° above the horizontal
2. Use the accurate scale drawing to find the components of the horizontal and vertical component of the forces described above.
3. A force of 15 N at 30° above the horizontal to the left and another force of 20 N at 60° below the horizontal to the left with the third force of 10 N at 10° below the horizontal to the right.
 - a) Find the resultant horizontal force of the three forces.
 - b) Find the resultant vertical force of the three forces.
 - c) Calculate their resultant in magnitude and direction.

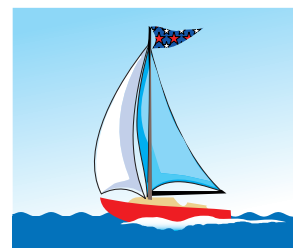
HINT: Use the following formula:

$$\tan \theta = \frac{\vec{F}_x}{\vec{F}_y} \text{ or } \theta = \tan^{-1} \left(\frac{\vec{F}_x}{\vec{F}_y} \right) \text{ and } F_R^2 = F_x^2 + F_y^2$$

4. Consider the tow truck at the below. If the tensional force in the cable is 1 000 N and if the cable makes a 60° angle with the horizontal, then what is the vertical component of force that lifts the car off the ground?



5. Critical thinking: One of the most important applications of vector components is in the operation of sailboats. Sailboats are propelled forward by the force that the wind exerts on the sail. It is easy to understand that if the wind blows in the direction to which the boat is moving, then the boat will move forward. But how come sailboats can move 'into the wind' ∇ towards the direction from which the wind is coming?



Many people believe that this is not possible, but it does happen in real life. If it were not possible, then sailboats would not be able to reach their intended destinations because they would be tossed around by the winds in the oceans.

Do your own investigation on how sailboats work and how the principle of vector components can explain the fact that sailboats can sail 'against' the wind.

1.7 Friction

1.7.1 The importance of friction

Usually when we hear about friction, we associate it with something that needs to be reduced or eliminated. This may lead us to think that friction is always a bad thing!

However, friction has many important uses in Science. Friction is a resistance force that slows down or prevents motion. It is necessary in many applications where we might want to hold items together or prevent slipping or sliding.

But how does that apply to real life? Let's look at a few examples of how having friction can be advantageous.

Imagine there was no friction. You would not be able to walk properly because you need friction between your shoes and the ground. As you step forward, you push your foot backward. Friction holds your shoe to the ground, thus allowing your body to move forward. Think about when you have tried to walk on a slippery floor. Slippery surfaces usually have very little friction acting on them.

How about the importance of friction when driving in a car? The car would not start moving if it wasn't for the friction of the tires against the road. With no friction, the tires would just spin and the car would not move. Similarly, a car would not stop without the friction of the brakes and the tires. So, we need friction!

Ancient people used friction to light fire. Making fire was not as easy as we know it today and it cannot be compared to lighting a match – in which case the fire lighting tool has already been created. One method of making fire involved the use of dry wooden sticks that were ground by rapidly rubbing them against each other or a hard surface.



Figure 1.17 San people in Botswana starting fire by hand

This required skill, fitness and conducive environmental conditions. In this case, effort is focused on grinding dust off burnable wooden material and producing enough heat that will make the dust smoulder. The critical role played by friction in this process can be easily seen. With friction fire, effort is focused into grinding dust off of soft solid burnable material such that the dust is smouldering.

Another example of the application of friction is the hand drill shown in Figure 1.16. Without friction, the hand drill would not work. It is actually suggested that the **hand drill** is the modern version of making fire by friction, in which case the wooden shaft that used to be spun by hand is replaced by a drill; but has the same effect of producing heat and applying pressure and grinding dust.

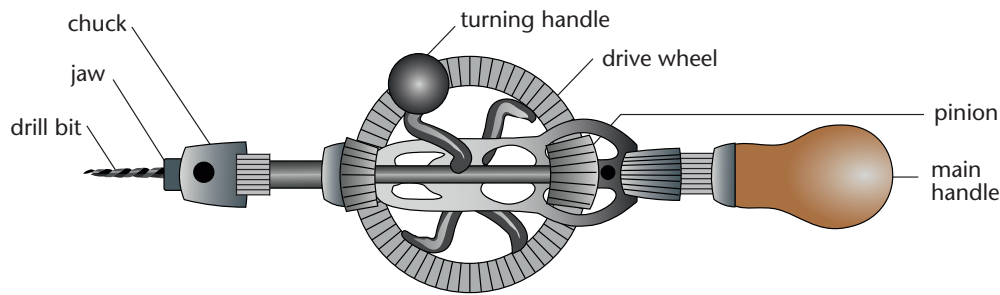


Figure 1.16 Manual hand drill

We can think of many more examples, but just considering these examples we can deduce that friction is one of the most important phenomena in the physical world.

1.7.2 So what is friction

Frictional force is the force that an object encounters when it moves or attempts to move along a surface that opposes the motion or tendency of motion. It is always directed parallel to the surface in question.

When surfaces that are in contact with one another move relative to each other, the friction between the two surfaces converts **kinetic energy** into thermal energy (that is, it converts work to heat).

This property is illustrated by the use of friction when rubbing pieces of wood together to start a fire. In this case, kinetic energy is converted to thermal energy whenever motion with friction occurs.

1.7.3 Types of frictional forces

There are many different types of frictional forces in nature, but in mechanics we focus mainly on the two types. These are:

- kinetic frictional force
- static frictional force.

Friction, like normal force, is exerted by the surface. But while normal forces is always perpendicular to the surface on which it acts, frictional force is tangent to the surface.

Static frictional force, which is denoted by $\vec{f}_s$, is the force that keeps an object 'stuck' on a surface and prevents it from moving. The direction of the static frictional force is opposite to the direction in which the object would move if there were no friction.

It is given by the formula: $f_s = \mu_s N$, where N is the normal force

The static frictional force depends on the magnitude of the force acting on the object.

Stationary objects have frictional forces between zero and a maximum value, $f_s^{\max}$. We define a maximum value for the static friction as $f_s^{\max} = \mu_s N$.

If you apply a force that is greater than $f_s^{\max}$, the object moves.

The maximum static frictional force is also known as limiting static frictional force

$$f_s^{\max} = \mu_s N$$

Where

$f_s^{\max}$ = limiting static frictional force

μ_s = the dimensionless constant called the coefficient of static friction

F_n = the normal force

The coefficient of friction is the ratio of frictional force to the normal force.

$$\therefore \mu = \frac{f}{F_N}$$

The coefficient of friction is dimensionless (it has no units).

This can be felt when we try to accelerate a stationary object (by exerting a force on it). The difficulty we experience is mainly due to static frictional force.

Once the object starts moving, accelerating it becomes easier than when it was stationary. This means that as the applied force is increased, the static frictional force is increasing until it reaches its maximum at the moment when the object is at the verge of starting to move.

Once the object is in motion, it takes lesser effort to accelerate it. The object then experiences the 'so called' kinetic frictional force. Kinetic (dynamic) frictional force acts between the surfaces when the object is moving. Because it takes lesser effort to accelerate a moving object than to cause an object to move, the moving object experiences lesser opposition to its motion than a stationary object. Therefore, maximum static frictional force is always greater than the kinetic frictional force (as shown in Figure 1.17).

Let's look at each type of force using examples to illustrate them.

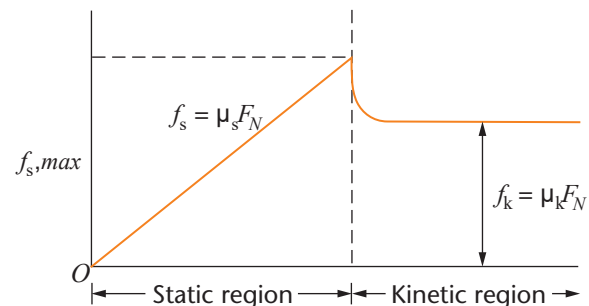


Figure 1.17 Static vs kinetic frictional force

Kinetic frictional force

Kinetic frictional force is the force:

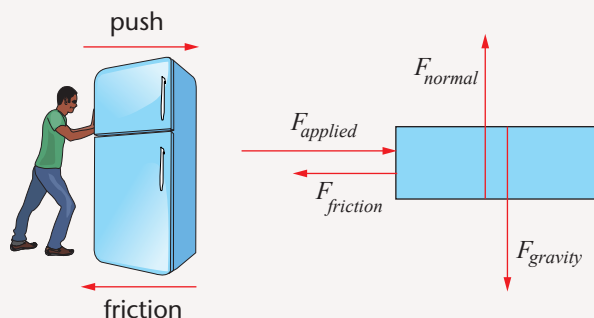
- that arises when two surfaces are in contact
- hinders (opposes) the mutual displacements of the two surfaces
- acts along the surfaces in reciprocal contact
- always acts in opposite direction to the relative motion
- is tangent to the surfaces in contact.
- is calculated by the formula: $f_k = \mu_k F_N$

Example 1.11**KINETIC FRICTIONAL FORCE**

Temba pushes a fridge weighing 78 kg across the horizontal floor at a constant velocity.

If the co-efficient of kinetic friction between the floor and the fridge is 0,7; calculate the force parallel to the floor to keep the box in motion.

Note: Always use a sketch or a drawing to describe the process

**SOLUTION**

Given: the mass of the fridge in kilograms = 78 kg; $\mu_k = 0,7$

TO CALCULATE

Note: Start by calculating the weight from the mass given

$$\vec{F}_N = -\vec{w} = -mg$$

$$\vec{F}_N = -(78)(9,8)$$

$$\vec{F}_N = -764,4 \text{ N}$$

$$\vec{f}_k = \mu_k F_N$$

$$\vec{f}_k = (0,7)(764,4)$$

$$\vec{f}_k = 535,08 \text{ N}$$

Because the fridge is moving at constant velocity, it is not accelerating (the object is in equilibrium). Therefore, the resultant of all the collinear forces acting on the fridge is zero. Therefore, the applied force required to keep the fridge moving at a constant velocity has the same magnitude as the frictional force (equilibrant force in this case) experienced by the fridge.

$$\vec{F}_{\text{applied}} = 535,08 \text{ N in the direction of motion/opposite to the frictional force}$$

**Activity 1.12**

1. Name four instances where friction is a disadvantage.
2. Define the co-efficient of friction.
3. The co-efficient of friction between Nomthandazo's shoes and the floor is 0,72. If her mass is 85 kg, calculate the limiting frictional force between her shoes and the floor.
4. A wooden crate with a mass of 80 kg is dragged across a horizontal concrete floor at a constant velocity. If the co-efficient of friction between the floor and the concrete is 0,8, calculate the dynamic frictional force between the crate and the floor.



EXPERIMENT 2: FRICTION

In the following experiment we will do the following:

1. Determine the relationship between the limiting frictional force and the normal force
2. Determine the coefficient of friction between the surfaces f_s and F_N .

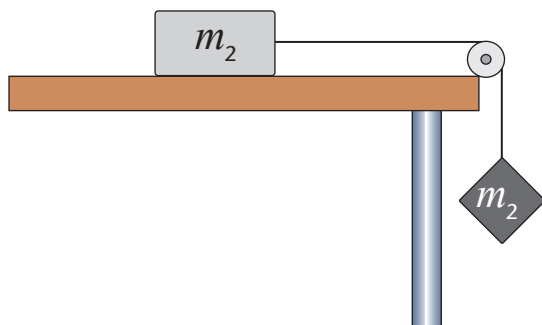
EXPERIMENT 2 (PART 1): RELATIONSHIP BETWEEN LIMITING FRICTION AND THE NORMAL FORCE

Apparatus

- Flat table with a pulley attached to one end
- String
- Mass pieces
- Wooden block

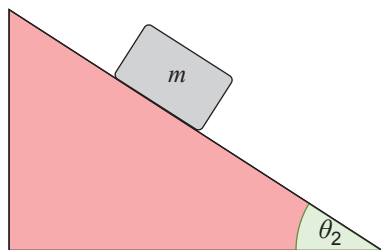
Procedure

1. Set the experiment as indicated in the diagram below:



2. Increase the hanging mass by adding more mass pieces until the moment the wooden block starts sliding at a constant speed.
3. Record the mass of the hanging mass m_2 and the mass of the wooden m_1 block
4. Increase the mass of the trolley by adding fewer mass pieces on it, until you have about five different readings. Repeat the last two steps above.

EXPERIMENT 2 (PART 2) CALCULATING μ .



1. Place the block on the wooden surface.
2. Slowly lift the end of the plank until the trolley starts sliding from rest.
3. Fix the plank in that place and measure the inclination it makes.
4. Repeat for at least 5 values.

Results: Experiment 1

Trial #	m_1	$F_{g1} = m_1g$	m_2	$F_{g2} = m_2g$	μ
1					
2					
3					
4					
5					

1. The magnitude of the limiting frictional force between the block and the plank is given by:
 $f = m_2g$
2. The normal force on the block is given by: $F_N = m_1g$
3. To calculate the coefficient of friction, use the formula: $\mu = \frac{f}{F_N}$
4. Use the results to plot the graph of f (y-axis) versus F_N (x-axis)

Trial #	Limiting angle	$m_s = \tan\theta$
1		
2		
3		
4		
5		

5. Calculate the average value of $\mu_s =$ _____

Conclusion

1. What is the shape of the graph for Experiment 1?
From the graph of Experiment 1, write a conclusion about the relationship between the limiting frictional force and the normal.
2. Calculate the average value of m for Experiment 1 from the table of results.
3. Now calculate the slope of the graph using any two points that lie on the line.
4. How do your answers to number 2 and 3 compare?

Review exercise

Multiple choice questions

1. The resultant of two collinear vectors is minimum when the angle between them is:
 - A 180°
 - B 90°
 - C 0°
 - D Greater than 180°
2. Identify the vector quantities from the descriptions below:
 - A A speed limit of $120 \text{ km}\cdot\text{h}^{-1}$
 - B A distance of 100 km
 - C A car driving at $120 \text{ km}\cdot\text{h}^{-1}$ due East
 - D An angle of 45°
3. The following technique cannot be used to find the resultant of two perpendicular vectors:
 - A Head-to-tail method
 - B Parallelogram of forces
 - C Theorem of Pythagoras
 - D Collinear vectors addition
4. A car accelerates from rest and reaches a certain velocity which it maintained for some time. Choose the correct statement below:
 - A When the car was at rest, the static friction was at its maximum, that is why the car remained stationary.
 - B When the car was moving, its static frictional force dropped to zero, and the car had kinetic frictional force.
 - C The static frictional force increased while the car tried to start moving until it reached the maximum when it was at the verge of moving.
 - D The car would not move unless its kinetic frictional force was equal to its static frictional force
6. The force experienced by an object parallel to the surface that opposes the motion of an object is the:
 - A Applied force
 - B Gravitational force
 - C Normal force
 - D Frictional force

Long questions

7. A Grade 12 class at Cedar High School was interested in finding the relationship between the acceleration of the trolley and the pulling force.

To achieve this, they set up the experiment as shown below. They maintained the total mass, by moving some the mass pieces they placed on the trolley and adding them to the hanging mass that pulls the trolley. Each time they added the mass, they would calculate the pulling force and the acceleration.

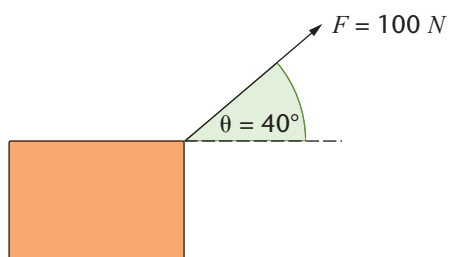


Below is the summary of the results they obtained:

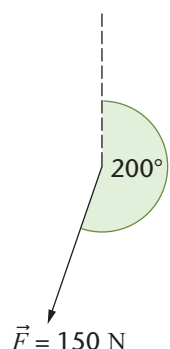
Trial #	Hanging mass (kg)	Trolley mass (kg)	Acceleration ($\text{m}\cdot\text{s}^{-2}$)	Force (N)
1	0,005	0,525	0,094	0,049
2	0,010	0,520	0,187	0,098
3	0,015	0,515	0,27	0,147
4	0,020	0,510	0,36	0,196
5	0,030	0,500	0,54	0,294

- From the results above, identify the variable that is:
 - a constant
 - independent
 - dependent
 - Use the results above to plot the graph of acceleration versus pulling force.
 - From the graph, and the table above, what conclusion can the learners draw about the relationship between the acceleration and the pulling force?
7. The following forces act simultaneously on an object:
- $\vec{F}_1 = 25 \text{ N}$ in the positive y -direction
 - $\vec{F}_2 = 10 \text{ N}$ in the negative x -direction
 - $\vec{F}_3 = 15 \text{ N}$ in the negative x -direction
 - $\vec{F}_4 = 10 \text{ N}$ in the negative y -direction
- Calculate the resultant of the forces in the x -direction, $\vec{F}_x$.
 - Calculate the resultant of the forces in the y -direction, $\vec{F}_y$.
 - By using accurate scale drawings, find the magnitude of the resultant of all the forces.
 - Using calculations, show the accuracy of the answer you obtained in c). above.

8. The angle between two forces $\vec{F}_1$ and $\vec{F}_2$, of magnitude 18 N and 15 N respectively is 60° . Use accurate parallelogram of forces diagrams to find the resultant of the two forces.
9. A force of 100 N pulls a box at angle of 40° to the horizontal, as shown below:



- a) Calculate the horizontal component $\vec{F}_x$ of the force $\vec{F}$.
 - b) Calculate the vertical component $\vec{F}_y$ of the force $\vec{F}$.
 - c) If the box experiences a constant frictional force while being pulled to the right such that it moves at a constant velocity, calculate the:
 - (i) normal force on the object
 - (ii) coefficient of kinetic friction between the box and the surface.
10. Use accurate scale drawings to find the components of the force shown below.



Chapter summary

Key terms

Mechanics is a 'branch of physics that deals with the study of the forces acting on a body and keeps it in equilibrium (objects or bodies at rest) or in motion'. Generally, mechanics can be divided into:

- **Kinematics** – the branch of classical mechanics that describes the motion of points (alternatively 'particles'), bodies (objects), and systems of bodies without consideration of the masses of those objects nor the forces that may have caused the motion.
- **Dynamics** – the branch of physics (mechanics) that deals with the effect of forces on the motion of bodies. It can also be understood as the study of the forces affecting moving objects.

Sign convention

Vectors have two important features: that is the magnitude and the direction. The direction of a vector can be defined in terms of Cartesian coordinates (especially for collinear vectors). Conventionally, one direction of collinear vectors is taken as positive, so that the opposite will be negative.

Alternatively, the direction of a vector in 2-D can be described in terms of the bearing, and/or compass directions. A bearing is an angle that a vector makes as measured from the North pole of the compass in a clockwise direction.

Graphs

Certain mathematical skills are of importance in finding relationship between parameters under investigation in technical science.

Two variables are said to be directly proportional to each provided that:

- when the independent variable (x) is increased by the factor of a , the dependent variable (y) also increases by the same factor
- the ratio is $y : x$ is a constant (k), such that y is related to x according to the equation $y = kx$. The positive constant k is called the proportionality constant and is equal to slope of the graph of $y = kx$.
- Since $y = kx$, we can generalise that: $\frac{y_1}{x_1} = \frac{y_2}{x_2}$
the graph of y versus x is a straight line, that passes through the origin

Two variables are said to be inversely (or indirectly) proportional to each other provided that:

- when x increases by the factor of a , y decreases by the same factor
- the product of x and y is a constant (k), such that $y = \frac{k}{x}$. The positive constant k is called the proportionality constant.
- the graph of y versus x is hyperbola, which does not intersect with the axes, but gets closer when x is decreased to approximately zero, or increases to a very big number.

Collinear and co-planar vectors

Collinear vectors are vectors that are along the same line of action. They are parallel to one other. They can be added mathematically using the conventional sign rule or graphically, by drawing the vectors along the same line of action.

Co-planar vectors are vectors that lie along the same plane (for example, the x - y Cartesian plane). They are 2-D vectors.

When two co-planar vectors are perpendicular to each other, either the theorem of Pythagoras or an accurate scale drawing using the head-to-tail method, may be used to calculate their resultant.

Generally, the resultant of two simultaneous vectors that are separated by an angle θ can be found by using the method of the parallelogram of vectors.

The Parallelogram Law of Forces (or vectors) states that if two forces acting at a point can be represented by the adjacent sides of a parallelogram both in magnitude and direction, then the diagonal from the point gives the resultant of the two forces.

A vector that is acting an angle θ to the horizontal can be resolved into its horizontal and vertical components according to the formulae:

Horizontal component: $F_x = F \cos \theta$

Vertical component: $F_y = F \sin \theta$

Alternatively, the two components can be found by using accurate scale drawings

Friction

Frictional force is the force that an object encounters when it moves or attempts to move along a surface that opposes the motion or tendency of motion. It is always directed parallel to the surface in question.

The static frictional force acts between the two surfaces when the object tends to move.

When the object is accelerated by applying a force on it, the magnitude of static friction increases from zero until it reaches its maximum value (just when the object is at the verge of moving).

The maximum value of static friction (called limiting static friction) is given by the formula:

$$f_s^{\max} = \mu_s F_n$$

When the object is moving it opposes friction in the form of kinetic frictional force.

Kinetic frictional force is lesser than the static frictional. That is why it is more difficult to set a stationary object in motion, than to speed up an object already in motion.

The magnitude of the kinetic frictional force is given by: $f_k = \mu_k F_n$

Frictional force is directly proportional to the applied force

The coefficient of friction is the ratio of frictional force to the normal force: $\mu_s = \frac{f}{F_N}$



Objectives

By end of this chapter learners will gain a broad understanding and acquire skills relating to the following concepts:

- magnets
- magnetic fields
- poles of permanent magnets
- direction of magnetic fields
- the magnetic field of a bar magnet
- the force of a magnet
- the properties of magnetic field lines
- Earth's magnetic field

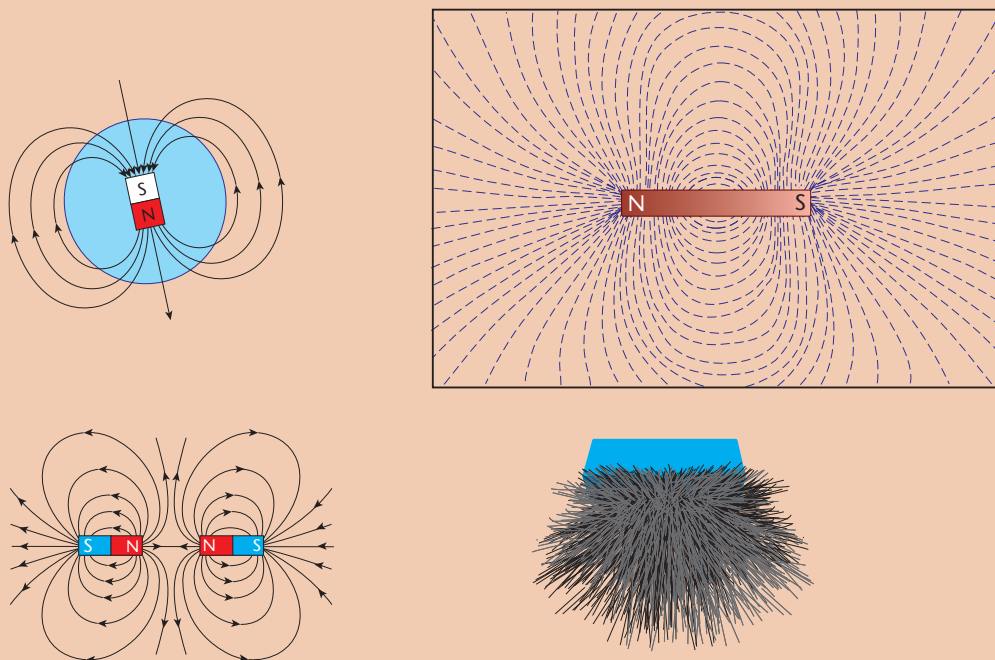


Why magnetism matters

Physicists' have made many important discoveries about how we are able to use magnets in different ways. Their knowledge has also enabled the development of many technologies that we use in our everyday lives.

Refrigerators, cars, elevators, and smart phones are only a few examples of gadgets that make use of magnets and magnetisms. All electric motors, generators – whether producing hydroelectric power or running bicycle lights – use magnetic fields. Even recycling facilities use magnets to separate iron from other refuse.

Thus magnetism plays many important roles in our lives.



2.1 Introduction

Magnets are made from minerals known as lodestones. Lodestones were discovered close to a town in the Greek Province of Magnesia, and the Magnates (people who lived in the town) found that the lodestones could attract iron objects. The lodestones became commonly known as magnets.

A bar magnet has two poles: north and south. These were just labelled by convention because when the Magnesia first discovered the loadstones, they took them, magnetised a needle and placed it in a piece of cork and bucket of water. The needle pointed to the Earth's magnetic north.

Like poles of the magnet repel each other and unlike poles attract one another.

A magnet generates a magnetic field around it. The magnetic field is generated by the electrons that spins around the magnet. Only certain materials, such as iron, cobalt, nickel, and gadolinium, exhibit strong magnetic effects. Such materials are called ferromagnetic, which is a combination of the Latin word for iron, *ferrum*, and the word magnetic.

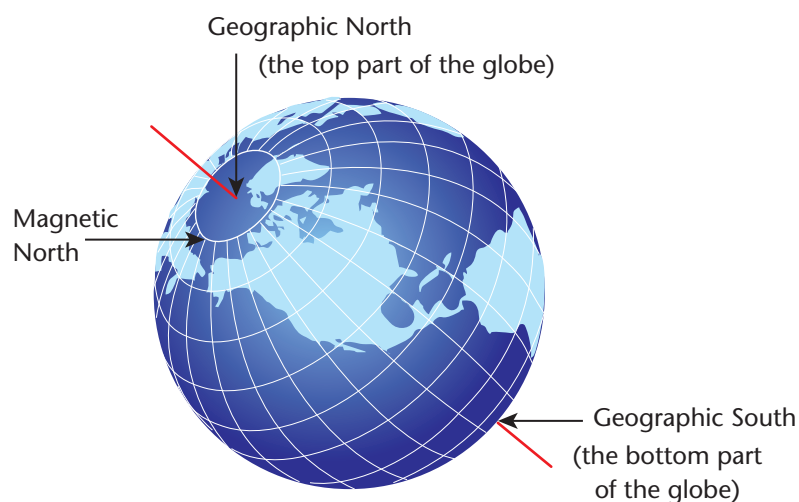
2.2 Important definitions

It is important for you to know and understand the terms we will use when we are learning about magnetism. Here are some important terms that we need to know:

2.2.1 Geographic North and South

The Geographic North Pole is the northern-most point on the planet where the Earth's axis intersects with its surface (that is, the top part of the globe).

The geographic South Pole is the southern-most point of the planet where the Earth's axis intersects with its surface (that is, the bottom part of the globe).



Simply put, the Geographic North Pole and Geographic South Pole are directly opposite to each other.

2.2.2 Magnetic north and south

The magnetic north is the place on Earth to which the north pole of magnets point.

The magnetic south is the place on Earth to which the south pole of magnets point.

2.3 Magnets

2.3.1 What magnets are

We can describe a magnet as a material that attracts magnetic objects towards it. As we have learned, all magnets have a pair of opposite poles – a north and south pole. Even if the magnet is cut into tiny pieces, each piece will still have both a north and south pole.

All types of magnets attract iron-containing objects such as paper clips, and nails as shown in Figure 2.1.

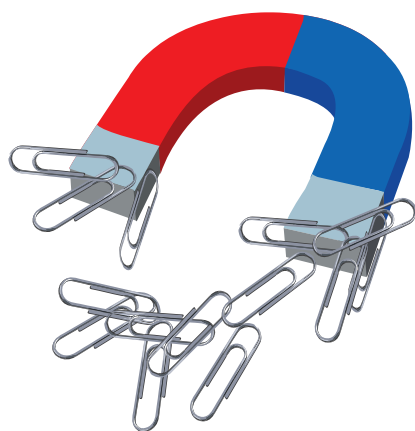


Figure 2.1 Paper clips attracted to the magnet

A magnet can hold these objects, or even make them move. The pulling force of the magnet is called its magnetic force. The physical phenomenon, which results in attractive and repulsive forces between objects, is called magnetism.

2.3.2 A dipole magnet

Look at the magnet shown in Figure 2.2. This type of magnet is known as a bar magnet.



Figure 2.2 A bar magnet

A bar magnet is a dipole. A dipole magnet is a magnet in which opposite poles (that is, the north and south poles) are on opposite sides of the magnet.

The simplest example of a dipole magnet is a bar magnet.

Materials containing iron have a strong attraction to the ends of such a magnet. If a bar magnet is suspended from its midpoint so that it can swing freely in a horizontal plane, it will rotate until its north pole points North and its south pole points South.

Let's look at this phenomenon.



Experiment 1: Determining the north pole of the Earth using a bar magnet

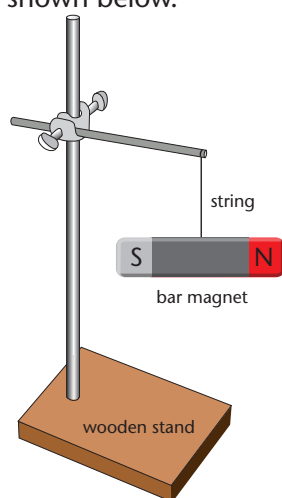
Aim To determine the north pole of the Earth using a bar magnet.

Material

- wooden stand or something similar
- bar magnet
- compass

Procedure

1. Tie a string in the middle of the magnet so that it can be suspended from a wooden stand as shown below.



2. Make sure that the magnet can rotate freely.
3. Allow the magnet to come to rest.
4. Mark two points on the ground to show the position of the ends of the magnet when it comes to rest.
5. Draw a line joining the two points. This line shows the direction in which the magnet was pointing in its position of rest.
6. Now, rotate the magnet by gently pushing one end in any direction and let it come to rest. Again, mark the position of the two ends in its position of rest. Does the magnet now point in a different direction?
7. Rotate the magnet in other directions and note the final direction in which it comes to rest.

Results

Write down your results.

Conclusion and discussion

- Discuss your findings with a partner and write down your conclusion.
- Did you find that the magnet always comes to rest in the same direction?
- Repeat this activity with an iron bar and a plastic or a wooden scale instead of a magnet. Do not use light objects for this activity and avoid doing it where there are currents of air.
- Do the other materials also always come to rest in the same direction?

2.3 Technological applications of magnetism

Magnets are also used in:

- meters
- motors
- generators
- loud speakers
- sound-and video-recording equipment
- on computer disks.

Apart from the uses of magnets discussed above and on page 40, magnets can also be used in large electromagnets that pick up heavy loads, as shown in Figure 2.4.

Electromagnets are currently used to contain extremely high-temperature plasmas that are used for research.

They are also used to levitate modern trains and in controlled nuclear fusion experiments.

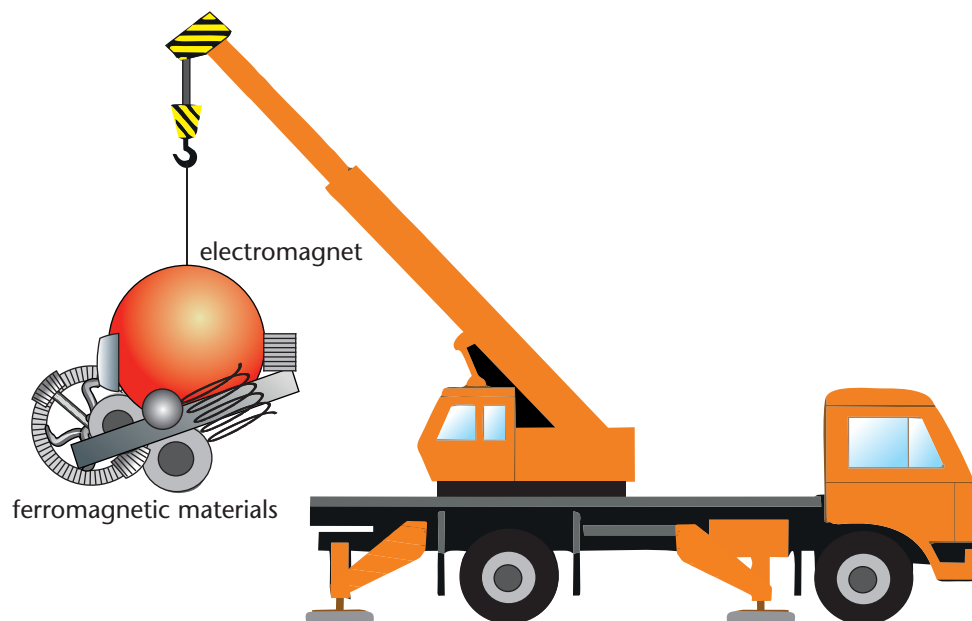


Figure 2.4 An electromagnet



PRACTICAL INVESTIGATION

Making a simple electromagnet

Scientists have found many links between electricity and magnetism, with one benefit of being an electromagnet that it can be turned on and off when needed.

Let's make our own electromagnet.

You will need:

- a long insulated copper wire
 - another shorter wire
 - an iron nail (with a 'relatively soft' core)
 - a cell
 - a switch
 - a box of pins or paper clips
1. Take a nail and hold it in one hand. Start winding the wire tightly around the nail.
 2. Make at least 20 turns in the wire, but make sure that you leave enough wire at the ends to attach to the switch and the cell.
 3. Strip the ends of the wire. Join one stripped end of the wire around the nail to the switch. Join the other end of the same wire to the negative terminal of a cell. Attach the shorter wire to positive terminal of the cell, and its end to the switch.
 4. Turn on the electric current. Place the end of the nail into the box of pins or paper clips. Observe what happens.
 5. Add another cell to your electromagnet. Does this make a difference? Does wrapping more wire around the nail to make more coils make a difference?

2.3.1 Like poles repel each other, and unlike poles attract each other

The north pole of a magnet is attracted to the south pole of another magnet, while two north poles (or two south-poles) brought together will repel each other. The magnetic force between two magnets can be likened to the electric force between charged objects. But electric charges differ from magnetic poles because they can be isolated, whereas magnetic poles cannot.

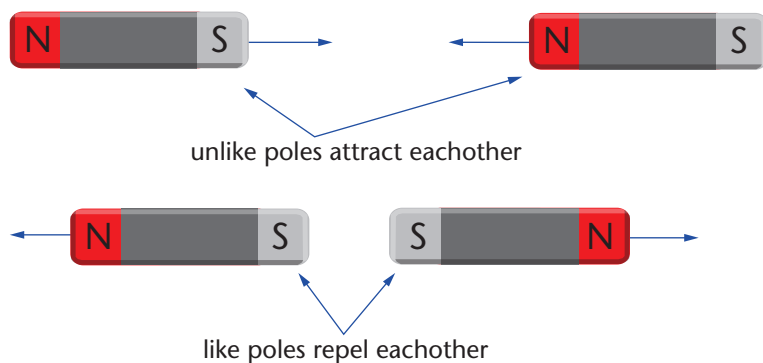


Figure 2.5 Like poles of the magnet repel each other and unlike poles attract one another

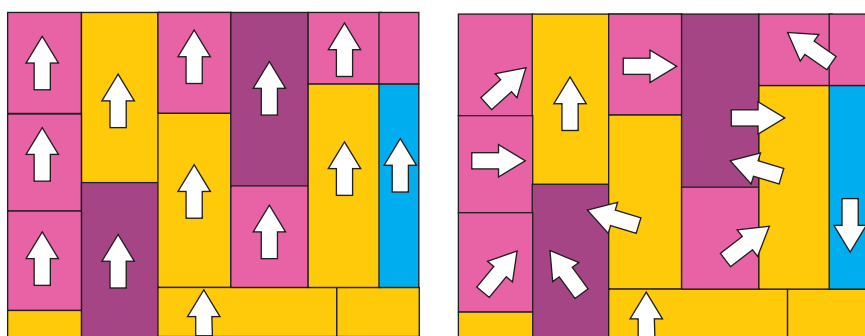
2.4 Magnetic domains

The magnetic properties of many materials can be explained using a model. In terms of this model, an electron is said to spin much like a top does. The spinning electron represents a charge that is in motion.

In substances such as wood and plastic that contain many electrons, the electrons pair up with their spin opposite, thus causing their magnetic fields to cancel each other. However, in substances such as iron, cobalt and nickel, the magnetic field produced by the electron spins do not cancel completely. Such substances are said to be ferromagnetic.

In ferromagnetic substances, a strong coupling occurs between neighbouring atoms. These couplings form large groups of atoms whose net spins are aligned. The ferromagnetic substance has very small (microscopic) regions in which the magnetic moments of the atoms move in the same direction. These microscopic regions are called magnetic domains.

Figure 2.6 shows that when a substance is unmagnetised, their domains are randomly orientated. Once an external magnetic field is applied, the orientation of the magnetic field of each domain may change slightly. The domains will become more closely aligned with the external magnetic field. Domains that are already aligned with an external field may also grow at the expense of other domains. This alignment enhances the applied magnetic field.



Domains of unmagnetised and magnetised materials.

- (a) When a substance is magnetised its domains are more closely aligned. (b) When a substance is unmagnetised its domains are randomly ordered.

Figure 2.6 Domains of magnetised and unmagnetised materials

2.5 Inducing unmagnetised iron (Fe)

Iron responds more strongly to magnets than all other ferromagnetics. As a result, iron can induce and magnetise all other material and make them into permanent magnets.

Figure 2.7 shows how an unmagnetised piece of iron is placed between two magnets, heated, and then cooled, or simply tapped when cold. The iron then becomes a permanent magnet.

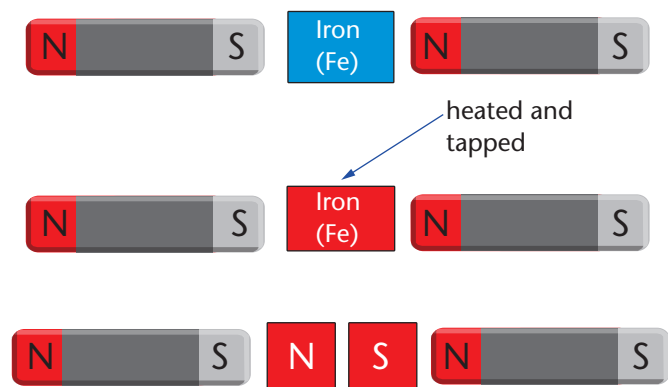


Figure 2.7 Iron becomes a permanent magnet



Activity 2.1

1. How many poles does a bar magnet have?
2. Describe what happens when like poles of a bar magnet get close to one other and what happens when unlike poles get close to one other.
3. Where is the force of a magnet the strongest?
4. What is the difference between permanent magnets and temporary magnets?
5. How can you turn an iron nail into an electromagnet?
6. Explain why an electromagnet is a temporary magnet.
7. How are electromagnets and bar magnets alike? How are they different?

2.6 Magnetic field

Magnetic field is the region in space where another magnet or ferromagnetic material will experience a force. Magnetic field is generated by the electrons that spins around it. Just like gravitational force, magnetic force acts at a distance. We therefore define a magnetic field to represent magnetic force.

The pictorial representation of magnetic field lines helps us to visualise the strength and direction of the magnetic field. Figure 2.8, shows the direction of magnetic field lines to be the direction in which the north end of a compass needle points.

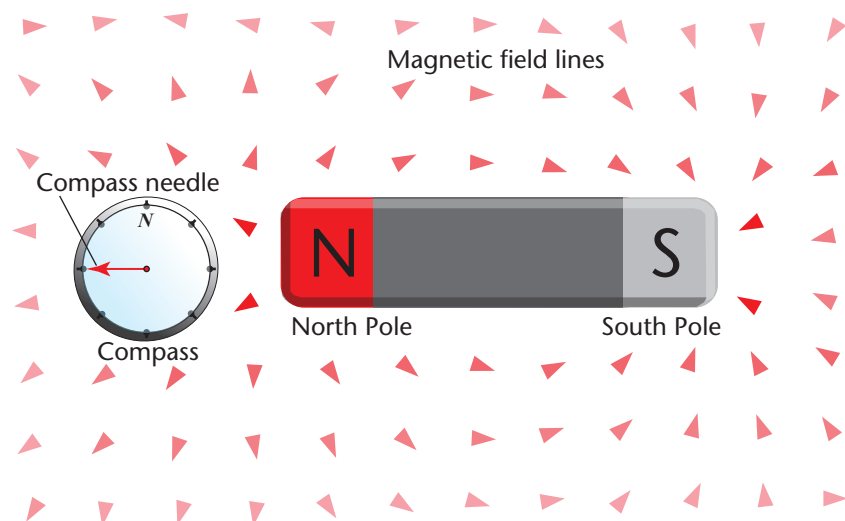


Figure 2.8 Direction of the magnetic field lines around a bar magnet (adapted from Phet submissions)

The red arrows indicate the direction of magnetic field lines. The magnetic field lines move from the north pole to the south pole outside the magnet. However, the field lines move from the south pole to the north pole inside the bar magnet. Magnetic field lines are closed – they do not have a starting point and an ending point.

2.4.1 Magnetic field between two bar magnets

A simple experiment can be carried out to visualise the behaviour of the magnetic field lines around a bar magnet. When two bar magnets are placed on a flat surface, a white sheet of paper (page) is placed on top of it, iron powder is sprinkled liberally on and around the region where the bar magnet is placed, and the page is tapped gently on all sides, we will observe a magnetic field pattern.

Note: You could use iron filings instead of iron powder, but iron powder gives a clearer result.

This is shown in Figure 2.9(a) and (b).

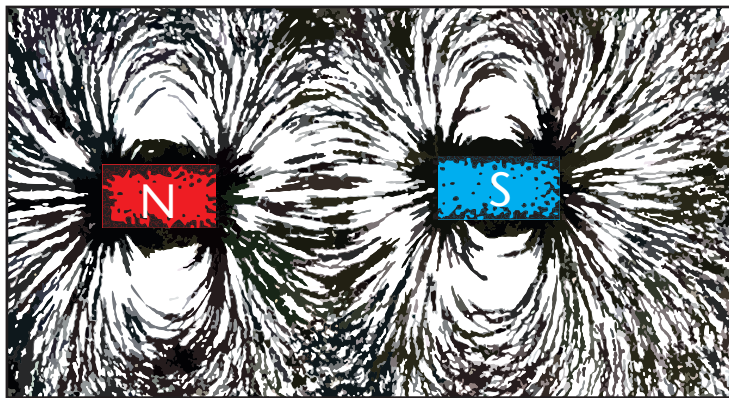


Figure 2.9(a) *Iron filings showing magnetic field lines around two bar magnets (unlike poles)*

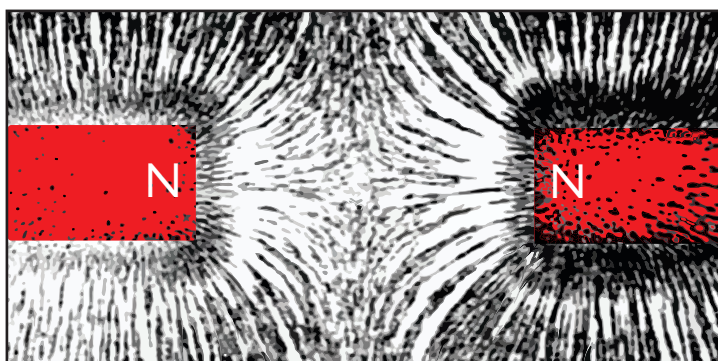


Figure 2.9(b) *Iron filings displaying magnetic field lines around two bar magnets (like poles)*



Experiment 2: Magentic field lines

Aim To map the magnetic field

Material

- bar magnet
- compass
- blank A4 or A3 paper

Procedure

1. Begin by putting the magnet in the middle of a large sheet of paper and outlining its form on the paper with a pencil. Label the N and S poles of the magnet on the paper.
2. Put a compass at one corner of the north pole of the magnet. On the paper, using dots, mark the positions of the N and S poles of the compass needle.
3. Move the needle a little further from the magnet until the new position of its S pole coincides with the dot marking the previous position of its N pole. Mark the new position of the N pole by a dot.
4. Again move the compass making the S pole coincide with the previous location of the N pole and mark the new position of the N pole by a dot.
5. Continue the process until the compass reaches the S pole of the magnet. This closed curve is a complete line of force. Place an arrow on it, showing its direction (away from the N and toward the S).
6. Beginning at another point on the N pole of the magnet, trace a second complete line of force. Continue with this process until you have a minimum of 8 lines of force.

Results

Redraw your magnetic field map.

Discussion and conclusion

Write down your conclusions

The filed lines should be somewhat symmetric and balanced. If they are not, look for other magnets in the area. If time permits, map the field between two pole configurations assigned by your teacher.

Questions

1. Are the lines more concentrated in some areas than in others? What does that tell you about the relative strength of the field in those places?
2. Lines of force never cross. Explain.

You should have observed a pattern similar to that shown in Figure 2.10.

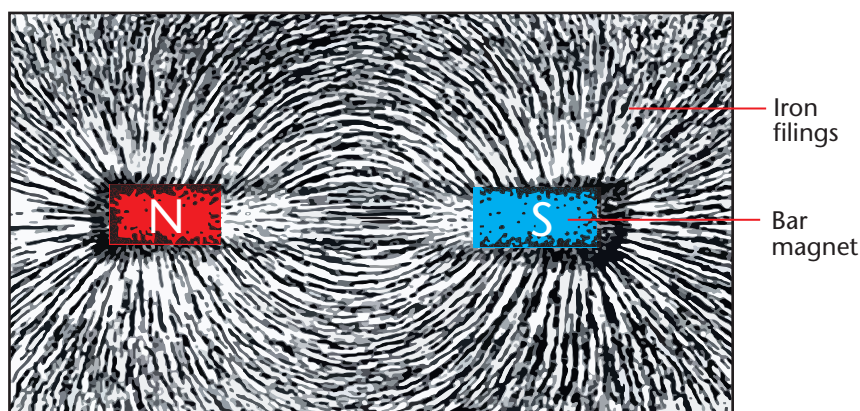


Figure 2.10 *Iron filings on thin sheets of paper over bar magnet.*

3. Draw magnetic field lines for each of the following:
 - a) around a bar magnet
 - b) between two opposite bar magnets (i.e. north pole facing south pole)
 - c) between two like bar magnets (i.e. north pole facing north pole of the other magnet).

2.7.2 Properties of magnetic field lines

We use magnetic field lines to represent the field. Their properties can be summarised by these rules:

1. The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line.
2. The strength of the field is proportional to the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines (called the arial density).
3. Magnetic field lines can never cross, meaning that the field is unique at any point in space.
4. Magnetic field lines are continuous, forming closed loops without beginning or end.
5. Magnetic field lines move from the north pole to the south pole.

Remember that the north and south poles cannot be separated.

2.8 Earth's Magnetic field

Earth has a magnetic field that is similar to that of a bar magnet. The north and south pole of a small bar magnet are described as 'north seeking' and 'south seeking' poles.

This description means that if a magnet is used as a compass, the south pole of the magnet will seek to, or point to, a location near the geographic North Pole of the Earth.

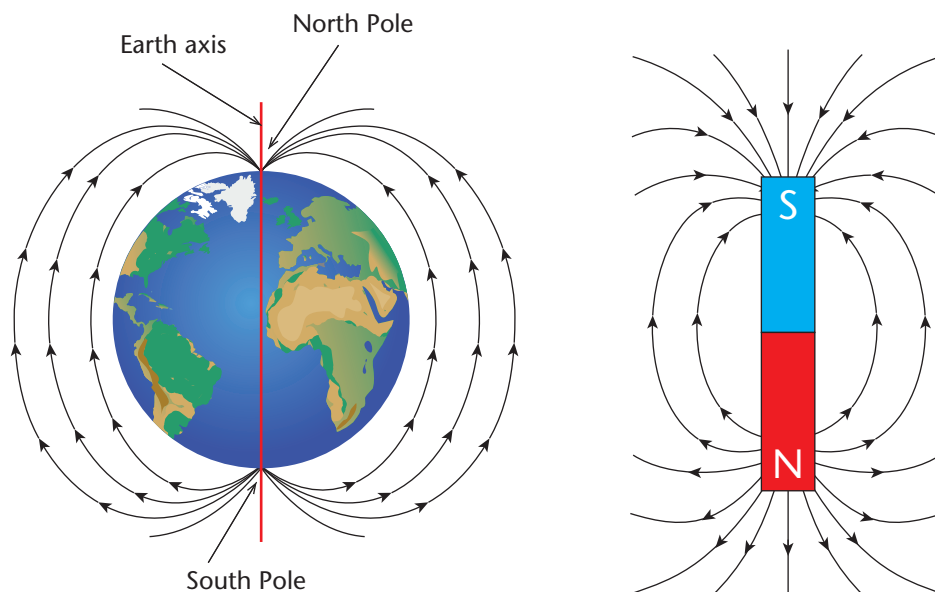


Figure 2.11 a) and b) The Earth has a magnetic north pole and south pole

The Earth's magnetic north and south pole is surrounded by a magnetic field, just as a bar magnet's north and south pole are. But the Earth's magnetic north pole corresponds to the south pole of a bar magnet, and the Earth's magnetic south pole corresponds to the north pole of a bar magnet. This is true because unlike poles attract.

If a compass needle is allowed to rotate both perpendicular and parallel to the surface of the Earth, the needle will be exactly parallel with respect to the Earth's surface only near the equator. As the compass is moved northward, the needle will rotate so that it points more towards the surface of the Earth. Finally, at a point just north of Hudson Bay, in Canada, the north pole of the needle will point perpendicular to the Earth's surface. This site is considered to be the location of magnetic South Pole of the Earth. It is approximately 1 500 km from the Earth's geographic North Pole. Similarly, the magnetic north pole of the Earth is roughly the same distance as from geographic South Pole.

The difference between true north, which is defined by the axis of rotation of the Earth, and north indicated by the compass, varies from point to point on Earth. This difference is referred to as magnetic declination.

2.8.1 Geographic North vs magnetic north pole

The difference between the geographic North Pole and the magnetic north pole is that the former is a geographic pole with a stationary location at 90° North. This geographic North Pole, also known as true north, is the fixed northern-most point on the Earth from which all points lie south.

The magnetic pole is not based on true north, but on the magnetosphere of the planet. The distance is about 1 500 km from true north, with its exact position constantly changing. This is shown in Figure 2.12.

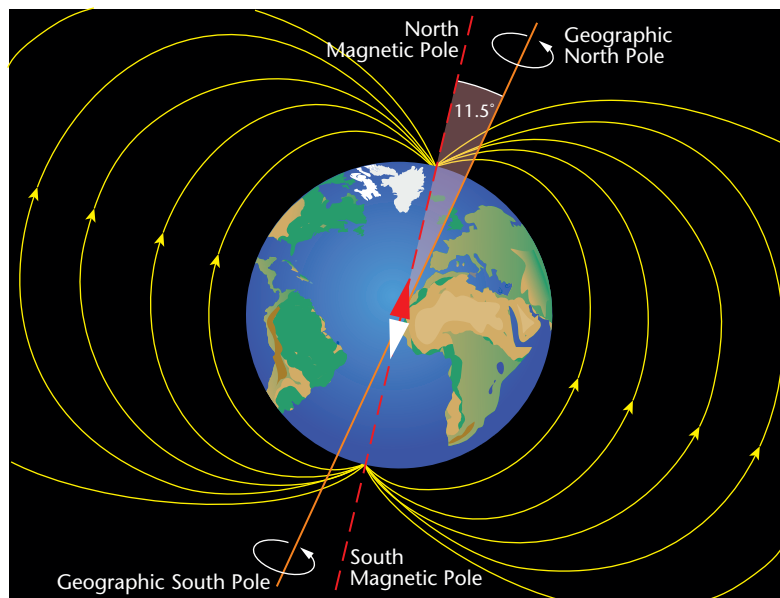


Figure 2.12 The Earth is a large magnet.

2.8.2 The importance of the magnetic field to life on Earth

The Earth's magnetic field is very important for humans and other animals on Earth because it protects us from being bombarded (struck) by high energy charged particles, which are emitted by the Sun.

The stream of charged particles (mainly positively charged protons and negatively charged electrons) coming from the Sun is called a solar wind. When these particles come close to the Earth, they are deflected by the Earth's magnetic field and cannot shower down to the surface where they can harm living organisms. Astronauts in space are at risk of being irradiated by the solar winds because they are outside the zones where the charged particles are trapped.

The region above the Earth's atmosphere in which charged particles are deflected by the Earth's magnetic field is called the magnetosphere. This is shown in Figure 2.13.

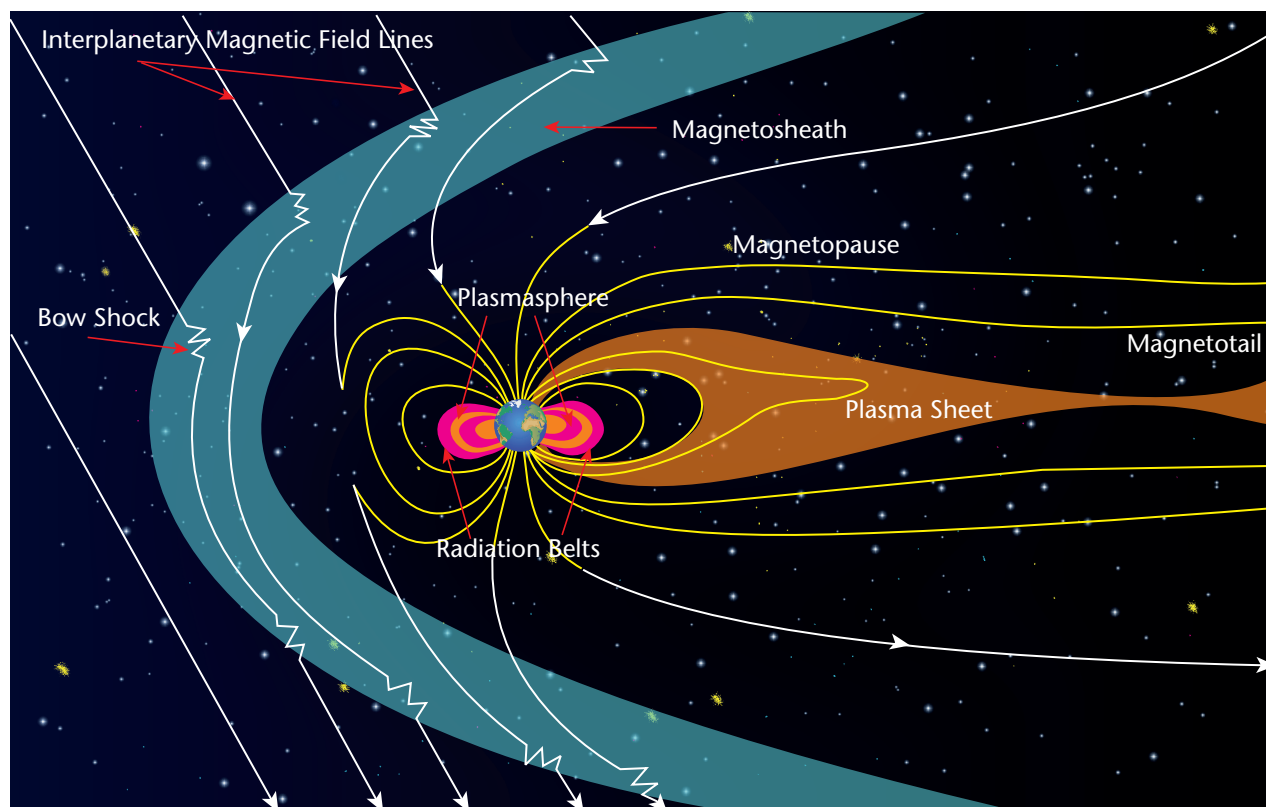


Figure 2.13 A magnetosphere is that area of space, around a planet, that is controlled by the planet's magnetic field. The shape of the Earth's magnetosphere is the direct result of being blasted by solar wind. The solar wind compresses its sunward side to a distance of only 6-10 times the radius of the Earth.

Relatively often, in addition to the usual solar winds, the Sun may eject a large bubble of material (protons and electrons) with its own magnetic field from its outer atmosphere. Sometimes these bubbles travel towards the Earth where their magnetic fields can join with Earth's magnetic field. When this happens, a huge amount of energy is released into the Earth's magnetosphere causing a geomagnetic storm. These storms cause rapid changes in the Earth's magnetosphere which in turn may affect electric and magnetic systems on the Earth such as power grids, cell phone networks, and other electronic systems.

2.8.3 Aurora Borealis Aurorae (pronounced Or-roar-ee)

Another effect caused by the Earth's magnetic field is the spectacular Northern and Southern Lights, which are also called the Aurora Borealis (Figure 2.14) and the Aurora Australis respectively (Figure 2.15).



Figure 2.14 *Aurora borealis photographed in Alaska photographed from space (adapted from NASA)*

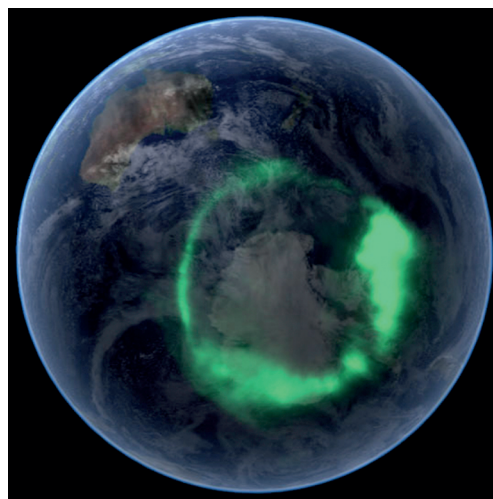


Figure 2.15 *Aurora australis (adapted from NASA)*

When charged particles from the solar wind reaches the Earth's magnetosphere, they spiral along the magnetic field lines towards the North and South poles. If they collide with particles in the Earth's atmosphere, they can cause red or green lights that stretch across a large part of the sky. This is called an aurora.

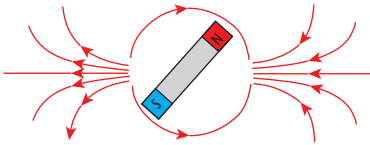
As this only happens close to the North and South poles, we cannot see the aurorae from South Africa. However, people living in the high Northern latitudes in Canada, Sweden, and Finland, for example, often see the Northern lights.

Review exercise

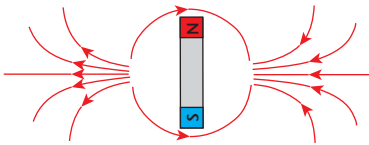
MULTIPLE CHOICE QUESTIONS

1. A bar magnet is divided in two pieces. Which of the following statements is true?
 - A. The bar magnet is demagnetised.
 - B. The magnetic field of each separated piece becomes stronger.
 - C. The magnetic poles are separated.
 - D. Two new bar magnets are created.
 - E. The electric field is created
2. A bar magnet is divided in two pieces. Which of the following statements is true about the force between the broken pieces if they face each other with a small separation?
 - A. There is an electric repulsive force between the broken pieces.
 - B. There is an electric attractive force between the broken pieces.
 - C. There is a magnetic repulsive force between the broken pieces.
 - D. There is a magnetic attractive force between the broken pieces.
 - E. There is no force between the broken pieces since they are demagnetised
3. Which of the following magnetic fields is correct for a single bar magnet?

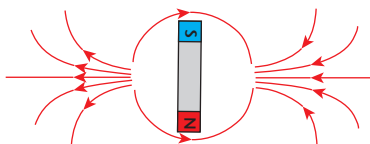
A



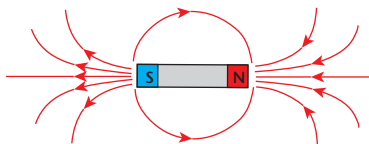
B



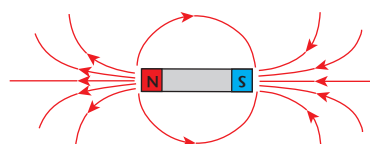
C



D



E


4. Magnetism is similar to electricity, but different from gravity, because magnetism and electricity:
 - A. depend on charge
 - B. can attract and repel
 - C. depend on mass
 - D. all three
 - E. none of the above

5. A magnetic field is different from both an electric and a gravitational field because:
- A. it only acts on a few elements
 - B. does not follow an inverse square law
 - C. has closed field lines
 - D. none of the above
 - E. all of the above
6. What is true about the field lines of all electric, magnetic, and gravitational fields? They:
- A. form loops
 - B. radiate from charges or masses
 - C. show the path that a particle will follow
 - D. have same direction
 - E. never cross

LONG QUESTIONS

- 7. What is a magnet?
- 8. Explain what is meant by the term magnetic field.
- 9. Explain, with the aid of a diagram, why permanent magnets have a magnetic field around them. Refer to domains in your explanation.
- 10. List the examples of ferromagnetic materials.
- 11. What happens when a permanent magnet is cut into pieces?
- 12. What happens when the like poles of a magnet are brought closer together?
- 13. What happens when the opposite poles of a magnet are brought closer together?
- 14. Discuss the properties of magnetic field lines.
- 15. Draw the magnetic field lines around the bar magnet shown below:



- 16. Explain how a compass indicates the direction of the magnetic field.
- 17. Compare the magnetic field of the Earth and that of the bar magnetic. Use diagrams to enhance your explanation.
- 18. Explain the difference(s) between the geographical North and the magnetic north pole of the Earth.
- 19. Give examples of phenomena that are affected by the Earth's magnetic field.
- 20. Draw a diagram showing the magnetic field of the Earth.
- 21. Compare the geographic North Pole with the magnetic north pole.
- 22. Explain the difference between the geographical North pole and the magnetic North pole of the Earth.
- 23. Discuss qualitatively how the Earth's magnetic field provides protection from solar winds.

3

Waves and sound



Objectives

By end of this chapter learners will gain a broad understanding and acquire skills relating to the following concepts:

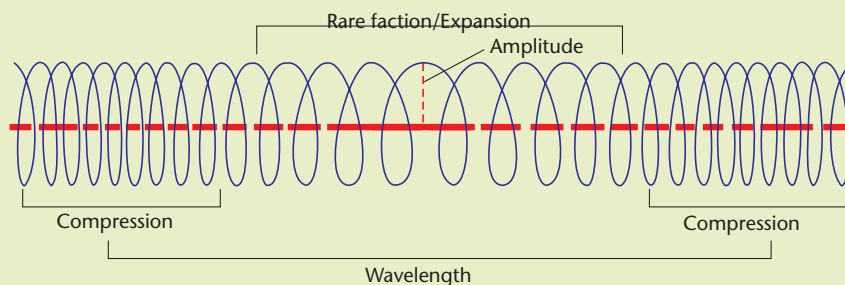
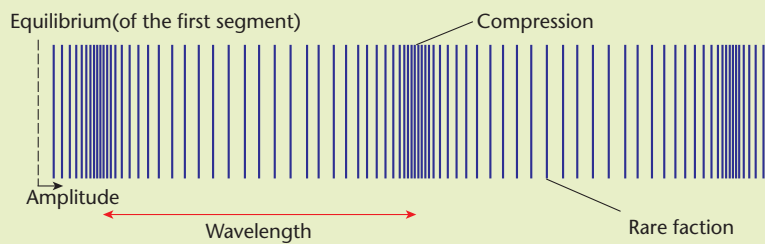
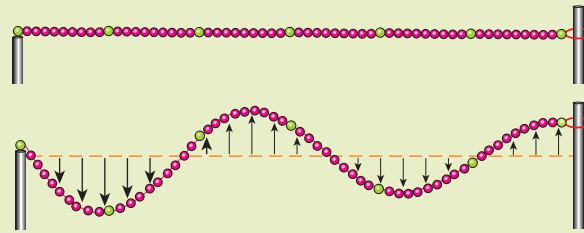
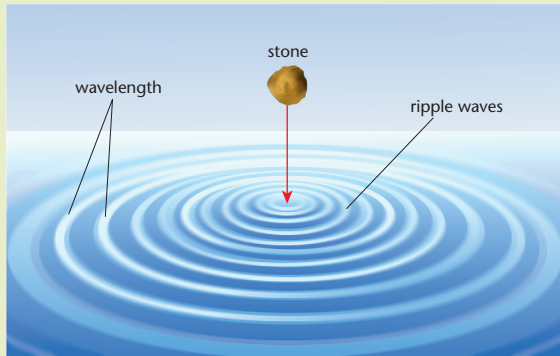
- pulse wave and periodic wave
- transverse and longitudinal wave
- relationship between frequency and period
- wave speed
- superposition of waves
- sound waves
- speed of sound in different media
- reflection of sound (echo)
- pitch, loudness, range of sound frequencies.



Why waves and sound matters

Seeing, hearing, feeling warmth, surfing, tuning the radio, using a cell-phone – are just some of the many activities that rely on waves.

Studies conducted by scientists and engineers involving vibrating strings and waves, helped them to understand what happens in atoms and molecules, electronic apparatus and antennae. Thus, learning about the vibrations in strings and the resultant waves, supports our scientific understanding.



3.1 Introduction

Waves are everywhere, they transfer energy from one form to another. For example, what you listen to on the radio and watch on TV, is broadcast using waves. Talking to others on a cell phone is made possible with the use of waves. You even use waves – by using the microwave – to warm and cook some food.

Thus waves are very useful to us on a daily basis. However, there are some waves that can also be harmful – even deadly – to us.

Look at Figure 3.1. Ripple waves in a river start with a disturbance at some point in the water. This disturbance causes water on the surface near that point to move, which in turn causes points farther away to move.

The waves travel outward in a circular pattern away from the original disturbance.

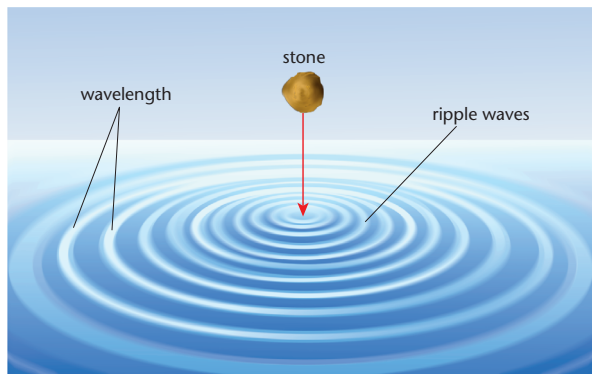


Figure 3.1 *Ripple waves in a river*

In this example, the water in the river is the medium through which the disturbance travels. Particles in the medium move up and down as the wave passes through.

Remember that the medium does actually travel with the waves. So in this example, after the waves have passed, the water returns to its original position.

3.2 Pulses

A **pulse** is a single disturbance that moves through a medium. This is shown in Figure 3.2.

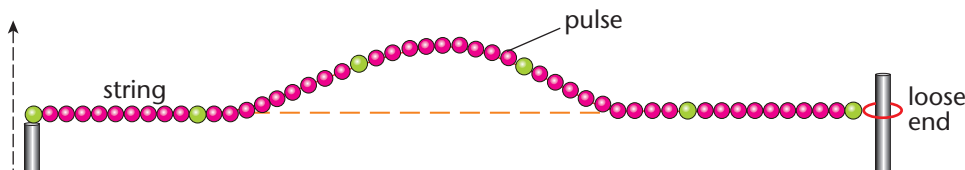


Figure 3.2 *A transverse pulse*

When a series of pulses are produced, in a regular, repetitive manner, a wave is formed. If the pulses are transverse pulses, then the wave formed is a transverse wave. If the pulses formed are longitudinal pulses, then the wave formed is a longitudinal wave.

In this chapter we will focus on two pulses, namely, transverse and longitudinal pulses.

3.2.1 Transverse pulse

A **transverse pulse** is a pulse where all the particles disturbed by the pulse move perpendicular (at right angles) to the direction in which the pulse is moving as shown in Figure 3.2.

3.2.2 Longitudinal pulse

A longitudinal pulse is a single disturbance in which particles of the medium move parallel to the direction in which the wave is moving (propagating). This is shown in Figure 3.3.

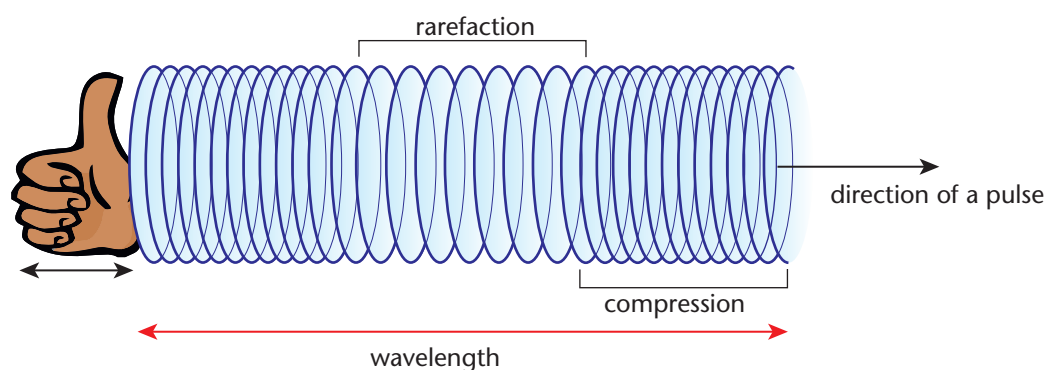


Figure 3.3 A longitudinal pulse

The particles move back and forth as the wave moves through.



PRACTICAL INVESTIGATION

Demonstrate a single vibration in different media

Materials

- shallow dish
 - water
 - coin or stone
1. Fill a shallow transparent Petri dish or any dish with water. The water must be still.
 2. Drop a coin or small stone into the water so that it falls into the centre of the dish.

Questions

1. What pattern does the coin produce in the water?
2. Where does the energy to make the pulse come from?
3. Explain your observation.

3.3 Waves

What do an ocean buoy, a child in a swing, the coil inside a speaker, a guitar, atoms in a crystal, the motion of chest cavities, and the beating of hearts all have in common? They all oscillate – that is, they move back and forth between two points.

Many systems oscillate, and they have certain characteristics in common. All oscillations involve force and energy. For example, you push a child in a swing to get the motion started; or you put energy into a guitar string when you pluck it.

Some oscillations create waves. So in our examples, a guitar string creates sound waves; or waves are made in a swimming pool by slapping the water with your hand.

A wave is a succession of pulses. Each wave transports energy from one location (its source) to another location. During this exchange, no matter is transported, but each individual particle of the medium is temporarily displaced before returning to its original equilibrium position.

This is illustrated in Figure 3.4.

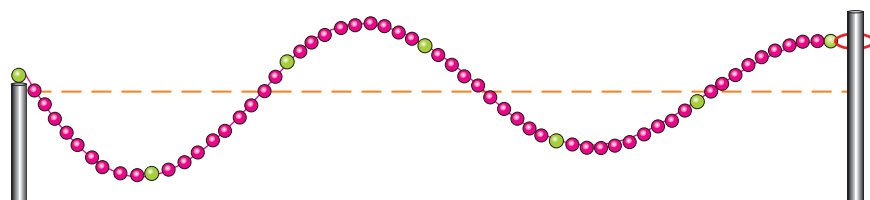


Figure 3.4 Succession of pulses – a wave

Some electromagnetic waves such as gamma ray, x-rays, ultraviolet, visible light, infrared, microwaves and radio waves can travel through a vacuum.

However, some waves require a material medium in which to travel. These waves are called mechanical waves. For example, sound waves cannot travel through vacuum, but need a medium such as air or water.

3.3.1 Medium

A medium is just the substance or material through which waves move. In other words, the medium carries the wave from one place to another. The medium does not create the wave and the medium is not the wave.

Air, water and rock are good examples of media (media is the plural of medium). Air is a medium for sound waves, water is a medium for water waves and rock is a medium for earthquakes (which are also a type of wave).

3.3.2 Transverse wave

As we have already learned, a transverse wave is a wave in which the particles of the medium vibrate at right angles (perpendicular) to the direction of propagation of the wave. Look at Figure 3.4(a). It shows a string tied to a fix point.

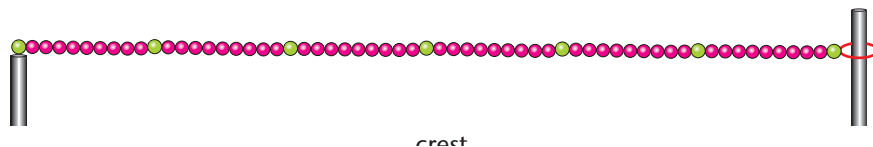


Figure 3.4(a) A string tied to a fix point.

Figure 3.4(b) shows that when we shake the end of the string up and down, we will observe transverse waves propagating through the string.

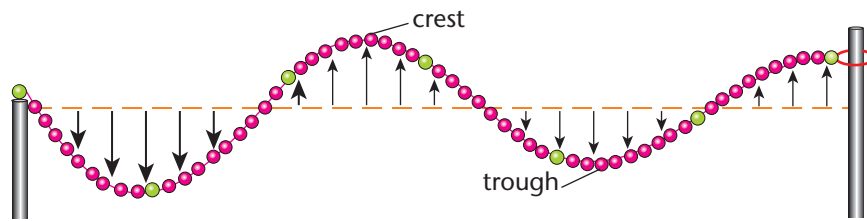


Figure 3.5(b) Transverse wave particles of the medium move perpendicular to the direction of propagation

High points in the wave are called crests. Low points in the wave are called troughs. A series of crests and troughs form a transverse wave. The crests and the troughs propagate along the string, and the particles in the string move up and down.

The distance between the successive crests or troughs is called a wavelength. This is shown in Figure 3.6.

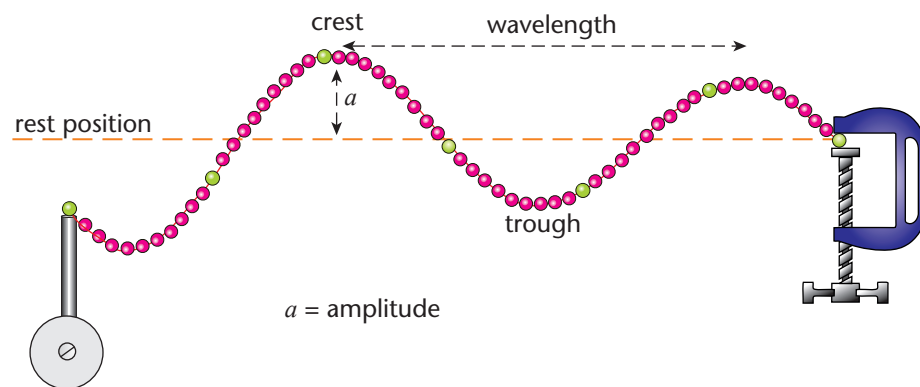


Figure 3.6 A transverse wave

The x -axis represents the equilibrium position of the string. The curve shows the displacement of the wave at time t .

3.3.3 Longitudinal wave

In a longitudinal wave the particles move in the medium in the same dimension as the direction of movement of the wave. The wave particles vibrate back and forth along the path that the wave travels.

Examples of longitudinal waves include:

- sound waves
- P -type earthquake waves
- compression wave

Longitudinal waves create areas of compression where particles are pushed together (higher density), and rarefaction where particles are pulled apart (lower density). This is shown in Figure 3.7.

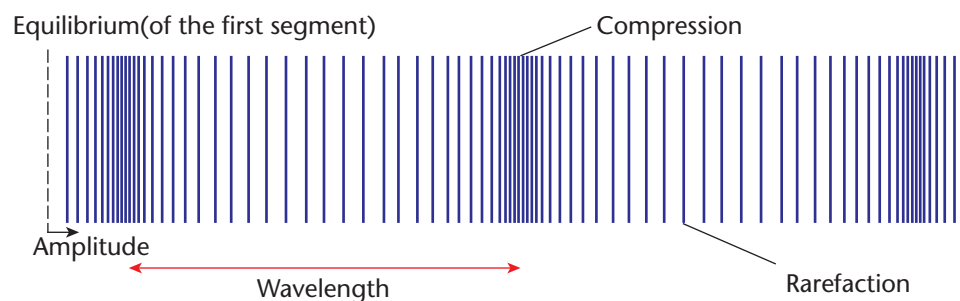


Figure 3.7 A longitudinal wave



PRACTICAL INVESTIGATION

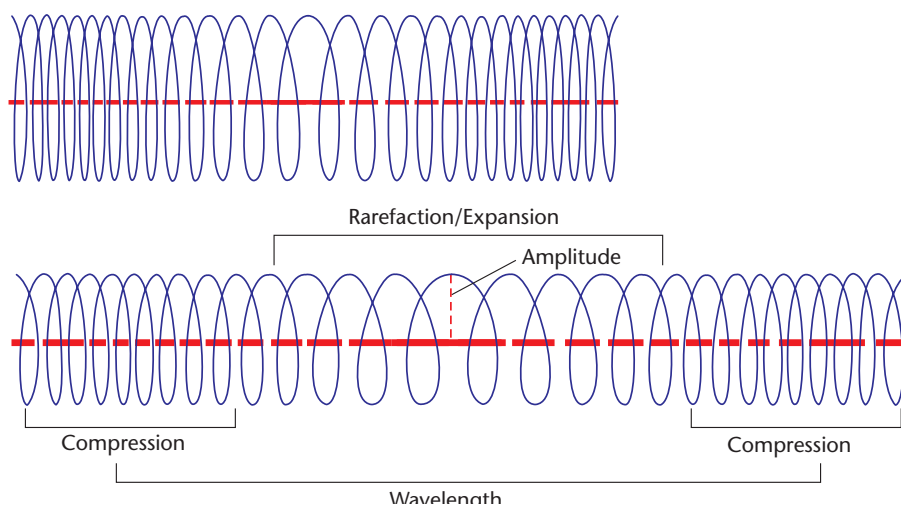
Generate a longitudinal wave in a slinky or spring

Materials

- Slinky

Method

1. Hold a slinky stretched between two learners on a smooth surface such as the floor.
2. Quickly move your hand forwards and backwards.
3. Observe the wave produced.
4. Tie a piece of ribbon to one of the coils. This will represent a particle in the medium.



Questions

1. What is a pulse?
2. In which direction does the pulse move?
3. In which direction does the particle in the medium move?
4. How does the particle move relative to other particles in the medium?
5. What do we call a series of repeating or periodic disturbances that move through a medium from one location to another?

3.3.4 Differences and similarities between transverse and longitudinal waves

Table 3.1 compares how transverse and longitudinal waves are similar and in which ways they are different.

Table 3.1 Comparison of transverse and longitudinal wave

Differences	
Transverse wave	Longitudinal waves
Particle of the medium vibrate parallel to the direction of propagation of the wave	Particle of the medium vibrate perpendicular to the direction of propagation of the wave
The wave travels in the form of compressions and rarefaction	The wave travels in the form of crests and troughs
One compression and a rarefaction constitute one wave	One crest and one trough constitute one wave
Cannot be polarised	Can be polarised
Similarities	
They are both mechanical waves—they require medium to propagate	
Both a transverse and longitudinal wave can be described with a displacement time graph.	

3.4 Wave terminology

To master the concepts you will learn about in this Chapter, it is important for you to understand the terms used. The key terms are, frequency, period, wave speed, wavelength and wave speed.

3.4.1 Frequency and period

Frequency and period are distinctly different, yet related, quantities. The quantity, frequency, is often confused with the quantity, period. Thus it is important for us to understand the difference between these two quantities.

Frequency

Frequency is the number of waves passing a point per second. Frequency:

- refers to how often something happens
- is a rate quantity
- is the cycles/second.

Frequency is measured in Hertz (Hz) or per second (s^{-1}) and we use this formula to calculate it:

$$f = \frac{\text{number of waves}}{\text{time}} = f = \frac{1}{T}$$

Period

A period is the time taken to complete one wave. Period:

- refers to the time it takes something to happen
- is a time quantity
- is the seconds/cycle.

Period (T) is measure in seconds (s) and we use this formula to calculate it:

$$T = \frac{\text{time}}{\text{number of waves}} = T = \frac{1}{f}$$

The relationship between frequency and period is: $f = \frac{1}{T}$

3.4.2 Differences between frequency and period

Table 3.2 lists the differences between frequency and period.

Table 3.2: Differences between frequency and period

Frequency	Period
Frequency refers to how often something happens	Period refers to the time it takes for something to happen
Frequency is a rate quantity (Hz or s^{-1})	Period is a time quantity (s)
Frequency is the cycles/second $f = \frac{1}{T}$	Period is the seconds/cycle $T = \frac{1}{f}$

Example 3.1

DETERMINE THE FREQUENCY OF MEDICAL IMAGING DEVICE

A medical imaging device produces ultrasound by oscillating with a period of 0,3000 ms . What is the frequency of this oscillation?

1 ANALYSE

Given: $T = 0,300\mu\text{s} = 0,300 \times 10^{-6}\text{s}$

Unknown: $f = ?$

2 SOLVE

Use the equation relating frequency and period:

$$f = \frac{1}{T}$$

$$f = \frac{1}{0,300 \times 10^{-6}\text{ Hz}}$$

$$\therefore f = 3,33 \times 10^6\text{ Hz}$$

The frequency of sound ($3,33 \times 10^6\text{ Hz}$) is much higher than the highest frequency (2 000 000 Hz) that humans can hear and, therefore, is called ultrasound.

Appropriate oscillations at this frequency generate ultrasound used for non-invasive medical diagnoses, such as observations of a foetus in the womb.

Example 3.2**DETERMINE THE PERIOD OF MIDDLE C ON A MUSICAL INSTRUMENT**

The frequency of middle C on a typical musical instrument is 260 Hz.
What is the time for one complete oscillation?

1 ANALYSE

Given: $f = 260 \text{ Hz}$

Unknown: $T = ?$

2 SOLVE

Use the equation relating frequency and period:

$$T = \frac{1}{f}$$

$$T = \frac{1}{260}$$

$$\therefore T = 3,85 \times 10^{-3} \text{ s} = 3,85 \text{ ms}$$

The period found is the time per cycle, but this value is often quoted as simply the time in convenient units (ms or milliseconds in this case).

**Activity 3.1**

1. A medical imaging device produces ultrasound by oscillating with a period of 0,400 ms. What is the frequency of this oscillation?
2. The frequency of middle D on a typical musical instrument is 294 Hz. What is the time for one complete oscillation?
3. Identify an event in your life (such as receiving a monthly salary) that occurs regularly. Identify both the period and frequency of this event.

3.4.2 Wave velocity

Wave velocity (speed) is not the same as wave frequency. It is the speed with which a wave crest passes by a particular point in space in a particular direction. It is measured in $\text{m}\cdot\text{s}^{-1}$.

So while wave frequency refers to the number of cycles occurring per second, wave velocity refers to the metres travelled per second.

A wave can vibrate back and forth very frequently, yet have a small speed; or a wave can vibrate back and forth with a low frequency, yet have a high speed.

We use the following formula to calculate wave velocity: wave velocity = frequency $\times$ wavelength or $v = f \times \lambda$. Thus, wave speed is equal to the product of frequency and wavelength.

We can also derive an expression for speed of a wave in terms of its period and frequency. Let's see how this can be done.

Table 3.3 Derivation of the wave speed formula

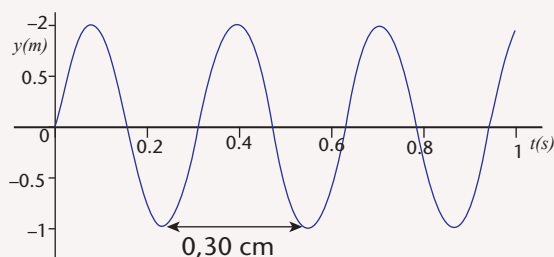
We know that speed is equal to displacement divided by the time it takes to undergo that displacement.	$v = \frac{\Delta x}{\Delta t}$
For waves, a displacement of one wavelength (λ) occurs in a time interval equal to one period of vibration (T).	$v = \frac{\lambda}{T}$
But frequency and period are inversely proportional (that is, $T = \frac{1}{f}$). Substituting this frequency relationship in $v = \frac{\lambda}{T}$.	$\therefore v = \frac{\lambda}{\frac{1}{f}} = f\lambda$ $v = f\lambda$

Let's look at an example to help us understand wave velocity.

Example 3.3

MEASURING THE WAVE VELOCITY OF A TRANSVERSE WAVE

Measure the wave velocity of the transverse wave below:



1 ANALYSE

1. Count the number of crest(s) passing a point in one second.
2. In the figure above there are 3,25 waves passing a point in one second.
3. The wavelength is given as 0,30 cm.

2 SOLVE

1. Calculate the frequency of the source that generated the waves. Since there are 3,25 waves passing a point in one second, the frequency is $\frac{1}{3,25} = 0,31$ Hz.
2. To calculate the speed of a wave, use the formula $v = f \times \lambda$.

Note Remember to make sure that the quantities are expressed in SI units.

Since the wavelength is expressed in centimetres, convert it to metres:

$$0,30 \text{ cm} = \frac{0,30 \text{ cm}}{1} = \frac{1 \text{ m}}{100 \text{ cm}} = 0,0030 \text{ m}$$

Therefore, the speed of a wave will be $0,31 \times 0,0030 = 0,00093 \text{ m}\cdot\text{s}^{-1}$

3.5 Speed of sound in different media

The speed of a sound wave depends on what type of medium it is traveling through, and if that medium is a gas or liquid. A significant change in temperature can also affect the wave speed.

Table 3.4 shows the speed of sound in different media. For example, the speed of sound in water at 25° is 1 493 m·s⁻¹.

Table 3.4 *Speed of sound in different media*

Medium	Velocity (m·s ⁻¹)
Air (20 °C)	343
Air (0 °C)	331
Water (25 °C)	1 493
Sea water	1 533
Diamond	12 000
Iron	5 130
Copper	3 560
Glass	5 640

3.6 Formal experiment: Determine the speed of sound in air

The average speed of sound through air is about 344 metres per second at room temperature. However, changes in temperature and humidity will affect this speed.

Apparatus

- stop watch
- two blocks of wood, or other items that make a loud, sharp sound when struck together or a toy pistol
- a friend to help with the experiment
- a tape measure or long line of known length

Method

1. Find a large empty area, such as a field or large court (at least more than 100 m).
2. Choose two spots on opposite ends of the area where each person will stand.
3. Measure the distance between the two spots using a tape measure. Alternatively, you can count off measured steps between the two spots.
4. Have your friend take the blocks and stand at one spot, holding them up high.
5. Take the stopwatch and stand at the other spot. Make sure you have a clear view of the blocks.
6. Signal your friend to bang the two blocks together hard.
7. Start the stopwatch as soon as you see the blocks hit each other.
8. Press stop as soon as you hear the sound from the blocks.

9. Calculate the speed of the sound by dividing the distance between you and your friend by the elapsed time. To get a more accurate measurement, repeat the above steps a few times and then take an average of the results.
10. By measuring the length of the area – and so the length of the distance between you – and dividing that by the number of seconds you measured as a delay, you'll get the approximate speed of sound.
11. Repeat the experiment on different times of the day, different humidity conditions and different temperatures.

3.5.1 Speed of light versus speed of sound

Why do we first see lightning flash before we hear the thunder during a thunderstorm? To answer this question, we need to compare the speed of sound to that of light.

From Table 3.4 above, we can see that the speed of sound through air is about $343 \text{ m}\cdot\text{s}^{-1}$ whilst light travels through air at an enormous speed of $300\,000\,000 \text{ m}\cdot\text{s}^{-1}$. This is about a million times faster than sound.

When lightning occurs in the clouds, the flash and the sound associated with it travel away from where they are produced. For a person standing 5 km away from where the lightning occurred, the light will reach him almost instantaneously but the sound will only reach him a few seconds later because of the enormous speed at which light travels.

[Source: Jan Smit: *Quarks, Crickets, Catfish . . . Through the eye of a physicist*]

Example 3.4

DETERMINE THE WAVELENGTH OF PIANO STRING

A piano string tuned to middle C vibrates with a frequency of 262 Hz.

Assuming that the speed of sound in air is $343 \text{ m}\cdot\text{s}^{-1}$, find the wavelength produced by the string.

1 ANALYSE

Given:

$$v = 343 \text{ m}\cdot\text{s}^{-1}; f = 262 \text{ Hz}$$

Unknown: $\lambda = ?$

2 SOLVE

Use the equation relating speed, wavelength, and frequency of a wave:

$$v = f\lambda$$

$$343 = 262 \times \lambda$$

$$\therefore \lambda = 1,31 \text{ m}$$

Example 3.5**CALCULATE THE FREQUENCY OF WAVE PROPAGATION**

A transverse wave with a wavelength of 300 mm has a speed of $9 \text{ m}\cdot\text{s}^{-1}$.

Calculate the frequency of the wave.

1 ANALYSE

Given:

$$\lambda = 300 \text{ mm} = \frac{300}{1\,000} = 0,3$$

$$v = 9 \text{ m}\cdot\text{s}^{-1}$$

Unknown:

$$f = ?$$

2 SOLVE

Use the equation relating speed, wavelength, and frequency of a wave:

$$v = f\lambda$$

$$9 = f \times 0,3$$

$$\therefore f = \frac{9}{0,3}$$

$$\therefore f = 30 \text{ Hz}$$

**Activity 3.2 Relationship between speed, frequency, period and wavelength**

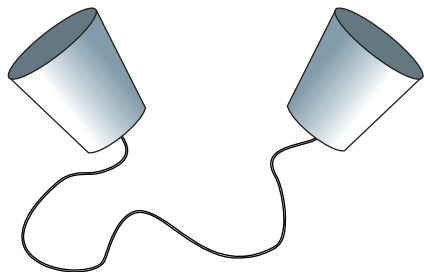
1. Define the following terms:
 - a) wave speed
 - b) frequency
 - c) period
 - d) wave velocity
2. The Note A above middle C on a piano emits a sound wave with a wavelength of 0.77 metres.
 - a) What is the frequency of the wave?
Use $340 \text{ m}\cdot\text{s}^{-1}$ as the speed of the sound wave.
 - b) Calculate the period of the sound wave.



PRACTICAL ACTAIVITY (PROJECT)

How to make a string telephone (project)

Besides travelling through air, sounds can also travel through solid objects.



Materials

- 2 paper or plastic cups (empty yogurt containers work well) or empty tins
- 1 piece of string about 2 metre long
- scissors
- 1 thick needle
- 2 paperclips

Method

1. Poke a small hole in the bottom of each cup with the needle.
2. Thread the string through the holes and tie a paperclip to each end of the string to ensure that it is secured inside the cup.
3. Give one cup to a friend, and take the cups far apart, so that the string is tight. Talk and listen to each other through the string telephone.

Questions

1. What happens if the string hangs loose?
2. What happens if you hold the string?
3. What happens if you connect three or four string telephones together?



FORMAL EXPERIMENT

Determining the difference between pitch and loudness using an oscilloscope

Background

The amplitude and the frequency of longitudinal waves cannot be measured directly. Instead we use an oscilloscope. An oscilloscope detects the compressions and rarefactions of the longitudinal waves and translate them into an electric signal to produce a graph of distance against time. The distance read on the vertical axis represents an amplitude of the longitudinal waves.

Do not confuse the graph you observe on the screen with a transversal wave. The oscilloscope detects the change in pressure as the sound waves strike the detecting device. When the oscilloscope

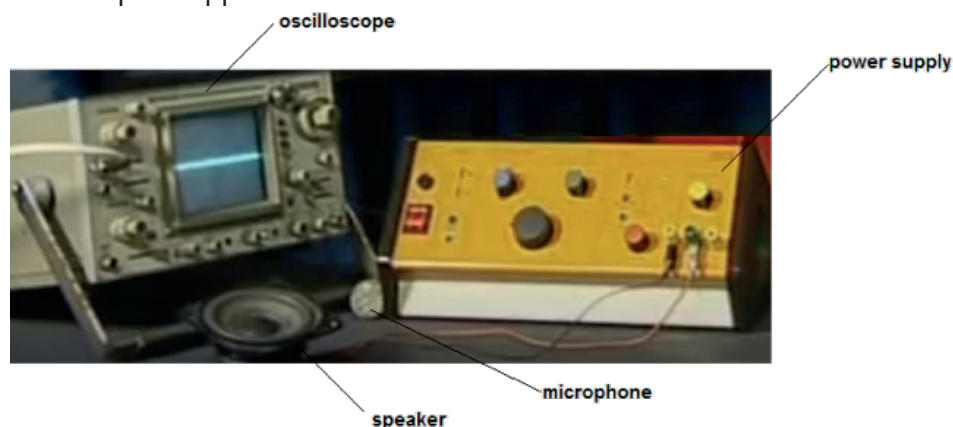
detects high pressure, it corresponds to the compressions; and when it detects low pressure, it corresponds to rarefactions.

Apparatus

- oscilloscope
- speaker
- microphone
- power supply

Method

1. Setup the apparatus as shown below:



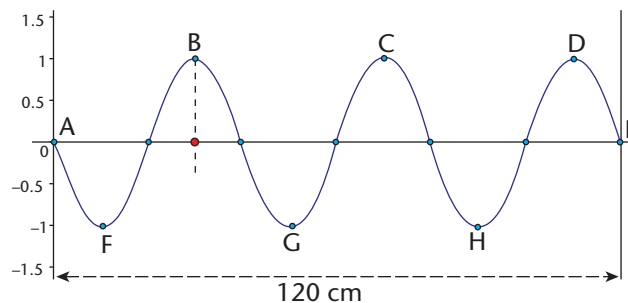
2. Switch on the power supply and bring the microphone closer to the speaker.
3. Write down what you observed from the oscilloscope screen.
Now increase the frequency to 200 Hz.
 - a) Describe what you hear?
 - b) Draw the pattern you see on the screen.
4. Increase the frequency to 2 000 Hz.
 - a) Describe how this sound differs from the one you heard.
 - b) Draw the pattern you see on the screen.
5. Now increase the volume and describe the sound you heard and draw the graph you see on the screen.
6. Write down your conclusion.



Activity 3.3 Transversal waves

1. If a string is continuously shaken from side to side, it generates a series of transverse pulses, which forms a transverse wave train as shown alongside: It takes 0,3 s to complete the pattern from A to E.

Study the wave pattern and answer the questions that follow:



Note All measurements are in centimetres.

- Define the transverse pulse?
- Explain what is meant by points in phase.
- Name two points that are in phase.
- Give three sets of points, which represent one wavelength.
- What is the name given to the line AE?
- Determine the amplitude of the wave?
- Calculate the period of the wave?
- Calculate the frequency of the wave?
- Calculate the wavelength and the speed of the wave.

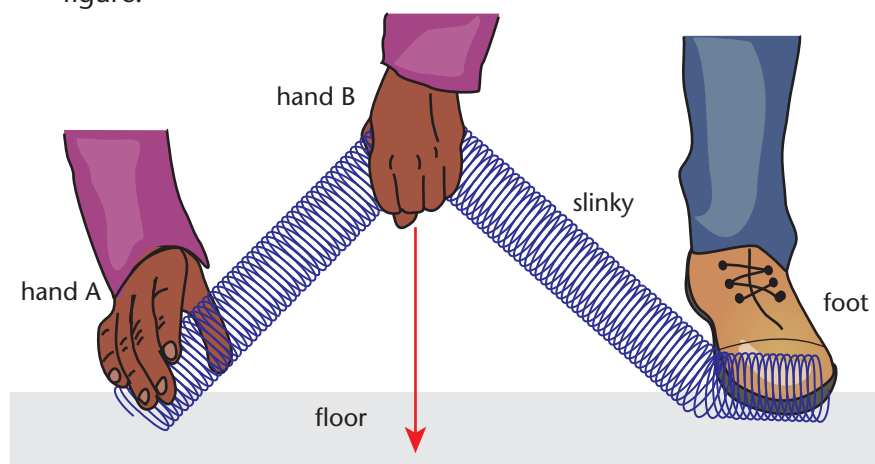


PRACTICAL DEMONSTRATION

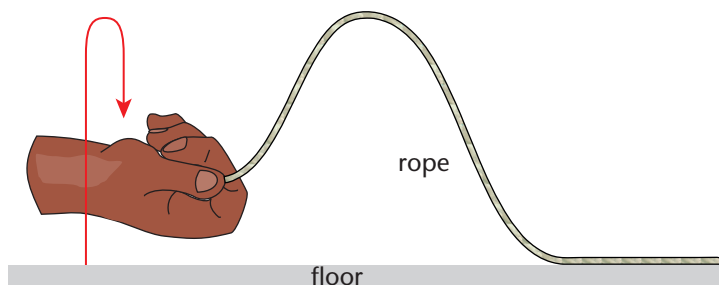
Make a pulse on a string and on a rope

Part A

- Put the slinky on a smooth floor. Keep it a bit stretched. Place your foot down as shown in the figure.



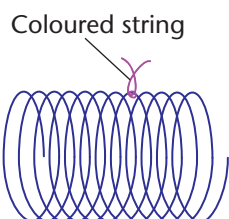
- Pull the slinky sideward, that is, parallel to the floor (hand B). Release hand B. A pulse will travel along the slinky. By putting the foot and hand B in different positions, pulses of different shapes can be made.
- Put the rope on a smooth floor and keep it tight or pulled straight. From the rest position (shown by the arrow in the figure), quickly move your hand sideward (parallel to the floor) and back again to the rest position.



- By moving your hand faster or slower, and by varying the distance that you move away from the rest position, you can make pulses with different shapes (this is not as easily done as with the slinky.)

Part B

- What is the direction the coils of the slinky move?
- Tie a short piece of coloured string (wool) to one of the coils.
- This represents a particle in the medium. (Or use the rope – Tie a short piece of coloured string (wool) somewhere to the rope.)



Questions

- In what direction does the coloured string move as the pulse passes?
- Write down your observation.



Activity 3.4 Calculations involving wave equation

- Use the general wave equation: $v = f\lambda$ to answer the questions that follow:
 - What is the f if $v = 345 \text{ m}\cdot\text{s}^{-1}$ and $\lambda = 0,25 \text{ m}$?
 - What is the λ if $v = 345 \text{ m}\cdot\text{s}^{-1}$ and $f = 790 \text{ Hz}$?
 - What is the v if $\lambda = 3 \text{ m}$ and $f = 10 \text{ Hz}$?
 - What is the λ if $v = 100 \text{ m}\cdot\text{s}^{-1}$ and $f = 3 \text{ Hz}$?
 - What is the v if $\lambda = 1 \text{ m}$ and $f = 345 \text{ Hz}$?
- How long is the wavelength of metro radio whose broadcast frequency is 97,1 MHz? (97,1 MHz = 97,100,000 Hz and $v = 300\,000\,000 \text{ m}\cdot\text{s}^{-1}$)
- Joe, the whistle maker, knows that the maximum volume for a whistle will occur if the length of the whistle is exactly $\frac{1}{4}$ of the wavelength. If Joe must make a whistle that plays at a pitch of 320 Hz, how long will the whistle be?
- Using the velocity of sound at $343 \text{ m}\cdot\text{s}^{-1}$ and given the frequencies of a piano scale, compute the wavelengths of that scale.

Note	Frequency	wavelength	Note	Frequency	Wavelength
C ₄	261,6		G ₄	392	
D ₄	293,6		A ₄	440	
E ₄	323,6		B ₄	493,9	
F ₄	349,2		C ₅	523,2	

3.8 Superposition of waves

When two waves travel through a medium, they interact. Fortunately, we can often assume that the interaction is linear, that is, the amplitude of the sum is the sum of the amplitudes. This relationship is known as the principle of superposition.

Superposition of waves

Superposition of waves is an algebraic sum of the amplitudes of the waves that meet at the same point simultaneously.

3.9 Interference

Interference is what happens when two or more waves come together. Depending on how the crest and troughs of the waves are matched up, the waves might add together or they can partially or even completely cancel each other.

Note that in this chapter we only discuss interference as it applies to transversal and longitudinal waves, but it applies to other waves as well.

3.9.1 What happens when waves come together?

When waves come together, those waves are superimposed: they add together, with the amplitude at any point being the addition of the amplitudes of the individual waves at that point.

3.9.2 Constructive interference

Constructive interference occurs whenever waves come together so that they are in phase with each other. This is shown in Figure 3.12.

For two waves of equal amplitude interfering constructively, the resulting amplitude is twice as large as the amplitude of an individual wave. This phenomenon is shown in Figure 3.13. The diagram shows

two pulses coming together, interfering constructively, and then continuing on together as if they had never encountered one another.

Although the waves interfere with each other when they meet, they continue travelling as if they had never encountered each other. When the waves move away from the point where they came together, their form and motion is the same as it was before they came together.

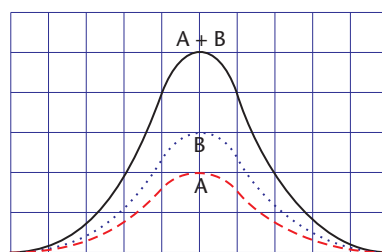


Figure 3.12 Wave A and B meet and combine constructively

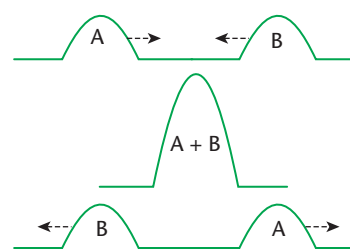


Figure 3.13 Constructive interference of two waves

3.9.3 Destructive interference

Destructive interference occurs when waves come together in such a way that they completely cancel each other out. This is shown in Figure 3.14.

When two waves interfere destructively, they must have the same amplitude and propagate in opposite directions. Figure 3.15 depicts two pulses with the same amplitude moving in opposite directions. The pulses meet and combine destructively, and cancel each other. After interference the pulses continue to move in their respective directions.

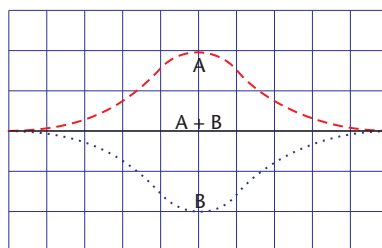


Figure 3.14 wave A and B meet and combine destructively

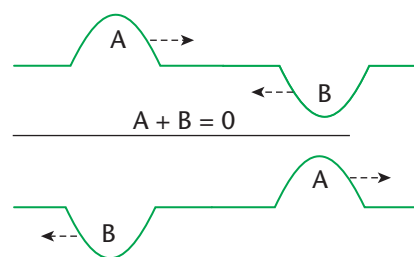


Figure 3.15 Wave A and B meet and combine destructively

Figure 3.15 shows two pulses interfering destructively. Again, the pulses moves away from the point where they combine as if they never met each other.



PRACTICAL ACTIVITY

Interference of pulses

Material

- slinky
- rope

Method

1. Create two identical pulses with a string or rope, one on each side of the rope.
2. Release both pulses at the same time.
3. Create the pulses, one on the negative and one on the positive side of the rope and then both on the positive side.
4. Observe what happens at the point where the two pulses meet.

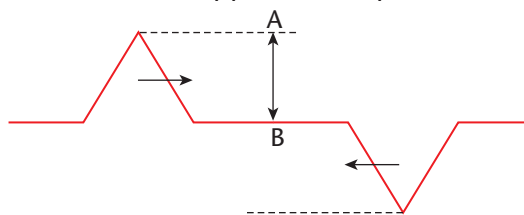


Figure (a)

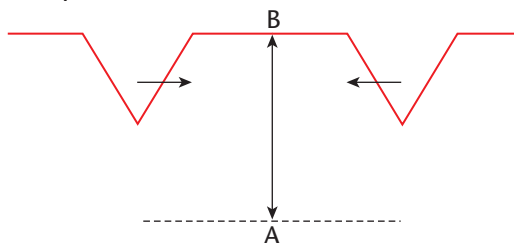


Figure (b)

5. Fill in the missing words and delete the incorrect words.

- a) In Figure (a), the displacements of the two pulses are in _____ directions. When the two pulses meet, there is a large / small / no displacement of the medium. It seems that when the two pulses meet we can find the total displacement by _____ (fill in: the correct mathematical operation) the displacements of the individual pulses.
 - b) In Figure (b), the displacements of the two pulses are in the _____ direction. When the two pulses meet, there is a large / small / no displacement. It seems that when the two pulses meet, we can find the total displacement by _____ (fill in: the correct mathematical operation) the displacements of the individual pulses.
 - c) In both situations we observe that a little while after the two pulses meet, both pulses appear again. The pulse travelling to the right continues to travel to the _____ and its _____ remains the same. The pulse travelling to the left continues travelling to the _____ and its _____ remains the same.
6. Formulate the Principle of Superposition.



Activity 3.5 The ripple tank experiment

1. Set up a ripple tank with the two vibrator beads to produce just a single pulse as shown in Figure 3.16.
2. Place a clean sheet of paper under the ripple tank.
3. Fill the ripple tank with water.
4. Switch the light source above the ripple tank on.
5. Set the vibrator of the ripple tank to produce single vibrations. The two vibrating beads must produce single pulses.
6. The vibrating beads produce a radiating outward single pulse.

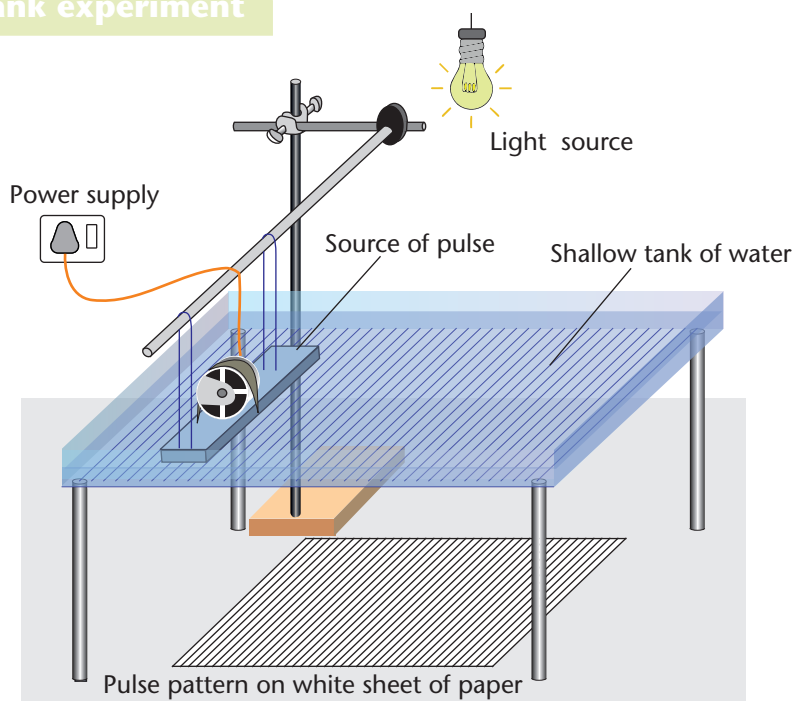
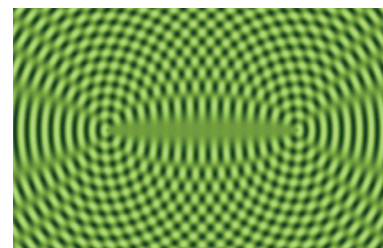


Figure 3.16 Ripple tank experiment setup – adapted from DBE waves and sound guide

Questions

1. Observe what happens if the distance between the two beads change.
2. How does the distance between the sources of the pulses influence the pattern formed on the sheet of paper?
3. Why are there regions that appear dark? Which type of interference cause these dark bands?
4. When the crest of one pulse coincides with a trough of another pulse, it results in the _____ of the pulse as they move over



A series of pulses produce this interference pattern.

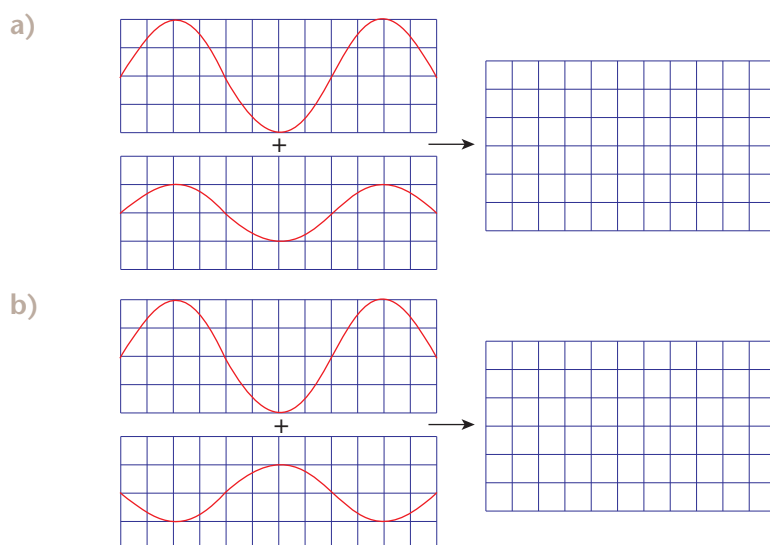
each other. If the pulses are of equal amplitude, the result will be _____ at that point. We call this _____ interference.

5. When the trough of one pulse coincides with the trough of another, it results in a _____ trough. This is visible on the paper as a region of lighter bands. This is known as _____ interference



Activity 3.5 Superposition of waves

1. In each set of waves below, the two waves at the left represent two waves traveling at the same time. Combine the two waves and show the results at the right.



- c) In the top example, (constructive, destructive) _____ interference produces a (louder, softer) _____ sound.
- d) In the bottom example, (constructive, destructive) _____ interference produces a (louder, softer) _____ sound

3.10 Sound waves

A sound wave is the pattern of disturbance caused by the movement of energy propagating through a medium (such as air, water, or any other liquid, or solid matter). Sound waves do not travel in a vacuum. The source causes a vibration, such as a ringing telephone, or a person's vocal chords.

The vibration disturbs the particles in the surrounding medium; then those particles disturb those next to them, and so on. The pattern of the disturbance creates outward movement in a wave pattern, like waves of seawater on the ocean. The wave carries the sound energy through the medium, usually in all directions and less intensely as it moves farther from the source.

The frequency of an audible sound wave determines how high or low we perceive the sound to be. This is known as a pitch. As the frequency of the sound wave increases, the pitch rises. The

frequency of a wave is an objective quantity that can be measured, while pitch refers to how different frequencies are perceived by a human ear. An individual's hearing depends on variety of factors, including age and experiences with sound noises. The frequencies above and below the audible range are referred to as ultrasound and infrasound respectively.

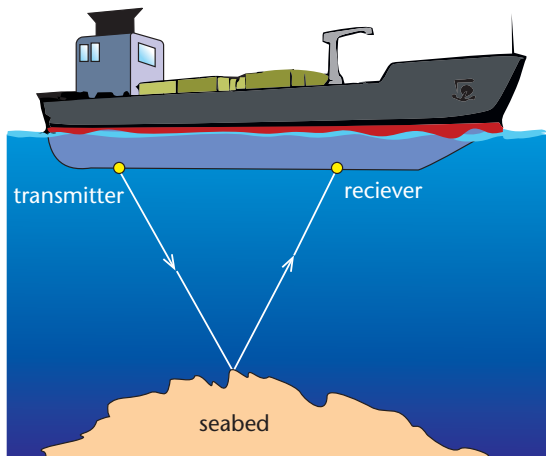
Ultrasound waves have a frequency above the normal range of human hearing. They can be used to scan for birth defects in unborn babies (OR monitor the heartbeat of a foetus) and for defects in manufactured equipment.

3.10.1 Some applications of ultrasound and infrasound

Sound waves with frequencies lower than 20 Hz are called infrasonic waves and those above 20 000 Hz are called ultrasonic waves.

Table 3.4 compares these two types of waves.

Table 3.4 Comparing ultrasound and infrasound

Ultra sound	Infrasound
Ultrasound – used as a Sonar Ships on the ocean make use of the reflecting properties of sound waves to determine the depth of the ocean. A sound wave is transmitted and bounces off the seabed.  Because the speed of sound is known and the time lapse between sending and receiving the sound can be measured, the distance from the ship to the bottom of the ocean can be determined.	Infrasound- used in pipelines as a leak detector Infrasound is used to forecast natural disasters like earthquakes, volcanic eruptions and tsunamis.  Infrasound can be used to track animals and monitor seismic activity.

Did you know?

Elephants use infrasonic sound waves to communicate with one another. Their large ears enable them to detect these low-frequency waves, which have relatively long wavelengths. Elephants can effectively communicate in this way, even if they are separated by many kilometres.



BELL JAR EXPERIMENT (INFORMAL EXPERIMENT)

Aim To investigate whether sound travels in a vacuum

Material required

- bell jar
- electric bell
- power source
- connecting wires
- vacuum pump

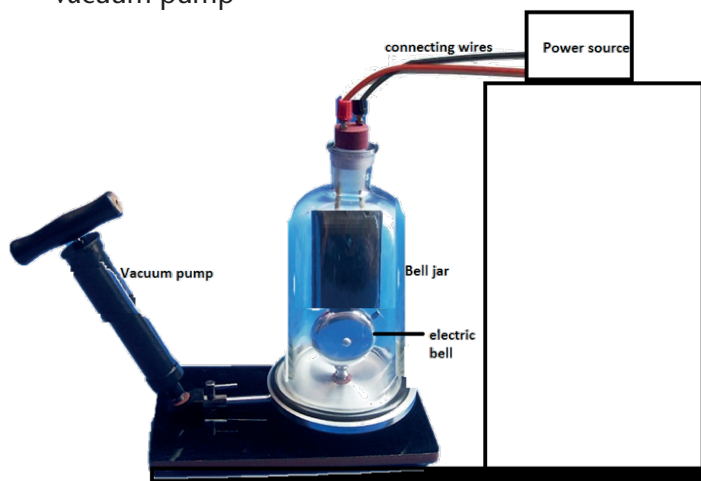


Figure 3.17 Bell jar experiment setup

Procedure

1. Setup the apparatus as shown in Figure 3.17.
2. Connect the electric bell and the vacuum pump to the air tight glass bell jar.
3. Close the switch to complete the circuit.
4. Reduce the air pressure inside the chamber by pumping out the air through the vacuum pump.

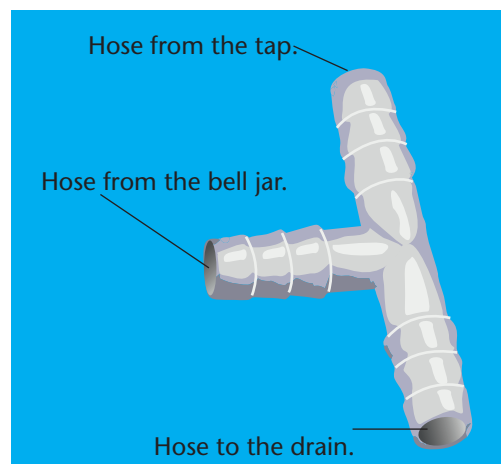
Observations

As the air in the jar is being pumped out, the sound becomes fainter, although it is the same current that is passing through the bell. On reducing the air pressure further, the intensity of the sound reduces and stops.

Conclusion

Sound waves do not travel in a vacuum.

Note In a case where the school does not have a vacuum pump. A t-connector can be purchased (it is very cheap and available in all hardware stores). It can be connected to the short pieces of used garden pipes. The water tap must be opened to create a vacuum.





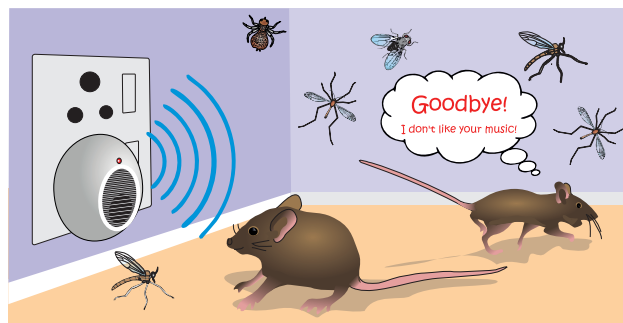
INVESTIGATION: APPLICATION OF SOUND

Humans can only hear sounds with frequencies of between 20 Hz and 20 000 Hz. Each individual's hearing however depends on a variety of factors. This includes age and experiences with sound.

Dogs, however, can hear sounds of frequencies of up to 45 000 Hz.

Have you observed that dogs generally respond excitedly to whistling sounds? This is because high frequency sounds are in the comfortable range of hearing for dogs. Try using a thick low pitch voice when communicating with a dog and compare its response to the ringing of a high pitch bell for instance.

For you to do: Do your own investigation on the use of ultrasounds as repellant for insects and rodents in homes, gardens and factories. Think of any other possible application of this property of sound. You can also read more about some of the applications below.

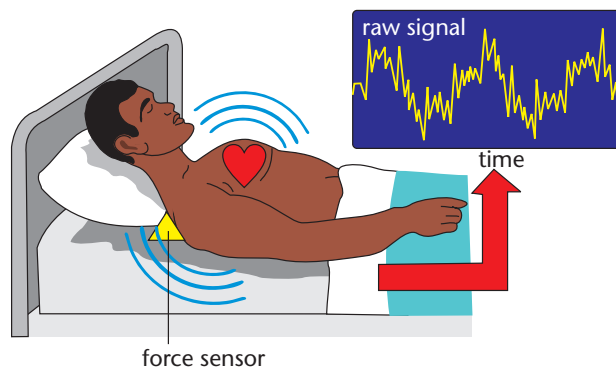


Did you know?

Infrasound is used in monitoring earthquakes, charting rock and petroleum formations below the earth, and also in ballistocardiography and seismocardiography to study the mechanics of the heart.

Did you know?

Ultrasound technology is used in water treatment to suppress algal growth and biofilm formation.



3.10.2 Pitch and loudness

Sound is vibrations. These vibrations can make solids, liquids or gases vibrate. These vibrations move in all directions from the source. They in turn make different parts of our ear vibrate so we can hear and interpret those vibrations.

Loudness is the description of how loud or soft a sound is perceived to be. Loudness is determined by the amplitude of the sound. The higher the amplitude, the louder sound.

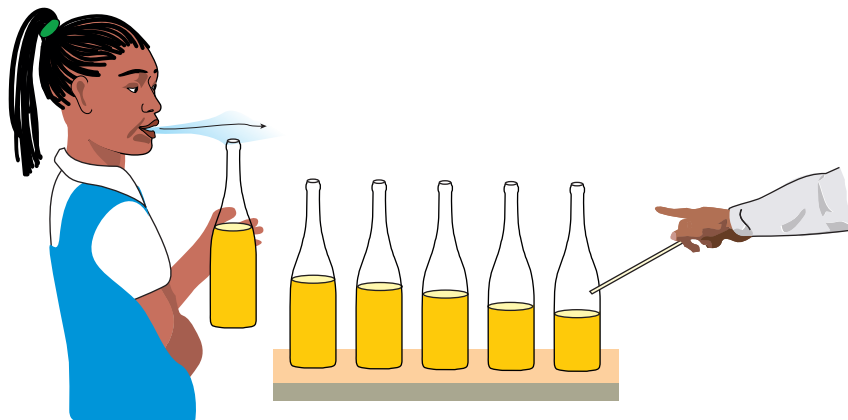
Two rules for objects that make sound:

- The shorter the column of air or the string being vibrated, the higher the pitch of the sound will be.
- The harder an object is hit, blown or plucked, the louder the sound will be.



INVESTIGATION: INVESTIGATION (PITCH OF WAVES)

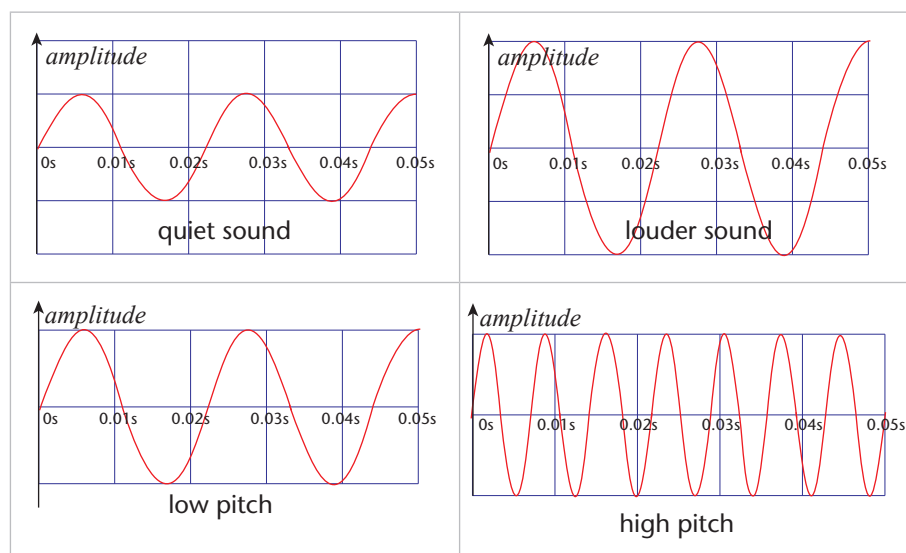
1. Place varying amounts of water into cool drink bottles.
2. Blow across each bottle and write down your observations.
3. Now tap each bottle with a spoon and write down your observations.
4. Write your conclusions.



3.10.3 Pitch and loudness on oscilloscope

The amplitude vs time graphs for pitch and loudness are shown in Figure 3.18. From the graphs we can deduce that the higher the frequency, the higher the pitch; and the higher the amplitude the louder the sound.

Figure 3.18 Loudness vs pitch on oscilloscope



3.10.4 Echo

An echo is a sound wave that is reflected back (bounced back) from a surface. Sound waves can bounce off smooth, hard objects in the same way that a rubber ball bounces off the ground. Although the direction of the sound changes, the echo sounds the same as the original sound.

Echoes can be heard in small places with hard walls, like wells; or where there are lots of hard surfaces around, for example, in the school hall or at a mountain range.

However, sound waves are not always reflected. If sound waves meet a soft surface, such as cushion, they will be absorbed and will not bounce back.



Activity 3.6

1. Define an echo and mention its applications.
2. A SONAR receives a strong echo of ultrasonic signal it sent downwards into the sea 3,6 seconds after the transmission. Calculate the depth of the sea-bed if the speed of the ultrasonic waves in sea-water is $1\,250\text{ m}\cdot\text{s}^{-1}$.
3. Name the units used to measure:
 - a) pitch
 - b) frequency
 - c) loudness
4. You hook up a stereo system. When you test the system, you notice that in one corner of the room, the sounds seem dull. In another area, the sounds seem excessively loud. Describe how the sound moving about the room could have resulted in this.
6. You observe two musical instruments that you cannot identify. One plays high-pitched sounds and the other plays low-pitched sounds.
How could you determine which is which without hearing either of them play?
7. Imagine that you observe two fireworks displays. You hear the explosion of one as soon as you see it. However, you see the other display several milliseconds before you hear the explosion. Explain why this is so.

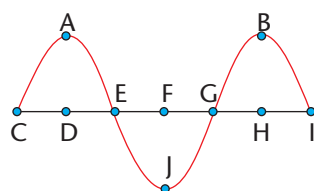
Review exercises

Multiple choice questions

1. What is the highest point on a wave?
 - A. trough
 - B. wave
 - C. crest
 - D. bones
2. A student holds two vibrating objects. Object A is vibrating faster than Object B. Which sentence below is TRUE?
 - A. A is LOUDER than B.
 - B. B is LOUDER than A.

- C. A will have a higher PITCH than B.
 - D. B will have a higher PITCH than A.
3. What is the distance between two consecutive crests or troughs called?
- A. wavelength
 - B. amplitude
 - C. speed
 - D. frequency
4. A boy thought that the sound level in his room was too high. He turned down the music in his room. What physical property of the sound changed due to this and how did it change?
- A. The frequency increased
 - B. The amplitude increased
 - C. The amplitude decreased
 - D. The frequency decreased
5. What does the highness or lowness of a sound represent?
- A. volume
 - B. pitch
 - C. wavelength
 - D. amplitude
6. If the energy in a longitudinal wave travels from south to north, the particles of the medium ____.
- A. move from north to south, only.
 - B. vibrate both north and south.
 - C. move from east to west, only.
 - D. vibrate both east and west.
7. When the particles of a medium are vibrating at right angles to the direction of energy transport, the type of wave is described as a ____ wave.
- A. longitudinal
 - B. sound
 - C. standing
 - D. transverse
8. The main factor which effects the speed of a sound wave is the ____.
- A. amplitude of the sound wave
 - B. pitch of the sound wave
 - C. loudness of the sound wave
 - D. properties of the medium

9. A transverse wave is travelling through a medium as illustrated in the diagram below. The particles of the medium are moving.



- A. parallel to the line joining AD.
B. along the line joining CI.
C. perpendicular to the line joining AD.
D. at various angles to the line CI.
10. Many wave properties are dependent upon other wave properties. Yet, one wave property is independent of all other wave properties. Which one of the following properties of a wave is independent of all the others?
- A. wavelength
B. frequency
C. period
D. velocity

Long questions

11. Why doesn't sound travel in a vacuum?
12. What factors does the speed of sound depend upon? What are some factors that it does not depend upon?
13. A cat can hear sound frequencies up to 70 000 Hz. Bats send and receive ultra-frequency squeaks up to 120 000 Hz. Which hears sound of shorter wavelengths, cats or bats? Explain your answer.
14. Why is it a safe prediction that you will have a significantly greater loss of hearing in your later years than your grandparents experienced?
15. If the frequency of a sound is doubled, what change will occur in its speed? What change happens to its wavelength?
16. The average wavelength in a series of ocean waves is 15,0 meters. A wave crest arrives at the shore on an average of every 10,0 seconds, so the frequency is 0,100 Hz. What is the average speed of the waves?
17. An FM radio station broadcasts electromagnetic waves at a frequency of 94,5 MHz (equal to 94 500 000 Hz). These radio waves have a wavelength of 3,17 meters. What is the speed of the waves?
18. Sound waves travel in air with a speed of $343 \text{ m}\cdot\text{s}^{-1}$. The lowest frequency sound that the average person can hear is 20,0 Hz; the highest frequency is 20 kHz. Find the wavelengths corresponding to these frequencies.



Objectives

By end of this chapter learners will gain a broad understanding and acquire skills relating to the following concepts:

- Coulomb's law
- electric fields
- electric field lines
- electric field between parallel plates
- Ohm's Law
- ohmic and non-ohmic conductors
- electric circuit calculations
- emf
- internal resistance.

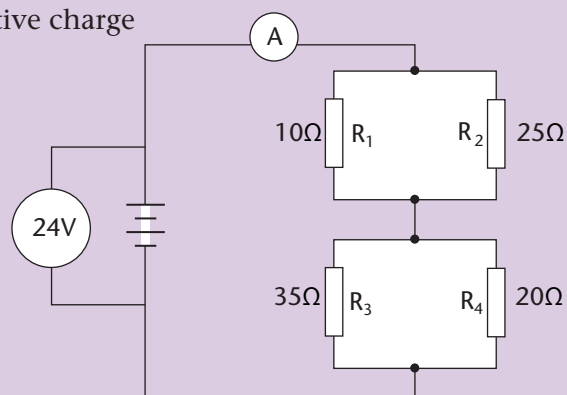
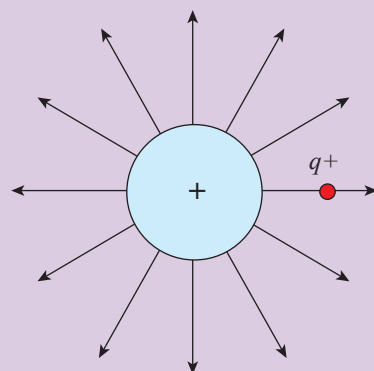
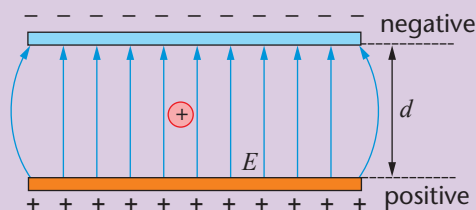


Why electrostatics matters

Electrostatics has various benefits in our everyday life. Even flowers use electric fields to communicate with insects!

Some examples of where electrostatics is used is in the operation of photocopiers, spray painting, electrostatic precipitators, and so on. An electrostatic copier works by arranging positive charges in a pattern to be copied on the surface of a non-conducting drum, and then gently sprinkling negatively charged dry toner particles onto the drum.

In spray painting, particles of paint are given a positive charge as they leave the nozzle of a spray gun.



4.1 Electrostatics

4.1.1 Introduction

Electrostatics is a branch of physics that deals with the phenomena and properties of stationary or slow-moving electric charges. One example of how electrostatics is used, is in the operation of electrostatic sprayers. One such example is shown in Figure 4.1 below.

Did you know?

At the tip of the sprayer there is a small electrode. This electrode creates high voltage electricity. As the spray particles pass through the nozzle at a slow speed, they become negatively charged. The positively charged surface is the crop surface. It has a magnetic attraction to the negatively charged particles from the sprayer.

As you spray the liquid, the negatively charged spray particles will stick to the positively charged crop surface.



Figure 4.1 An electrostatic sprayer

In Grade 10 we learned that there are two types of charges. These are the positive charges called protons, and negative charges called electrons. A neutral object has an equal number of protons and

electrons, resulting in a zero net charge. A positively charged object has a deficit of electrons, while a negatively charged object has an excess of electrons.

We also learned that like charges repel each other and that unlike charges attract each other (as shown in Figure 4.2). This is evidence that two charges exert a force on each other. This force is called an **electrostatic force**.

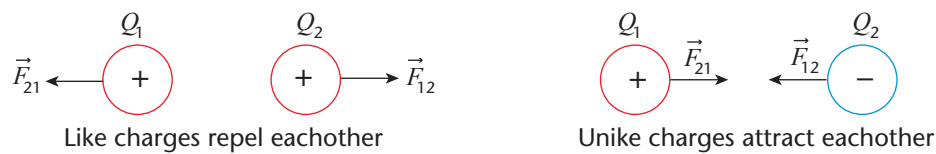


Figure 4.2 unlike and like charges

The charge of an electron (an elementary charge) is $q_e = -1,6 \times 10^{-19}$ C; whereas a proton has a charge of $q_e = 1,6 \times 10^{-19}$ C. This is the smallest value a charge can have.

Mathematically this can be expressed as $Q = nq_e$. Here n represent the number of electrons in excess (for a negative charge), or deficit (for a positive charge).

We learned further that the total charge of an isolated system will remain constant during any physical process. This statement is referred to as the **law of conservation of charge**.

4.1.2 Coulomb's law

Coulomb's law describes the relationship between force exerted by the charges, the charges themselves and the distance separating the charges.

Coulomb's law states that: The force (F) of attraction or repulsion between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance (r) between the charges.

Mathematically this relation can be expressed as:

$$F \propto Q_1 Q_2$$

and

$$F \propto \frac{1}{r^2}$$

Combining the two yields:

$$F \propto \frac{Q_1 Q_2}{r^2}$$

This can be written as a mathematical equation by introducing the proportionality constant k , such that:

$$F = \frac{(kQ_1 Q_2)}{r^2}$$

Where:

Q_1 = the magnitude of the point charge in Coulombs (C)

r = the distance between the stationary point charges in metres (m)

k = proportionality constant and has the value $k = 9 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$

F = the electrostatic force between Q_1 and Q_2 in Newton (N)

Conditions for Coulomb's Law validity

There are certain conditions that must be kept in order for the Coulomb's Law to hold true.

These conditions are:

- the charges under investigation must be point charges
- the charges must be stationary relative to each other

Calculations using the Coulomb's law:

Before doing any calculations, let's look at how to do unit conversions, especially for the electric charges. Table 4.1 below summarises typical submultiples of SI units.

Table 4.1 Typical submultiples of SI units

Micro	μ	$\times 10^{-6}$
Nano	n	$\times 10^{-9}$
Pico	p	$\times 10^{-12}$
Femto	f	$\times 10^{-15}$

Using the submultiples above, a charge of $6\mu\text{C}$, will be $6 \times 10^{-6} \text{ C}$ in SI units.

Note:

When using Coulomb's Law equation, we only consider the magnitude, and not the sign, of the charges.

Example 4.1

CALCULATIONS FOR ELECTROSTATIC FORCE

Two identical spheres A and B carrying charges of $Q_A = +8\text{nC}$ and $Q_B = -12\text{nC}$, respectively, are placed at a distance 10 mm.

Calculate the electrostatic force the charges exert on one another.

1. ANALYSE

Given: $Q_A = +8\text{nC}$ and $Q_B = -12\text{nC}$; $r = 10 \text{ mm}$

Convert all the given variables to their main SI units. In our case charges must be in C and not in n, and the distance be in m not mm

$Q_A = +8 \text{ C} \times 10^{-9} \text{ C}$ and $Q_B = -12 \text{ C} \times 10^{-9} \text{ C}$; $r = 10 \times 10^{-3} \text{ m}$

Unknown: $F = ?$

2. SOLVE

Use Coulomb's Law: $F = \frac{kQ_1Q_2}{r^2}$

$$F = \frac{(9 \times 10^9)(8 \times 10^{-9})(12 \times 10^{-9})}{(10 \times 10^{-3})^2}$$

$$F = 8,64 \times 10^{-3} \text{ N}$$

Because the particles are oppositely charged, they exert an attractive force between them.

Example 4.2**CALCULATIONS FOR ELECTROSTATIC FORCE USING RATIOS**

Two identical spheres carrying charges Q_A and Q_B are placed a distance r apart, and exert a force F on each other.

If the distance separating the charges is halved, what will be the magnitude of the new force, with respect to F , the charges exert on each other?

1. ANALYSE

Given: The force that the charges initially exert on each other is given by:

$$F = \frac{kQ_1Q_2}{r^2}$$

Halving the distance will result in new distance $\left(r_{\text{new}} = \frac{1}{2}r\right)$

Unknown: $F_{\text{new}} = ?$

2. SOLVE

Use Coulomb's Law: $F_{\text{new}} = \frac{kQ_1Q_2}{\left(\frac{1}{2}r\right)^2}$

$$F_{\text{new}} = \frac{kQ_1Q_2}{\frac{1}{4}r^2}$$

$$F_{\text{new}} = \frac{4kQ_1Q_2}{r^2}$$

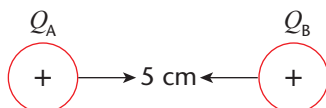
$$\therefore F_{\text{new}} = 4F$$

Halving the distance between the charges increases the force they exert on each other by the factor of 4.

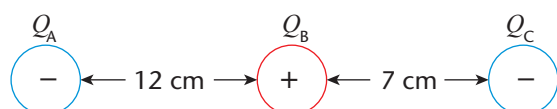
**Activity 4.1: Application of Coulomb's law**

- State Coulomb's law in words.
- Use your understanding of relationship between two variables to draw the generic graphs of:
 - F versus Q_1Q_2
 - F versus r^2
 - F versus $\frac{1}{r^2}$
- Two charged spheres carrying charges Q_A and Q_B are a distance r apart, and exert a force $\vec{F}$ on one another.
 - If the distance between the charges is doubled, and the charge on one of the two spheres is doubled, what will the new force that the charges will exert on each other be, relative to $\vec{F}$?
 - By what factor will the force the two charges exert on each other change, if the charges are both doubled?
 - If the distance between the charges is decreased by the factor of 3, by what factor will the force the charges exert on each other increase?

4. Two charged objects A and B are placed 5 cm apart, as shown in the sketch. The charge on A, $Q_A = +2,6\mu\text{C}$ and charge on B, $Q_B = +3,2\mu\text{C}$.



- Draw the force diagram (not to scale) of the force of A on B ($\vec{F}_{A \text{ on } B}$) and the force of B on A ($\vec{F}_{B \text{ on } A}$).
 - Will the two objects attract or repel each other?
 - Will ($\vec{F}_{A \text{ on } B}$) be equal to ($\vec{F}_{B \text{ on } A}$)? Give a reason for your answer
 - Calculate the magnitude of the force between objects A and B.
5. Two charged objects M and N are placed 4,5 cm apart.
- Calculate the magnitude of the force between the objects if the charge on M is $Q_M = +2,5\mu\text{C}$ and on N is $Q_N = +3,2\mu\text{C}$.
 - Calculate the force between the objects in (a) above when the distance between them is doubled.
 - Compare your answers to (a) and (b) above and determine the factor by which the force is reduced when the distance between the charges is doubled. Is this outcome in line with your initial expectation? Explain.
6. Two identical spheres carrying equal charges are placed a distance of 4 cm apart, and exert a force of $3,6 \times 10^{-4} \text{ N}$. Calculate the magnitude of the charge on each sphere.
7. Three charged objects A, B and C lie on a straight line as shown in the diagram. The distance between A and B is 12 cm and between B and C is 7 cm.



- Given that the magnitude of the charge on A is $Q_A = +3\mu\text{C}$, and on B is $Q_B = +5\mu\text{C}$, and on C is $Q_C = +2\mu\text{C}$:
 - how many forces are exerted on charge A?
 - how many forces are exerted on charge B?
 - how many forces are exerted on charge C?
 - Calculate the forces on charge A, and hence determine the net force on charge A. (Hint: draw force diagrams showing all the forces acting on A.)
 - Calculate the forces on charge B. Determine the net force on charge B.
8. Two identical spheres carrying charges $Q_A = -3,2\mu\text{C}$ and $Q_B = +4,8\mu\text{C}$ are placed a distance of 50 mm apart. The spheres are then brought in contact with one another and then placed back to their original positions.
- What will the new charge on each sphere be after they have been separated?
 - Calculate the force that the charges on the spheres exert on one another after they have been separated

4.2 Electric field

The previous section described the interaction between charges in terms of the force between them, the distance between them and their magnitudes. According to this description, the force exerted on the charges acts over a distance between charges, with no intervening medium.

The strength of the electrostatic force between two charges decreases as the distance separating the charges increases. Thus, at a certain point, the force the charges exert on each other will be significantly small such that it can be approximated to zero. This means that there must be a region within which two charged particles will experience the force due to the charges they carry.

In 1838, Michael Faraday introduced another type of interaction between charges. According to Faraday, there is 'something' that exists around charges. This 'something' he called an **electric field**.

A charge gives rise to an electric field that permeates the space around it. This in turn exerts a force on other charges. Thus, a charge A in the vicinity of another charge B; will experience a force exerted on it by the electric field of charge B. Electric fields act in the same direction as the force on charges, and are therefore vector quantities (they have definite direction).

Note

Even though electric fields cannot be seen, they do exist in reality. They exhibit physical qualities whose effects can be measured.

The electric field strength at a point is defined as the force per unit positive test charge. That is:

$$E = \frac{F}{q}$$

Where:

E = the electric field strength in Newton per Coulomb ($\text{N}\cdot\text{C}^{-1}$)

F = the electrostatic force experienced by the test charge, q , measured in Newton (N)

q = the test charge in Coulombs (C)

To describe the electric field quantitatively, we use the term electric field strength. The electric field strength is the magnitude of the electric field at a point. The electric field at a point is a vector quantity with magnitude as well as direction. The electric field at a point is defined as:

The electric field at a point ($\vec{E}$) is the electrostatic force ($\vec{F}$) experienced by the test charge (q) placed at that point divided by the charge itself. That is:

$$\vec{E} = \frac{\vec{F}}{q}$$

Example 4.3**CALCULATIONS FOR ELECTRIC FIELD STRENGTH**

A $Q_A = +9\mu\text{C}$ point charge experiences a force of $2,7 \times 10^{-5} \text{ N}$.

Calculate the electric field strength at the point where a point charge Q .

1. ANALYSE

Given: $F = 2,7 \times 10^{-5} \text{ N}$

$$Q = +9\mu\text{C} = 9 \times 10^{-9} \text{ C}$$

Unknown: $E = ?$

2. SOLVE

Use the formula for electric field strength. Thus:

$$E = \frac{F}{Q}$$

$$E = \frac{2,7 \times 10^{-5}}{9 \times 10^{-9}}$$

$$E = 3\,000 \text{ N}\cdot\text{C}^{-1}$$

The electric field strength on a charge Q experiencing a force $E = 3\,000 \text{ N}\cdot\text{C}^{-1}$.

Example 4.4**CALCULATIONS FOR ELECTRIC FIELD STRENGTH**

If the electric field of magnitude $2\,500 \text{ N}\cdot\text{C}^{-1}$ causes a charge Q to experience a force of $1,25 \times 10^{-5} \text{ N}$, calculate the charge Q .

1. ANALYSE

Given: $E = 2\,500 \text{ N}\cdot\text{C}^{-1}$

$$F = 1,25 \times 10^{-5} \text{ N}$$

Unknown: $Q = ?$

2. SOLVE

Use the formula for electric field strength. Thus:

$$E = \frac{F}{Q}$$

$$2\,500 = \frac{1,25 \times 10^{-5}}{Q}$$

$$\therefore Q = \frac{1,25 \times 10^{-5}}{2\,500}$$

$$Q = 5 \times 10^{-9} \text{ C}$$

$$Q = 5\text{nC}$$



Activity 4.2: Calculating the electric field strength

1. Define the following terms:
 - a) electric field
 - b) electric field strength
2. A charge of -5nC experiences an upward force of $4 \times 10^{-6}\text{ N}$ at a point in an electric field. At that point calculate:
 - a) the electric field strength
 - b) the force that an electron will experience.
3. Given that there is the electric field of $300\text{ N}\cdot\text{C}^{-1}$, calculate the magnitude of the force that the field exert on an Alpha particle. An alpha particle is a helium nucleus with a charge of two protons. (Charge of a proton $= +1,6 \times 10^{-19}\text{ C}$.)

4.2.1 Electric field lines

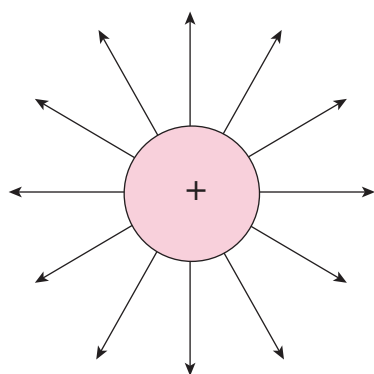
Electric field lines are a way of representing an electric field. Arrows on the field lines indicate the direction of the electric field.

Figure 4.3 show electric field lines around:

- a) a positive charge
- b) a negative charge
- c) two positive point charges
- d) two negative point charges; and
- e) the two opposite point charges.

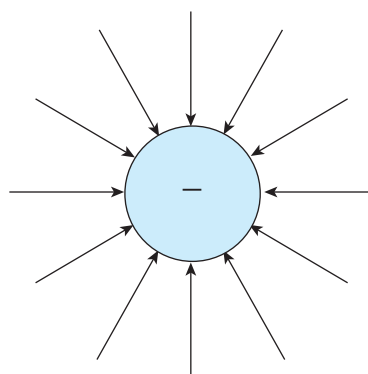
Figure 4.3 electric field lines around the charge(s)

a) Positive charge



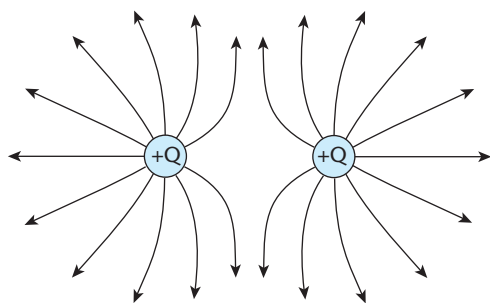
Electric field of a positive point charge

b) Negative charge

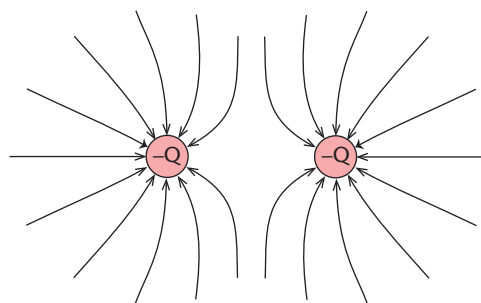


Electric field of a positive point charge

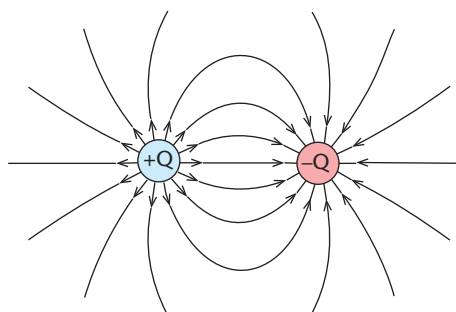
c) Two positive point charges



d) Two negative point charges



e) Positive and a negative point charges:



Hints on drawing the electric field lines

- The electric field lines are perpendicular to the surface of the charge carrier.
- They do not cross or intersect with one another
- They indicate the strength of the field. The closer they are to one another, the stronger the field strength.
- The lines are merely a representation, they do not really exist. The electric field spreads everywhere around the charge, not only 2-dimensional as we have drawn above.

4.2.2 The electric field between two parallel plates

The strength of an electric field of a point charge depends on the distance from the point to where the charge is placed. However, it is independent of the charge generating the field. This electric field is said to be non-uniform, but an electric field could be also uniform.

Figure 4.4 shows an example of a uniform electric field between two parallel plates.

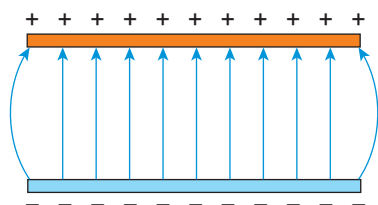


Figure 4.4 Electric field lines between two oppositely parallel plates

Characteristics of the electric field lines between two opposite parallel plates

- The electric field lines between parallel plates is uniform.
- The electric field lines are parallel and equally spaced between the parallel plates.

- The electric field strength between the parallel plates is calculated using the formula: $E = \frac{V}{d}$
- The electric field strength between two parallel plates is inversely proportional to the distance between the plates ($E \propto \frac{1}{d}$).

Example 4.5

CALCULATIONS FOR ELECTRIC FIELD STRENGTH

The electric field strength between the parallel plates is the same at any point between the plates.

- Calculate the electric field strength between two charged parallel plates that have a potential difference of 3 V and are 3 cm apart.
- Calculate the force that the field exert will exert on the proton between the plates.

1. ANALYSE

Given: $V = 3 \text{ V}$

$$d = 3 \text{ cm} = 3 \times 10^{-2} \text{ m}$$

Unknown: $F = ?$

Ensure all the variables are in their SI units

2. SOLVE

$$E = \frac{V}{d}$$

$$E = \frac{3}{0,03}$$

$$E = 100 \text{ N} \cdot \text{C}^{-1}$$

The force that the proton will experience because of this field can be calculated using $E = \frac{F}{Q}$

Here the charge is the charge of the proton. Thus:

$$Q = +1,6 \times 10^{-19} \text{ C}$$

$$E = \frac{F}{Q}$$

$$100 = \frac{F}{1,6 \times 10^{-19}}$$

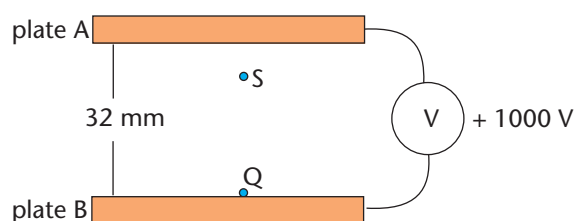
$$\therefore F = 1,6 \times 10^{-17} \text{ N}$$



Activity 4.3: Application of electric field strength

- Draw an electric field diagram:
 - surrounding a negative point charge
 - surrounding two positive point charges
 - surrounding two oppositely charged point charges

2. Two parallel plates are 2 cm apart and have a potential difference of 15 V.
 - a) Draw the electric field diagram of the two plates.
 - b) Calculate the electric field between the two plates.
 - c) If the distance between the plates is doubled, what will be the new field between the plates? (Do not use any formulae to answer this question.)
3. A distance between parallel plates is varied at constant intervals, while keeping the potential difference constant. Draw a graph showing the relationship between V and E .
4. The horizontal parallel plates A and B are separated by a distance of 32 mm. B is at a potential of +1 000 V.



- a) Draw a sketch to show the electric field lines between the plates A and B.
- b) Calculate the magnitude of the electric field strength between the plates.
- c) A tiny charged particle is stationary at S, 8 mm below plate A, which is at zero electrical potential. It has a charge of $3,2 \times 10^{-12}$ C.
 - (i) State whether the charge on this particle is positive or negative.
 - (ii) Calculate the force due to the electric field on the charge.

4.2.3 Applications of electrostatics in technology

Electrostatics in an inkjet printer

An inkjet printer uses electrostatic charge to direct the tiny ink droplets to the correct place on the page. Coloured ink is passed through a very small hole called a nozzle. The nozzle separates the ink into many tiny droplets, which are given an electrostatic charge.

The direction in which the charged ink droplets move can be controlled by electrically charged metal plates. A voltage on the plates means that the charged ink droplets will be attracted to one plate and repelled by the other.

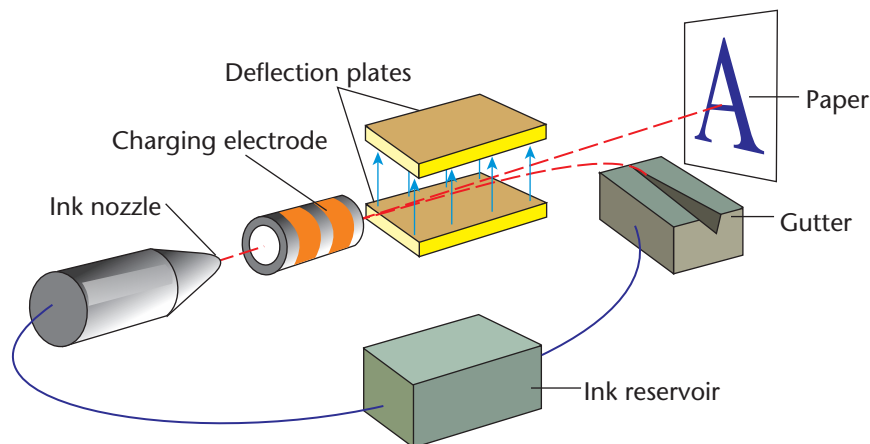
The ink droplets have a positive charge. The ink droplets are attracted to the negative plate and repelled by the positive plate.

By controlling the voltage on the plates, a particular ink drop can be precisely positioned on the paper.

There are many nozzles, and the final picture is made up of a very large number of coloured ink drops, each in exactly the right place for the image.



Figure 4.6 How is Electrostatic Charge used in an Inkjet Printer?



[Source: Adapted from <http://www.gcscience.com/pse9-electrostatic-charge-inkjet-printer-nozzle.htm>]

Electrostatics in spray painting

Millions of cars are made each year and the steel car bodies must all be painted to prevent them from rusting.

The paint is sprayed onto the car bodies and the process is made more efficient by using electrostatic charges.

The spray paint goes past high voltage positive needles as it leaves the spray gun and the tiny droplets of paint pick up a positive charge. They do this by losing negative electrons.

The car body is then given a high voltage negative charge which attracts the positively charged paint droplets. The paint droplets spread out more as they leave the gun because they all get the same positive charge and so they all repel each other. It covers a wider area more evenly. The paint droplets are attracted to the negative metal car body, and so less paint is wasted.



Figure 4.7 How is Electrostatic Charge used in Paint Spraying?

[Source: Adapted from <http://www.gcscience.com/pse8-electrostatic-charge-paint-spray.htm>]

Electrostatics in industrial chimneys

Pollution from industrial chimneys as well as the waste gases from burning coal (carbon dioxide and sulfur dioxide), can be reduced by using electrostatic charge.



Figure 4.8 Application of electrostatics in industrial chimneys

[Source: Adapted from <http://www.gcscience.com/pse11-electrostatic-chimney-pollution.htm>]

The chimney contains many small particles of unburnt fuel (mainly carbon). The chimney has a high voltage negative grid across it and this gives the small particles a negative charge as they escape causing them to gain electrons.

Further up, the chimney has positively charged plates. These plates attract the negatively charged particles. The particles of pollution build up on the plates until they are heavy enough to fall down into containers. In this way, much of the smoky pollution is removed from the chimney before it can get out into the atmosphere.

4.3 Electric circuits

4.3.1 Introduction

We rely on electric forces, electricity and electrical appliances to make many things possible in our daily lives. To understand the technology that uses electricity in the real-world, the study of electrical circuits is essential.

In this section we will learn about electric circuits, series and parallel combinations, and the application of Ohm's law.

Did you know?

During load shedding in our country we could not use the kettle to boil water for tea or coffee; could not use electric stoves or ovens to cook dinner; couldn't charge our cell phones nor watch a television. We were in the dark!

According to Eskom, load shedding is a measure of last resort to prevent the collapse of the power system country-wide.

When there is insufficient power station capacity to supply the demand (load) from all the customers, the electricity system becomes unbalanced. This can cause a country-wide blackout, which could take days to restore.

When power is insufficient, Eskom can thus either increase supply or reduce demand to bring the system back into balance. As the difference between supply and demand becomes small, we refer to the system becoming 'tight'. This implies that action has to be taken to prevent the system from becoming unstable. Eskom normally takes a sequence of steps to keep the system stable and to avoid load shedding. The steps include first asking large customers to reduce the load voluntarily.

However, if several power station units trip suddenly and unexpectedly, we may have to skip those steps and go straight to load shedding to prevent the system from becoming unstable. Scheduled load shedding is a controlled way of sharing the available electricity amongst all its customers. By switching off parts of the network in a planned and controlled manner, the system remains stable throughout the day, and the impact is spread over a wider base of customers.



Figure 4.9 Load shedding

In Grade 10 we learned the following about resistors connected in series and connected in parallel:

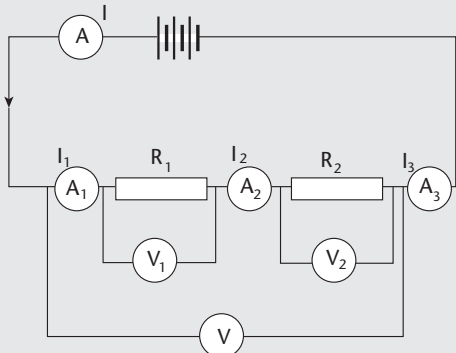
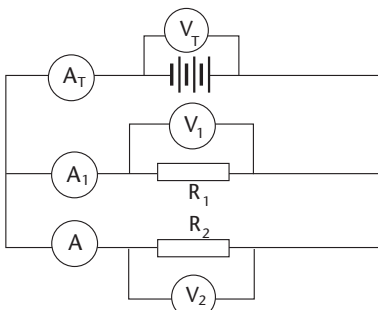
Resistance, current and potential difference in series circuit	Resistance, current and potential difference in parallel circuit
	
Effective/(equivalent) resistance: $R = R_1 + R_2$ The equivalent resistance in a series circuit is worked out by calculating the sum of all the resistors in the circuit.	Effective/(Equivalent) Resistance: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ The equivalent resistance is always smaller than the smallest resistance in the circuit.
Current: $I_1 = I_2 = I_3$ The current is the same anywhere in a series circuit.	For two resistors connected in parallel the following equation can also be used: $R_p = \frac{\text{product}}{\text{sum}} = \frac{R_1 \times R_2}{R_1 + R_2}$
Potential Difference: $V_T = V_1 + V_2 + V_3$ Resistors connected in series are voltage dividers.	Current: $I = I_1 + I_2 + I_3 + \dots$ Resistors in parallel are current dividers.
Potential Difference: $V = V_1 = V_2 = V_3$ The potential difference across all resistors connected in parallel will always be the same. It will also be the same the potential difference across the whole parallel combination.	

Figure 4.10 Series and parallel connections



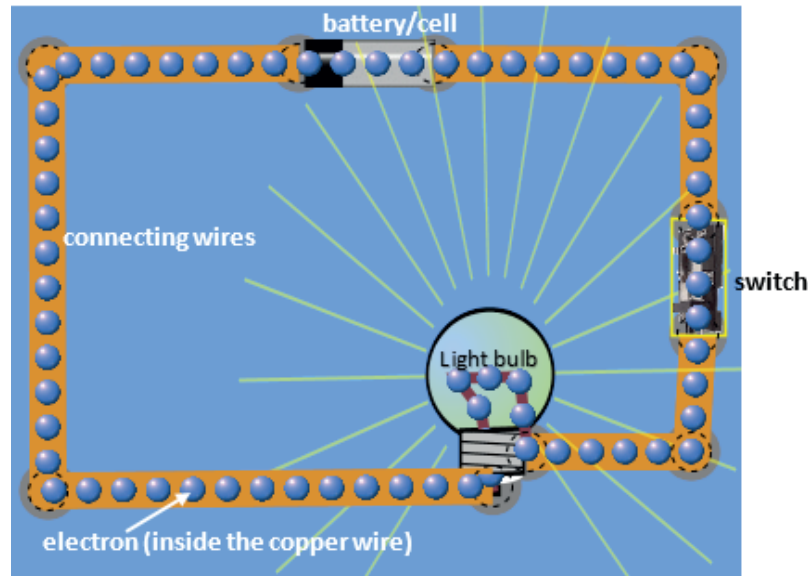
Activity 4.4: Electric circuits

- Use the keywords to complete the paragraph below.

negative loop positive path charges closed energy

A circuit will only work if it is _____. This means that it must make a complete _____, otherwise the electrical _____ cannot be transferred. A circuit is a _____ that allows _____ to pass through it. The conventional direction of the electric current is always travels from the _____ terminal to the _____ terminal.

2. In your own word, describe what is happening in the diagram. Make reference to the following conventional direction of the current, direction of electrons and energy conversion.



PRACTICAL INVESTIGATION (Informal)

Relationship between potential difference and current

Aim:

Investigate the relationship between the potential difference (V) across a resistor and the current through it.

To investigate the relationship between the potential difference (V) across a resistor and the current through it, we are going to apply the scientific method.

Investigative question

What is the relationship between the potential difference (V) across a resistor and the current through it?

Variables

- Independent: Potential difference
- Dependent: Current
- Controlled (fixed): Temperature of the resistor/ resistance of the resistor

Hypothesis

When current through a resistor increases, the potential difference across the resistor increases.

Apparatus

- 4 cells (1,5 V each)
- resistor
- voltmeter
- ammeter
- variable resistor
- switch
- connecting wires

Procedure

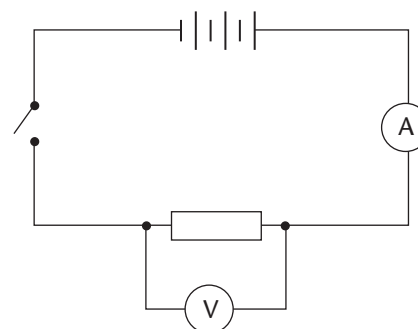
Step 1: Set up the circuit according to the following circuit diagram.

Step 2: Close the switch and measure the voltage across the resistor using the voltmeter, and the current in the circuit using the ammeter.

Step 3: Add one more 1,5 V cell to the circuit and repeat your measurements.

Step 4: Repeat until you have four cells.

Step 5: Record your result in the following table.



Circuit diagram1

Number of cells	Voltage, V (V)	Current, I (A)
0		
1		
2		
3		
4		

Step 6: Use the information in your table to draw a graph illustrating the relationship between the potential difference (V) and the current (I). Plot (I) on the y -axis, and (V) on the x -axis.

Step 7: Calculate the slope (gradient) of the graph.

Step 8: What physical quantity is represented by the slope of the graph?

Step 9: Analyse your results and graph and write down a conclusion for your investigation.

4.3.2 Resistance

In Grade 10 we defined **resistance** as the opposition to the flow of electric current. We also learned that the unit measure of the resistance is ohms (Ω). $1\Omega = 1 \text{ V}\cdot\text{A}^{-1}$.

From the investigation we found that the gradient of the graph (the slope) represents the reciprocal of the resistance, which is called conductance.

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{\Delta I}{\Delta V}$$

4.3.3 Ohm's law

Below is the summary of the results obtained in the experiment performed in the previous practical activity:

Number of cells	Voltage, V (V)	Current, I (A)
0	0	0
1	1,5	0.0015
2	3	0.003
3	4,5	0.0045
4	6	0.006

Graph of current versus potential difference across the resistor

From the results obtained above, one can therefore conclude that:

- the current flowing through the conductor is directly proportional to the potential difference across the resistor ($I \propto V$).

- from the graph we get the following linear equation

$$y = mx + c. \text{ Making:}$$

$$y = I$$

$$x = V$$

$$m = \frac{1}{R}$$

$$c = 0$$

- we get $\frac{1}{R} = \frac{\Delta I}{\Delta V}$, which is the constant of proportionality (slope/gradient of the graph).
Therefore, $R = \frac{V}{I}$.

However, for the statement above to be true we must ascertain that the resistance of the conductor remains constant. To ensure this, we must also ascertain that the:

- length of the conductor remains constant
- thickness of the conductor remains constant
- material of which the conductor is made of remains unchanged
- temperature of the conductor.

The first three factors are almost always guaranteed. The one factor that needs to be closely monitored is the temperature of the conductor.

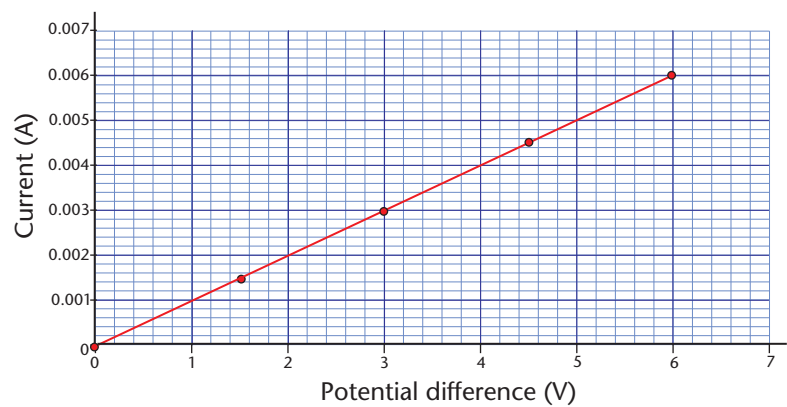
Therefore, we can modify the initial drawn statement from the experimental results to be:

- The current flowing through the conductor is directly proportional to the potential difference across the resistor, provided the temperature of the conductor remains constant.

The statement above was named after the German Physicist and Mathematician, George Ohm.

Using equipment of his own creation, Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor (resistor) and the current through it, provided that the temperature remains constant.

This relationship is known as Ohm's law.



Georg Ohm
(16 March 1789 - 6 July 1854)

Example 4.6**CALCULATIONS USING OHM'S LAW**

Calculate the resistance of a resistor if the potential difference across the terminals of the resistor is 6 V and current passing through is 1,5 A.

1. ANALYSE

Given: $I = 1,5 \text{ A}$

$$V = 6 \text{ V}$$

Unknown: $R = ?$

2. SOLVE

Using Ohm's Law, we know that:

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

$$\therefore R = \frac{6}{1,5}$$

$$R = 4\Omega$$

Therefore, the resistance of such a resistor is 4Ω.

Example 4.7**CALCULATIONS USING OHM'S LAW**

What is the current flowing through the resistor, if the potential difference across that resistor is 4 V and the resistance of the resistor is 10Ω?

1. ANALYSE

Given: $R = 10\Omega$

$$V = 4 \text{ V}$$

Unknown: $I = ?$

2. SOLVE

Using Ohm's Law:

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

$$10 = \frac{4}{I}$$

$$\therefore I = 0,4 \text{ A}$$

The current passing through such a resistor is 0,4 A.



EXPERIMENT 10 (formal)

Determine the resistance of an unknown resistor.

Background

Ohm's law states that: The current flowing through the conductor is directly proportional to the potential difference across the resistor, provided the temperature of the conductor remains constant.

Mathematically

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

Aim

To determine the resistance of an unknown resistor applying Ohm's law.

Apparatus

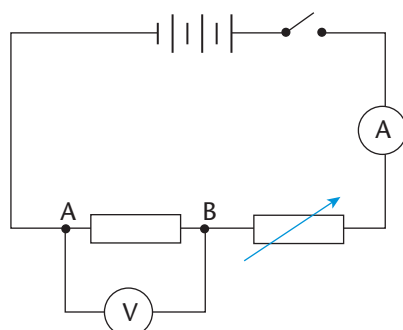
- battery/DC power supply
- resistance wire (resistor)
- rheostat (variable resistor)
- ammeter
- voltmeter
- connecting wires

Precautions

- Do not leave the switch closed at all times. The battery will run flat.
- Close the switch only for taking the readings on the voltmeter and ammeter.
- Take your readings accurately.
- Do not conduct the experiment with wet hands.

Method/Procedure

1. Set up a circuit according to the circuit diagram shown below, connecting the unknown resistor between points A and B.



Circuit diagram 2

2. Close the switch and adjust the rheostat to give a low voltage across the unknown resistor. Measure the voltage across the resistor using the voltmeter, and the current in the circuit using the ammeter.
3. Close the switch and change the resistance in the rheostat and take the ammeter and voltmeter reading.

4. Repeat the readings for different values of the resistance of the rheostat and record your results in a table below (Open the switch while recording the readings in order to spare the batteries' life span).

Trial No.	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		
4		
5		

5. Use your reading to plot a graph of potential difference against current.
6. Do the analysis and interpretation of the result.
 - a) What is the shape of the graph?
 - b) What does the gradient of the graph represent?
7. Use the graph to calculate the resistance of the unknown resistor.
8. Write down a conclusion for the experiment.

Example 4.8

OHM'S LAW

1. The learners were investigating the relationship between the potential difference across the resistor and the current passing through it. They added cells in series, starting with one cell. Before adding a new cell, a switch was closed and the voltmeter and ammeter reading were taken.

Use the results below to answer the following questions:

Number of cells	V (V)	I (A)
1	3.0	0.375
2	6.0	0.75
3	9.0	1.125
4	12.0	1.50

- a) Plot the graph of V vs. I .
- b) Explain how you would use the graph to determine the resistance of the resistor.
- c) Determine the resistance of the resistor used.
- d) From the graph, what conclusion can be drawn about the relationship between V and I ?
2. Calculate the resistance of the resistor, if the potential difference across the resistor's terminals is 3 V, and the current passing through it is 0,4 A.
3. The current flowing through a 10Ω resistor is 0,21 A.
 - a) What is the potential difference across the 10Ω resistor?
 - b) If the switch was on for 10 s, while taking the measurements, what is the energy delivered to the resistor. (Hint: recall that $V = \frac{W}{Q}$)

4. Below is a table of results for which Ohm's law is valid. Calculate the missing quantities.

Questions	Potential difference (V)	Current (I)	Resistance (R)
5.1	4,5 V	(a)	15 Ω
5.2	(b)	3 A	12 Ω
5.3	9 V	0,5 A	(c)
5.4	(d)	2,5 A	3 Ω
5.5	220 V	(e)	80 Ω

4.3.4 Series and parallel network

In Grade 10 we looked at how to calculate effective resistances of series and parallel circuits. At the beginning of this chapter we summarised those results as a reminder of what we did.

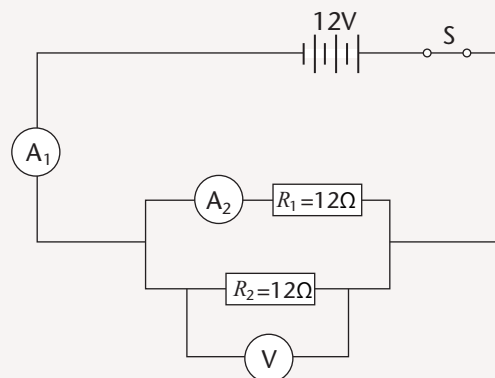
The following examples will still require us to apply such principles to which parallel and series circuits adhere.

Example 4.9

ELECTRIC CIRCUITS CALCULATIONS

Study the circuit diagram below and answer the questions that follow:

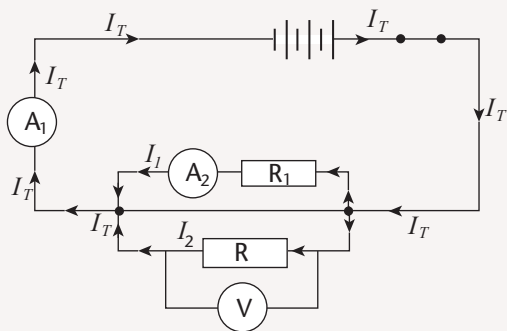
- Calculate the effective resistance of the circuit.
- Determine the reading on the ammeter A_1 .
- What is the reading on the voltmeter V?
- Determine the reading on the ammeter A_2
- If R_2 burned out what would happen to the reading on the ammeter A_1 ?



Solution

By tracing the path followed by the conventional current, we can see where the current divides. This tells us which resistors are in parallel.

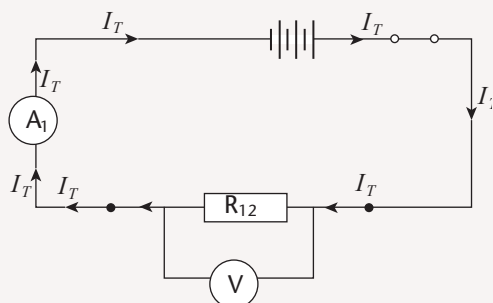
Below is the presentation of the flow of current in the circuit above:



We clearly see that at the junction of R_1 and R_2 the current divides.

We can thus deduce that R_1 and R_2 are parallel.

To simplify the problem, we can replace the resistors with one resistor R_{12} , which has the same effect as the two resistors.



We can see that the current flowing through R_{12} is the total current.

Since this is now the only resistor in the circuit, the potential difference measured by the voltmeter is the total external potential difference.

- a) Since we only have two resistors connected in parallel, the total resistance is:

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

$$R_T = \frac{4 \times 12}{4 + 12}$$

$$R_T = 3\Omega$$

- b) From the sketches, it is clear that A_1 measures the total current flowing in the circuit. Since we know the total voltage and the total resistance, we can easily calculate the total current:

$$I_T = \frac{V_T}{R_T}$$

$$I_T = \frac{12}{3}$$

$$I_T = 4\text{ A}$$

- c) As discussed above, the voltmeter V measures the total voltage of the circuit, since $R_{12} = R_T$. Therefore, the reading on the voltmeter is 12 V.

- d) We already know that the resistors in parallel have the same voltage. Therefore, potential difference across R_1 is also 12 V. Using Ohm's law we can easily calculate the current through R_1 , which will be reading on the ammeter A_1 .

$$I_1 = \frac{V_1}{R_1}$$

$$I_1 = \frac{12}{4}$$

$$I_1 = 3\text{ A}$$

- e) If R_2 burns, the total resistance of the circuit will increase. As the total potential difference is constant, the total current, according Ohm's law, will decrease. Therefore, the reading on A_1 will decrease.

Example 4.10**ELECTRIC CIRCUITS CALCULATIONS**

Study the diagram alongside, then answer the questions that follow.

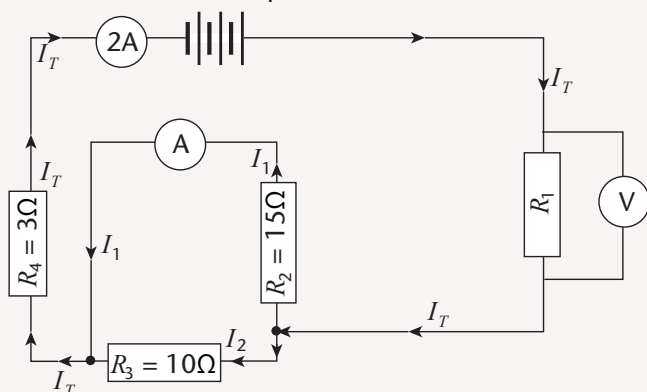
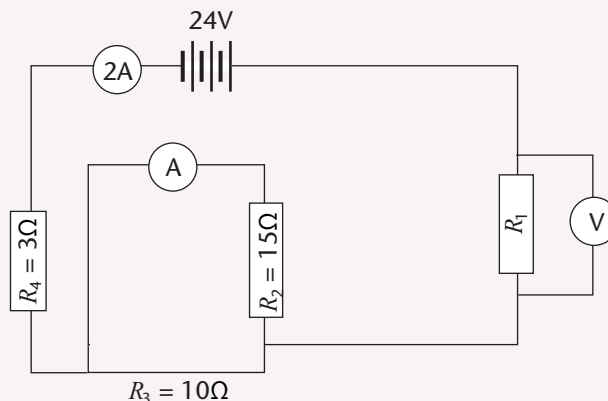
Calculate:

- the resistance of resistor, R_1 .
- the reading on A.

Solution:

Follow the same approach we used in the previous example.

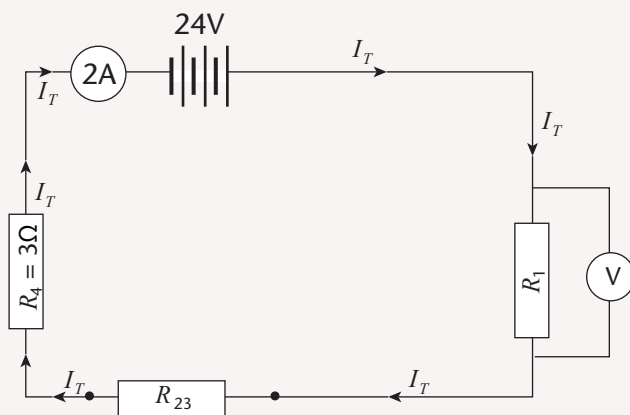
Trace the path of the current, thereby identifying the resistors that are parallel.



From the diagram above, we can see that current divides at the R_2 and R_3 junction.

Therefore, the resistors are parallel to each other.

This allows us to replace the two resistors with one resistor (R_{23}), which has the same effect as the two resistors.



Now the sketch is simplified, and we can answer the questions.

- a) We know the total current of the circuit, as well as the total voltage. We are therefore able to calculate total resistance from which we will be able to calculate R_1 .

$$R_T = \frac{V_T}{I_T}$$

$$R_T = \frac{24}{2}$$

$$R_T = 12\Omega$$

But the three resistors, R_1 , R_{23} and R_4 are in series. So if we can calculate the effective resistance of R_{23} , then we can easily calculate R_1 .

$$R_{23} = \frac{R_1 R_4}{R_1 + R_4}$$

$$R_{23} = \frac{15 \times 10}{15 + 10}$$

$$R_{23} = 6\Omega$$

Now for resistors in series we have:

$$R_T = R_1 + R_{23} + R_4$$

$$12 = R_1 + 6 + 3$$

$$\therefore R_1 = 3\Omega$$

- b) Ammeter A_1 measures the current through R_2 . If we can find the potential difference across effective resistance R_{23} , then we can solve the problem.

For resistors in series current is the same as the total current. Therefore, we have:

$$V_1 + V_{23} + V_4 = V_T$$

$$I_1 R_1 + V_{23} + I_4 R_4 = I_T R_T$$

$$2 \times 2 + V_{23} + 2 \times 3 = I_T R_T$$

$$\therefore 2 \times 2 + V_{23} + 2 \times 3 = 24$$

$$\therefore V_{23} = 12\text{ V}$$

$$\therefore I_2 = \frac{V_{23}}{R_1}$$

$$\therefore I_2 = \frac{12}{15}$$

$$\therefore I_2 = 0,8\text{ A}$$

In the next section we will explore how the results for good conductors such as copper compare with that of semiconductors.

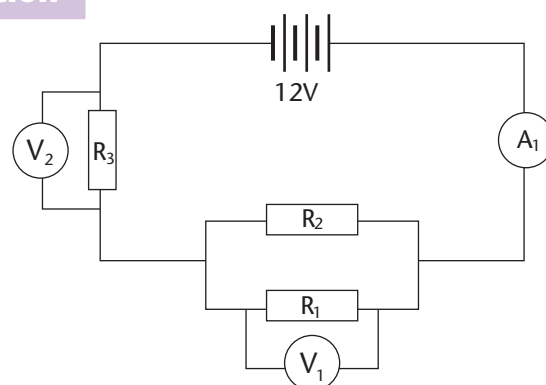


Activity 4.5: Series and Parallel Combination

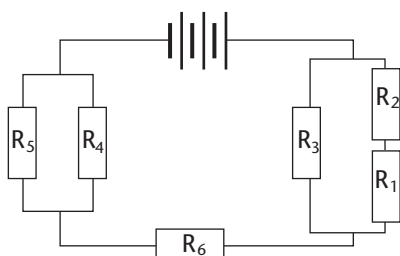
1. In circuit diagram below, a 12 V battery is connected to a combination of resistors. $R_1 = 3\Omega$, $R_2 = 6\Omega$ and $R_3 = 2\Omega$.

Calculate:

- The total resistance of the circuit.
- The reading on the ammeter A_1 .
- The reading on the voltmeter V_2 .
- The current flowing through the resistor R_2 .



- e) What will happen to the reading on ammeter A_1 if the resistor R_1 burned out? (Write only INCREASE, DECREASE, or STAY THE SAME). Explain how you reached your conclusion.
2. Calculate the missing information in the table for the following circuit. Show all your calculations. Note that the order in which the calculation must be done does not matter.



	V	I	R
Total	(m)	2A	(n)
R_1	(a)	(b)	5Ω
R_2	3,5 V	(c)	(d)
R_3	(e)	1,5 A	(f)
R_4	4 V	(g)	(h)
R_5	(i)	1 A	(j)
R_6	(k)	(l)	2Ω



EXPERIMENT

OHMIC AND NON-OHMIC CONDUCTORS

Aim:

To investigate the voltage-current relationship for a copper wire (resistor) and a diode (semiconductor) to determine which one obeys Ohm's law.

Materials

- battery/DC power supply
- resistance wire (resistor)
- rheostat (variable resistor)
- ammeter
- voltmeter
- connecting wires
- diode/led (semiconductor)

Precautions

Do not leave the switch closed at all times. The battery will run flat.

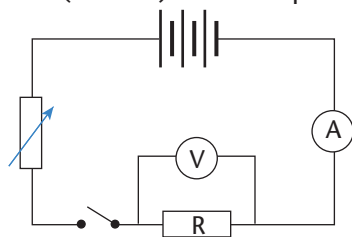
Close the switch only for taking the readings on the voltmeter and the ammeter.

Take your readings accurately.

Do not conduct the experiment with wet hands.

Method

1. Set up a circuit according to the circuit diagram shown below, connecting the copper wire (resistor) between points A and B.



2. Close the switch and adjust the rheostat to give a low voltage across the unknown resistor. Measure the voltage across the resistor using the voltmeter, and the current in the circuit using the ammeter.
3. Close the switch and change the resistance in the rheostat and take the ammeter and voltmeter reading.
4. Repeat the readings for different values of the resistance of the rheostat and record your results in a table below. (Open the switch while recording the readings in order to spare the batteries' life span.)

	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		
4		
5		

5. Replace the copper wire (resistor) with the diode/LED (semiconductor).
6. Close the switch and adjust the rheostat to give a low voltage across the diode/LED (semiconductor). Measure the voltage across the diode/LED (semiconductor) using the voltmeter, and the current in the circuit using the ammeter.
7. Repeat the readings for different values of the resistance of the rheostat and record your results in a table below (Open the switch while recording the readings in order to spare the batteries' life span).

Trial No.	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		
4		
5		

8. Use your reading to plot a graph of potential difference against current for both the copper wire and the diode/led (semiconductor).

9. Do the analysis and interpretation of the result. What is the shape of the graph for each the copper wire and the semiconductor?
10. Write down a conclusion for the experiment.
 - a) Which one of these components obey Ohm's law?
 - b) Which factor must remain constant for a component to obey Ohm's law?

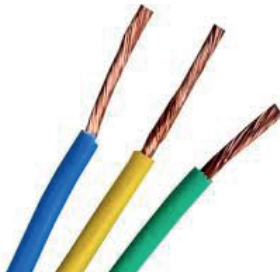
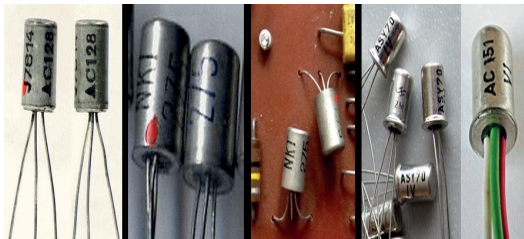
From the experiment we can deduce the following:

- Resistance is defined by a simple relationship: resistance is the ratio of potential difference across a circuit component and the current passing through it. The actual resistance of materials does not depend on the potential difference across it, nor on the current through it. Resistance is an intrinsic property of material that only depends on the cross-sectional area and the length of the material.
- Ohm's law is only valid for metallic conductors if the temperature of the conductors remains constant. When metallic conductors are heated, their resistance increases. However, resistance (resistivity) decreases with increasing temperature in semi-conductors and insulators.
- The correct causal relationship between potential difference and current in an electric circuit is that potential difference gives rise to current. Current cannot flow through a conductor if potential difference does not exist between the ends of the conductor.

Ohm's law is also valid for the colour-coded ceramic resistors used in electronic equipment. Conductors that obey Ohm's Law are referred to as Ohmic conductors and those that don't are referred to as non-ohmic conductors.

Examples of ohmic conductors and non-ohmic conductors are given in Table 4.2.

Table 4.2 Ohmic vs non-ohmic conductors

Ohmic conductors	Non-Ohmic conductors
Copper Wire 	Acid battery 
Nichrome 	Transistor 

Platinum 	Ionized gas tubes 
Carbon/graphite conductors 	Light Bulbs 
Light Emitting Diodes (LED) 	



Activity 4.6: Ohmic and non-Ohmic conductors

- Define the following terms
 - Ohm's law
 - Ohmic conductor
 - Potential difference
 - Current
 - Resistance
- List two examples of ohmic and non-ohmic conductors

4.4 Internal resistance and emf (electromotive force)

To produce a steady flow of charge in an electric circuit we need a device to do work on the charge carriers. Such a device is called an emf-device. This device is said to provide an emf (ε). The emf-device has a positive terminal (at a higher potential) and a negative terminal at lower potential). The terminals are called electrodes.

Until now we have only worked with ideal batteries. These batteries are not affected by the circuit or current in any way, and provide a precise voltage until they go flat. Thus, if you were to measure the potential difference across the terminals of a battery on its own, you will get a different value to what you measure when it is connected in a complete circuit. The value will be less when the battery is included in a complete circuit.

The emf of an emf-device is the maximum electric potential difference (in volts) that exists between the terminals of the emf-device such as a battery. Thus we can say that: the emf of an emf-device is the work (energy transferred) per unit charge that the device does in moving charge from its low-potential terminal to its high-potential terminal.

Note:

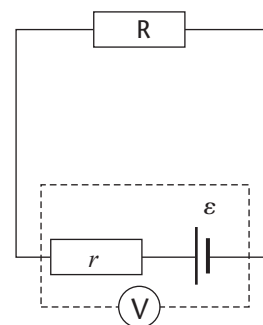
Sometimes the difference is called the lost *volts*.

Nothing has actually been lost but energy has been transferred.

Real batteries are made from materials that have resistance. This means that real batteries are not just sources of potential difference (voltage), but they also possess **internal resistance**. If the total potential difference source is referred to as the emf, ε , then a real battery can be represented as an emf connected in series with a resistor r .

Internal resistance is the resistance to flow of charges through a voltage source such as a battery that arises from the resistance of the materials from which the source is made. In a real battery, the internal resistance is due to chemicals within the battery. In a generator, the internal resistance is the resistance of the wires and the other components within the generator. The internal resistance of the battery is represented by the symbol r .

The circuit diagram alongside shows a cell with an emf ε and its internal resistance r , an external resistance R , an ammeter and a voltmeter:



In the circuit diagram, the reading of the ammeter will be:

$$I = \frac{\varepsilon}{R + r}$$

This is sometimes called Ohm's Law for a whole circuit.

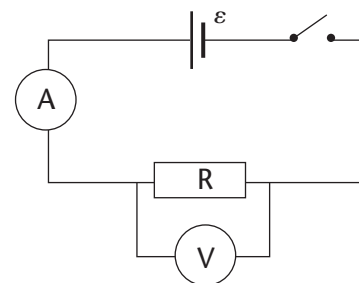
Now making ε the subject of the previous equation we have:

$$\varepsilon = I(R + r) \quad \text{OR} \quad \varepsilon = IR + Ir$$

$$IR = (V_{\text{load}}) \quad [\text{It is called terminal potential difference (potential difference } V \text{ across the external circuit)}]$$

$$Ir = \text{the drop of potential in the internal resistance } (V_{\text{internal resistance}})$$

$$IR = \varepsilon - Ir \quad \text{OR} \quad V_{\text{load}} = \varepsilon - V_{\text{int}} \quad \text{OR} \quad V_{\text{ext}} = \varepsilon - V_{\text{int}}$$





EXPERIMENT

Determine the internal resistance of a battery (informal)

Aim:

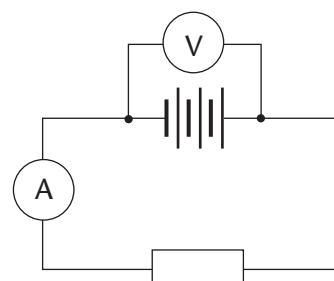
Determining the internal resistance of a battery

Apparatus

- 1 voltmeter
- 1 ammeter
- 1 rheostat
- 1 switch
- a battery (or cells)
- connecting wires

Procedure:

1. Connect a circuit consisting of a rheostat, switch, ammeter and battery connected in series as illustrated in the diagram. Ensure that, for the purpose of this experiment, you use new cells (or batteries).
2. Connect the voltmeter across the battery as illustrated.
3. Observe the reading on the voltmeter and the ammeter when the switch is open. Record these values in the table.
4. Close the switch and observe the readings on the voltmeter and the ammeter. Record these values in the table.
5. Repeat steps 3 and 4 two or three times.
6. Calculate the average potential difference (V) and current (I) for both open and closed switch.

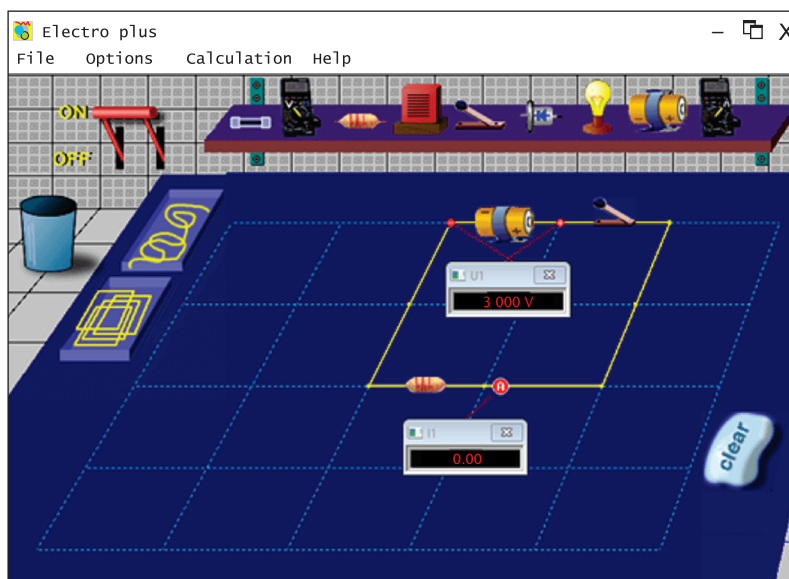


	SWITCH OPEN	SWITCH CLOSED		
Trial #	V (V)	I (A)	V (V)	I (A)
1				
2				
3				
Average				

7. Calculate the average drop in potential difference ($\Delta V = V_{\text{open}} - V_{\text{closed}}$)
8. Calculate the increase in current ($\Delta I = I_{\text{closed}} - I_{\text{open}}$)
9. Calculate the internal resistance (r) of one cell $r = \left(\frac{\Delta V}{\Delta I} \right)$
10. Write down a conclusion for the experiment.

Discussion

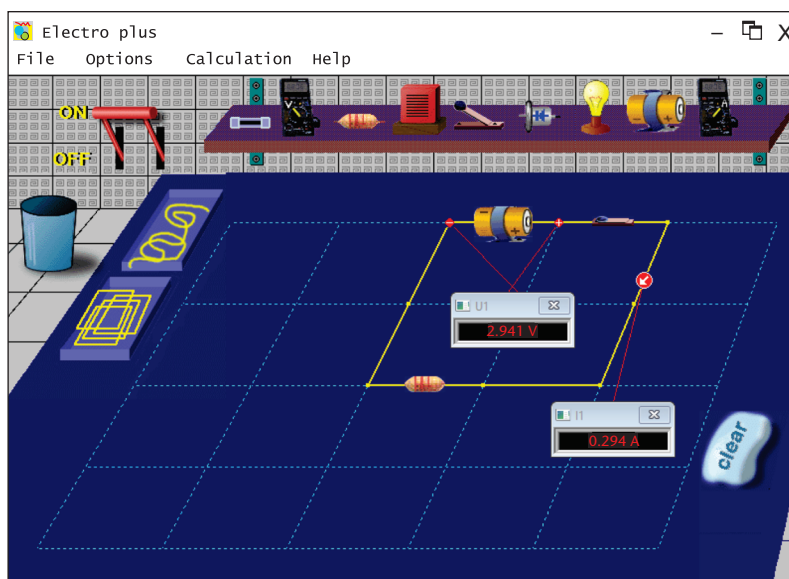
When the switch in a simple electric circuit is open, no current is flowing. If there is a voltmeter connected across the battery (or a cell), it will give a certain reading. The reading on the voltmeter connected across a battery when the circuit is open (that is when there is no current) flowing is called the emf.



When the switch is closed, the reading on voltmeter across the battery changes (it decreases). This is due to the resistance to the current as it flows through the battery.

The resistance inside a cell when there is current flowing through it is referred to as the internal resistance (denoted by the small letter r).

The potential difference across the battery when the current is flowing in the circuit is called the terminal voltage.



Screenshot from Electropus English software:

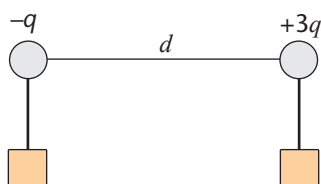
The voltmeter reading across the battery decreases when the switch is closed and there is current flowing in the circuit.

Review exercise

Multiple choice questions

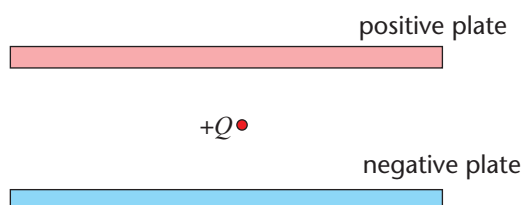
Choose one correct answer from the options below:

- Two small identical metal spheres, on insulated stands, carry charges $-q$ and $+3q$ respectively. When the centres of the spheres are separated by a distance d the one exerts an electrostatic force of magnitude F on the other. The spheres are now made to touch each other and are then brought back to the same distance d apart.



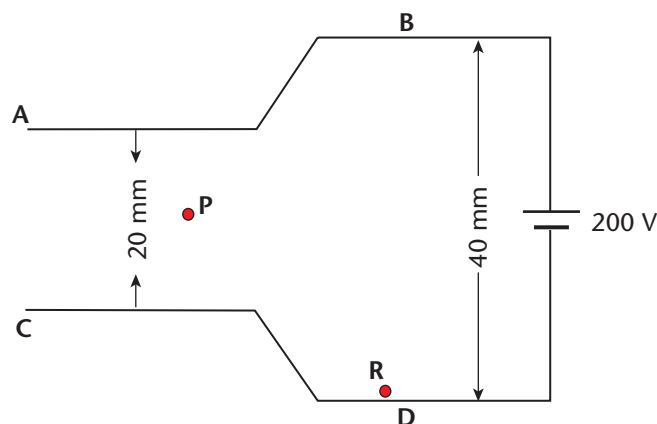
What will be the magnitude of the electrostatic force which one sphere now exerts on the other?

- $\frac{1}{4}F$
 - $\frac{1}{3}F$
 - $\frac{1}{2}F$
 - $3F$
- A positive charge Q is released from rest at the centre of a uniform electric field.



How does Q move immediately after it is released?

- It accelerates uniformly.
 - It moves with an increasing acceleration.
 - It moves with constant speed.
 - It remains at rest in its initial position.
- The sketch below shows two sets of parallel plates which are connected together. A potential difference of 200 V is applied across both sets of plates. The distances between the two sets of plates are 20 mm and 40 mm respectively.



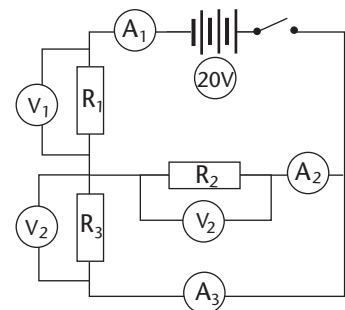
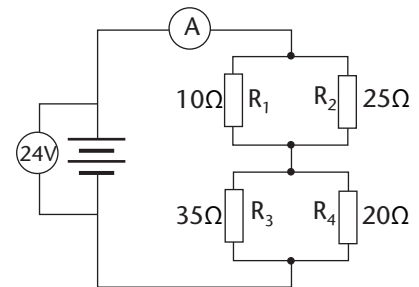
When a charged particle Q is placed at point R , it experiences a force of magnitude F .

Q is now moved to point P, halfway between plates AB and CD. Q now experiences a force of magnitude:

- A. $\frac{1}{2}F$
- B. F
- C. $2F$
- D. $4F$

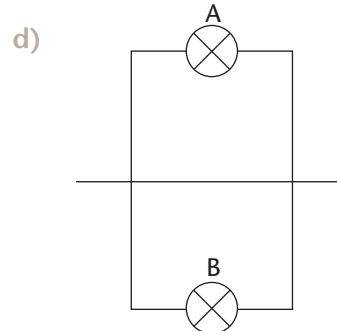
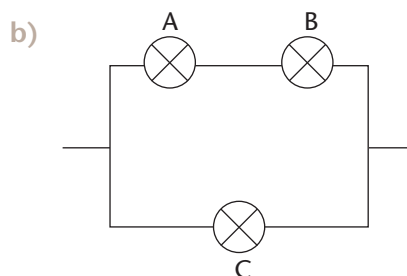
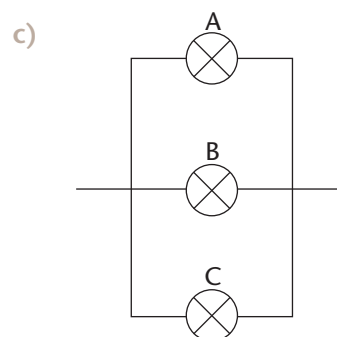
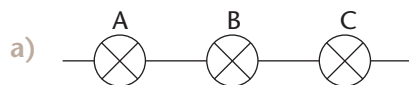
Long questions

4. Two charges of $+3\text{ nC}$ and -5 nC are separated by a distance of 40 cm. Calculate the magnitude of the electrostatic force that the point charges exert on each other.
5. Two insulated metal spheres carrying charges of $+6\text{ nC}$ and -10 nC are separated by a distance of 20 mm.
 - a) State Coulomb's law in words.
 - b) Draw the electric field diagram for the two charges
 - c) What is the electrostatic force between the spheres?
 - d) The two spheres are touched and then separated by a distance of 60 mm. What are the new charges on the spheres?
 - e) What is new electrostatic force between the spheres at this distance?
6. Calculate the potential difference between two parallel plates if it takes 5 000 J of energy to move $2,5\text{ nC}$ of charge between the plates.
 - a) If the plates are 5 mm apart, what is the electric field intensity between the two plates?
 - b) In this uniform field region, what will be the force experienced by an electron?
7. Calculate the electric field between the plates of a capacitor if the plates are 20 mm apart and the potential difference between the plates is 300 V.
8. Consider the circuit below and answer the questions that follow. The battery used has the negligible resistance.
 - a) Calculate the equivalent resistance of the four resistors.
 - b) What is the total current that flows in the circuit?
 - c) Calculate the potential difference across and the current that flows through
 - (i) The 10Ω resistor
 - (ii) The 35Ω resistor
 - (iii) The 25Ω resistor
 - (iv) The 20Ω resistor
9. In the circuit diagram below, the resistors $R_1 = 5\Omega$, $R_2 = 10\Omega$, $R_3 = 8\Omega$. The battery has a negligible resistance. When the switch is closed, calculate the following:
 - a) the total resistance of the circuit.
 - b) the reading on the ammeter A_1
 - c) the reading on V_1
 - d) the reading on V_2



- e) the reading on A_3
- f) the reading on V_3
- g) the reading on A_2

10. Rank each of the following bulbs in each combination below in terms of their increasing brightness strength (that is, from the dimmest to the brightest). Assume that all the bulbs are identical.



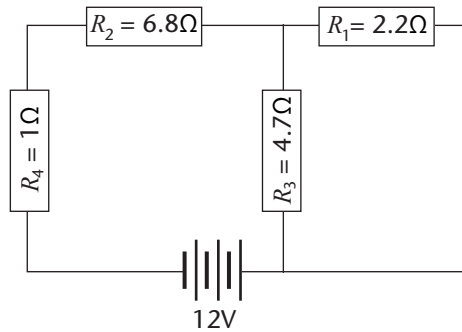
10. State Ohm's law in words.
11. Draw the graph that shows the relationship between the current in the circuit and the potential difference.
12. Explain the difference(s) between the Ohmic and the non-Ohmic conductors.
13. List two examples of non-Ohmic resistors
14. List the factors that affect the resistance of a substance
15. A group of learners conducted an experiment in which they wanted to determine the unknown resistance of a resistor. To achieve this, they set up an experiment adding cells in series, while recording the voltmeter and ammeter readings. Below is the table summarising the results they obtained:

Number of Cells	V (V)	I (A)	$R = \frac{V}{I} (\Omega)$
1	1,44	0,14	
2	2,88	0,29	
3	4,33	0,43	

- a) Complete the table below by calculating R for each number of cells.
- b) Calculate the average resistance.

- c) Plot the graph of V versus I .
- d) Calculate the slope of the graph, and use the slope to determine the resistance of the resistor.
- e) How does your answer to number b) compare to that of d) above?

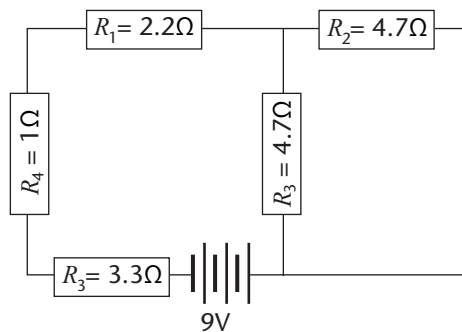
16. Study the circuit diagram below, and answer the questions that follow. The battery has an emf of 12 V, and a negligible resistance.



Do the appropriate calculations and complete the table below: (Hint: study the path of the conventional electric current)

		Quantity	R_1	R_2	R_3	R_4	Total
Voltage					12 V		
Current							
Resistance	2,2Ω	6,8Ω	4,7Ω	1Ω			

17. Study the circuit diagram below, and answer the questions that follow. The battery has an emf of 9 V, and a negligible resistance.



Do the calculations, and complete the table below:

		Quantity	R_1	R_2	R_3	R_4	R_5	Total
Voltage						9 V		
Current								
Resistance	2,2Ω	4,7Ω	4,7Ω	1Ω	3,3Ω			

18. Define the following terms:

- a) emf
- b) internal resistance

- c) resistance
 - d) potential difference
 - e) electric current
19. In a series circuit, certain general rules may be stated with regard to quantities of voltage, current and resistance. Express these rules using your own words:
- a) In a series circuit, voltage...
 - b) In a series circuit, current...
 - c) In a series circuit, resistance...
20. In a parallel circuit, certain general rules may be stated with regard to quantities of voltage, current and resistance. Express these rules using your own words:
- a) In a parallel circuit, voltage...
 - b) In a parallel circuit, current...
 - c) In a parallel circuit, resistance...



Objectives

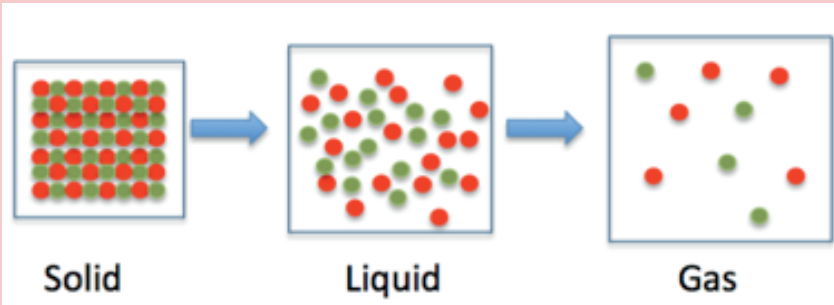
By end of this chapter learners will gain a broad understanding and acquire skills relating to the following concepts:

- define the specific heat capacity (c) of a substance
- define the heat capacity (C) of a substance
- use the equation for specific heat capacity to perform simple calculations
- discuss practical applications of heat capacity in technology.
- state the law of conservation of energy
- experimentally determine the heat capacity of a solid.
- define terms used in the study of thermodynamics
- list thermodynamic variables
- define internal energy of a thermodynamic system.
- state the first and second laws of thermodynamics
- describe how a heat engine operates
- describe how refrigerators operate



Why heat and thermodynamics matter

Most of the machines and appliances used in industry or in our homes, cars and even airplanes are driven by some kind of engine. The mechanism that drives most machines and engines can be explained through the laws of thermodynamics. Over the year scientists have found ways to harness the heat generated by different fuels and use it to the benefit of mankind. This chapter aims to introduce you to thermal physics and its applications in everyday life.



5.1 Introduction

In matter and materials you learnt that all matter is made up of constantly vibrating molecular particles, a branch of science known as thermodynamics. The observable states of matter are due to the nature of vibrations experienced by molecules that make up matter. In solids molecules vibrate but not at a fast pace. In liquids the molecules vibrate at a faster pace which allows them to slide over each other resulting in the fluid nature of liquids.

Sometimes the molecules move so fast that the intermolecular forces disconnect which



Figure 5.1 A cup of hot coffee

allows them to break free resulting in the gaseous state. Therefore, the difference between a cup of hot tea and a cup of cool tea lies in the movement of molecules that make up the two substances as shown in Figure 5.1. The molecular particles in a cup of hot tea vibrate faster than the molecules in a cup of cool tea.

When objects are in motion we say that they have kinetic energy and when they are still they are said to possess potential energy. Remember these concepts as you will come across them again in the next sections.

Therefore, we can say that the temperature of solids, liquids and gases depends on the average kinetic energy of their particles as shown in Figure 5.2.

So temperature of a gas refers to how fast the gas particles bounce back and forth.

For a liquid, temperature is determined by how fast the liquid particles slide past one another and for a solid temperature refers to how fast the particles vibrate in place.

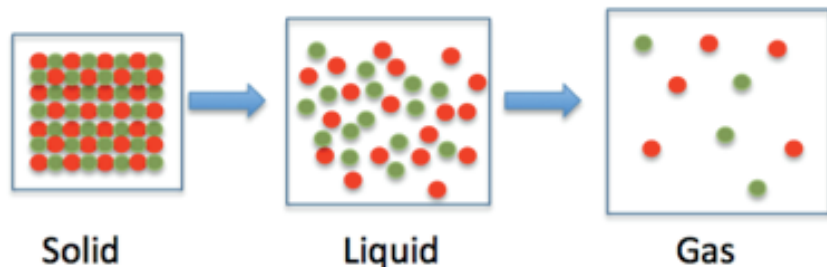


Figure 5.2 Arrangement of molecules in solids, liquids and gases

In Grade 10 you were introduced to the concepts of temperature, heat and how it can be transferred from one object to another. So what is temperature? What is heat?

In Grade 10 you learnt that:

Temperature is a measure of how hot or cold an object is. Temperature is a state variable that quantifies the hotness or coldness of a system (object).

Temperature is a measure of the average kinetic energy of molecular particles that make up a substance. However, as temperature is one of the seven SI quantities, temperature is measured on a Kelvin scale.

A unit often used to measure temperature is degrees Celsius ($^{\circ}\text{C}$). But in this chapter we do not use degrees Celsius to report temperature. Instead we use Kelvins. For example, 270 K is read (270 Kelvins)

Thermal energy is transferred in the direction from a hotter system (object) to a cooler system (object).

Each system consisting of molecular particles has thermal energy.

Internal energy (U)

Internal energy (U) is the sum of various kind of energy that the atom or molecules of a substance possesses. This include translational and rotational kinetic energy, vibrational energy and potential energy, chemical, and so on.

Thus, the internal energy (U) of a system (substance) is the sum of the kinetic energy (energy due to motion) and the potential energy (energy due to the interaction of particles) of all the particles constituting the system.

The faster the particles move, the higher the kinetic energy. So the temperature of an object depends on the average kinetic energy (movement) of the particles that make up the substance and not the amount of substance. If you pour half of the water contained in a cup onto the floor the temperature of the remaining water does not change. This is because the particles remaining in the cup still have the same average kinetic energy.

When you touch a hot stove we say that thermal energy is transferred from the stove to your hand because the stove is warmer. So heat is the thermal energy in transfer or the thermal energy that is transferred from one object to another due to a temperature difference, commonly measured in calories or joules. In other words:

Heat is the energy transferred between a system and its environment because of a temperature difference that exist between them.

OR

Heat is the energy that flows from a higher temperature object to a lower temperature object because of the difference in temperatures.

Before scientists realised that heat is transferred energy, heat was measured in terms of the ability to raise the temperature of water. Thus the calorie was defined as the amount of heat that would raise the temperature of 1 g of water from 14,5 °C to 15,5 °C. In 1948 the scientific community decided that since heat (like work) is transferred energy, the SI unit of heat is joule (J).

Note: A substance (system) does not contain heat, it contains thermal energy.

Heat is thermal energy in transit/transferred energy.

Once thermal energy has been transferred it is no longer referred to as heat.

5.1.1 Units for measuring heat

In science, heat is commonly measured in joules (J), but in America, energy is measured in Calories.

Did you know?

1 calorie = 4,19 J

Food labels usually show the energy rating of food in joules or calories because food is considered as fuel burnt by our bodies to release energy. For example, this packet of chips can give you 670 joules or 160 calories of energy when digested.



Nutrition facts	
Serving size 1 oz (28g About 15 chips)	
Amount per serving	
Calories 160	Calories from Fat 90
% Daily Value	
Total Fat	16%
Saturated Fat 1.5g	8%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 170mg	7%
Potassium 350mg	10%
Total carbohydrate 15g	5%
Dietary Fiber 1g	
Sugars less than 1g	
Protein 2g	
Vitamin A 0%	Vitamin C 10%
Calcium 0%	Iron 2%
Vitamin E 6%	Thiamin 4%
Niacin 6%	Vitamin B

Figure 5.4 Nutrition facts on the back of a packet of potato chips

5.2 Specific heat capacity

After warming a pie in the microwave oven, the filling could be too hot to eat even though the crust is not. This is because different substances have different thermal capacities for storing energy. Equal amounts of different materials require different quantities of heat to change their temperatures by a specific number of degrees.

One gram of water requires one calorie (4,19 J) of energy to raise its temperature by 1 °C. However, it takes less energy to raise the temperature of one gram of iron by 1 °C. As a result, we can say water has a higher specific heat capacity than iron.

Specific heat capacity is denoted by the small letter 'c'. It can also be regarded as the resistance of a substance to a change in temperature or resistance to releasing thermal energy. We saw in the previous example that it takes more energy input for one gram of water to increase its initial temperature by 1 °C compared to the same mass of iron.

5.3 Heat capacity

Heat capacity

Denoted by the capital letter 'C', refers to the amount of heat required to raise the temperature of the whole substance by 1 K or 1 °C.

In addition, the heat capacity (C) of an object is the proportionality constant between the heat (Q) that the object absorbs or loses and the resulting temperature change (ΔT).

$$Q = C\Delta T \quad \text{OR} \quad Q = C(T_f - T_i)$$

Heat capacity C has the unit of energy per degree ($\text{J}\cdot^\circ\text{C}^{-1}$) or degree per kelvin ($\text{J}\cdot\text{K}^{-1}$)

The energy needed to produce a certain temperature rise depends on the mass of the substance and what substance is being heated. Knowing the specific heat capacity of substances enables us to calculate the amount of energy required to raise their temperatures to specific amounts. Table 5.1 shows a list of specific heat capacities of some common substances.

Table 5.1 *specific heat capacities of some common substances*

Substance	Specific heat capacity ($\text{J}\cdot\text{kg}\cdot\text{K}^{-1}$)
Water	4 200
Ethanol	2 500
Ice	2 100
Aluminium	900
Concrete	800
Steel	500
Copper	380
Mercury	150

Table 5.1 shows that the specific heat capacity of water is $4\,200\text{ J/kg}\cdot\text{K}$ ($4\,200\text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$). This means: to raise the temperature of 1 kg of water by 1 K, you need 4 200 J of energy

Did you know?

Water has a higher specific heat capacity for storing thermal energy than almost any other substance. This means that it takes longer to warm up and longer to cool down. This property allows it to preserve aquatic life during cold winter and hot summer days.

Knowing the specific heat capacity of water means that we can calculate how much energy is required for any mass of water and any temperature rise.

For example:

To raise the temperature of 1 kg of water by 5 K you need $(5 \times 4\,200\text{ J})$ 21 000 J of heat

To raise the temperature of 3 kg of water by 1 K you need $(3 \times 4\,200\text{ J})$ 12 600 J of heat

Two objects of the same material will have heat capacities proportional to their masses. It is therefore convenient to define heat capacity per unit mass:

$C = \frac{c}{m}$ hence $C = cm$ where m is the mass of the substance and c is the specific heat capacity.

A general equation deduced from this reasoning can be written in words as follows:

Energy transferred = specific heat capacity $\times$ mass $\times$ temperature change.

Or in symbols as follows:

$$Q = cm\Delta T$$

Where:

Q is the heat

c is the specific heat capacity of the substance

m is the mass of the substance in kg

ΔT ($T_{\text{final}} - T_{\text{initial}}$) is the corresponding change in temperature of the substance in Kelvin (K)

Let us use the above equation to perform a simple calculation.

Example 5.1

DETERMINE THE AMOUNT OF ENERGY REQUIRED TO INCREASE THE TEMPERATURE OF A SUBSTANCE

Jabu uses an aluminium saucepan to boil 0,5 kg of water. The saucepan has a mass of 0,4 kg. The saucepan and the water start at a temperature of $20\text{ }^{\circ}\text{C}$. How much heat is needed to: (a) boil the water, (b) increase the temperature of the saucepan to $100\text{ }^{\circ}\text{C}$?

1 ANALYSE

Given: $m_{\text{saucepan}} = 0,4\text{ kg}$

$m_{\text{water}} = 0,5\text{ kg}$

$$T_{\text{initial}} = 20\text{ }^{\circ}\text{C}$$

The specific heat capacities of water and Aluminum are given in Table 1.

Unknown: $Q_{\text{water}} = ?$

$Q_{\text{saucepan}} = ?$

2 SOLVE

For both water and the saucepan, the temperature change is from $20\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$ (at standard atmospheric pressure).

$$\text{So } \Delta T = T_{\text{final}} - T_{\text{initial}} = 100\text{ }^{\circ}\text{C} - 20\text{ }^{\circ}\text{C} = 80\text{ }^{\circ}\text{C} \text{ or } 80\text{ K}$$

We use the equation: $Q = cm\Delta T$

For the water:

$$\begin{aligned} Q &= \frac{4\,200\text{ J}}{\text{kg}\cdot\text{K}} \times 0,5\text{ kg} \times 80\text{ K} \\ &= 168\,000\text{ J} \end{aligned}$$

For the saucepan:

$$\begin{aligned} Q &= \frac{900\text{ J}}{\text{kg}\cdot\text{K}} \times 0,4\text{ kg} \times 80\text{ K} \\ &= 28\,800\text{ J} \end{aligned}$$

168 000 J of heat is needed to boil the water and 28 000 J of heat is needed to increase the temperature of the saucepan to $100\text{ }^{\circ}\text{C}$. This is assuming that the whole saucepan reaches $100\text{ }^{\circ}\text{C}$, which may not be quite true in reality.



Activity 5.1 Calculations for the amount of heat

Show that the quantity of heat needed to raise the temperature of a 10 kg piece of steel from $0\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$ is 450 000 J. The specific heat capacity of steel is $450\text{ J}\cdot\text{kg}^{-1}\cdot^{\circ}\text{C}^{-1}$ or $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$.

5.3.1 Practical applications of heat capacity in technology

When the temperature of a substance rises, its molecules vibrate faster and move farther apart. The increase in the distance between molecules results in thermal expansion. The opposite is true when the temperature drops. Most substances expand when heated and contract when cooled. Even though this happens at the molecular level these changes are sometimes noticeable. Telephone wires are longer and they droop on a hot day compared to a cold day as shown in Figure 5.6.

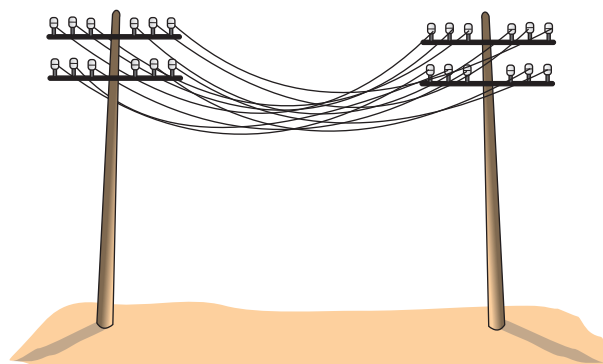


Figure 5.6 Sagging telephone lines on a hot summer's day

Metal lids on glass bottles can often be loosened by holding the lid under a hot tap water as shown in Figure 5.7. The hot water makes both the glass and the metal lid expand but because different materials expand with different amounts of heat, the metal lid expands more than the glass bottle and also expands much faster because of direct exposure.



Figure 5.7 Opening a jar using hot water

Technicians and Engineers must take thermal expansion into account when building structures and devices of all kinds. Engineers use reinforcing steel with the same expansion rate as concrete so that both materials can expand and contract the same under different temperature conditions as shown in Figure 5.8. Using reinforcement with a lower heat capacity than concrete may result in cracks in the concrete over time.



Figure 5.8 Concrete railway line of the Gautrain

Have you noticed that it gets bumpy while driving over a bridge? The bumps and gaps on the bridge are called expansion joints, they allow the bridge to expand and contract as shown in Figure 5.9. Even concrete roads and sidewalks have to be intersected with gaps which are sometimes filled with tar, to allow for expansion in summer and contraction in winter.



Figure 5.9 Expansion joints on a bridge

The fact that different substances expand and contract at different temperatures is taken advantage of in the making of bimetallic strips. A bimetallic strip is made out of two strips of different metals, welded together, one made out of brass and the other of iron. When heated the brass part of the strip expands more and bends the strip as shown in Figure 5.10. The resulting bend may be used to turn a pointer, regulate a valve or close a switch in an electric circuit. This concept is used in thermostats.

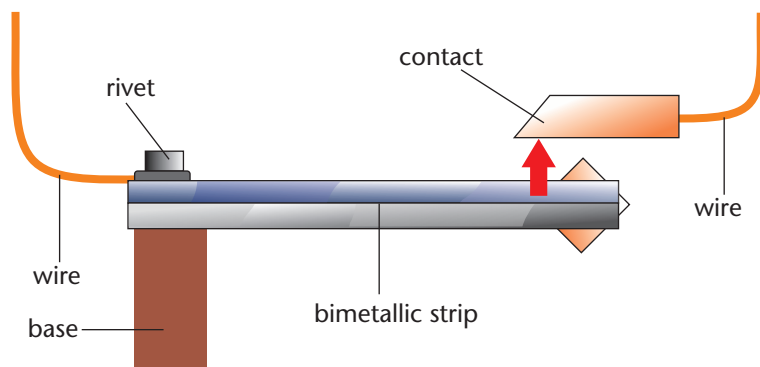


Figure 5.10 Bimetallic strip

A perfect example is the thermostat inside an electric iron shown in Figure 5.11. When it gets too cold, the bimetallic strip in a thermostat bends towards the brass side and activates an electrical switch and turns the iron on. When the electric iron gets too warm, the coil bends towards the iron metal which breaks the electrical circuit and turns the electrical iron off.

Thermal expansion of liquids is also the reason why a petrol tank should not be filled to the brim on a hot summer's day.

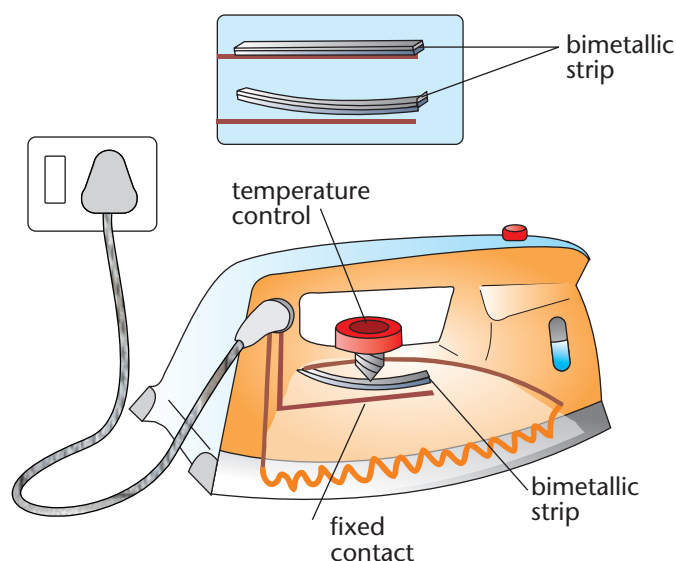


Figure 5.11 Bimetallic strip in a thermostat of an electric iron

5.4 Law of conservation of energy

We already know that heat is the energy transferred between a system and the environment as a consequence of a temperature difference between them.

On hot days people frequently put ice cubes into a hot soft drink to cool it quickly.

Figure 5.12 shows two systems interacting thermally, that is, heat is transferred from the hotter system to the colder system.

Energy cannot be created or destroyed, energy conservation indicates that energy leaving the hotter system must enter the colder system. That is the system exchange energy with no net loss or gain ($Q_{\text{net}} = 0$ J)

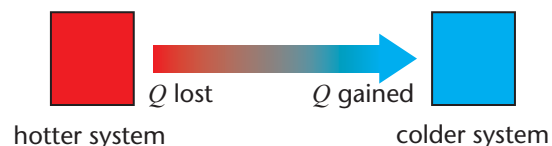


Figure 5.12 Two systems interacting thermally

To express this idea mathematically, we must take into consideration the signs of heat gained and heat lost by the hotter system. If we consider Q_{gained} as positive and Q_{lost} as negative, then the law of conservation of energy can be expressed mathematically as follows in terms of heat:

$$Q_{\text{gained}} = -Q_{\text{lost}}$$

When there is no exchange of energy with the environment (isolated system), then

$$Q_{\text{net}} = Q_{\text{gained}} + Q_{\text{lost}} = 0$$

If there are more than two systems, then systems $Q_1 + Q_2 + Q_3 + \dots = 0$

The same equation ($Q = cm\Delta T$) discussed in section 5.3 above applies to both heating and cooling. As a substance cools, its temperature falls and it loses thermal energy.

The energy released can be represented as follows:

Energy released = specific heat capacity $\times$ mass $\times$ temperature drop

Therefore:

$$(c_1 m_1 \Delta T_1)_{\text{gained}} = (c_2 m_2 \Delta T_2)_{\text{lost}}$$

Where ΔT is always $T_{\text{final}} - T_{\text{initial}}$

Law of conservation of energy (thermal energy)

The amount of thermal energy lost equals the amount of thermal energy gained, when no thermal energy is transferred to the environment.

OR

The total thermal energy of an isolated system is constant.

In symbols, the law of conservation of thermal energy is represented as follows:

Thermal energy gained = Thermal energy lost

$$E_{\text{TH gained}} = E_{\text{TH lost}}$$

In terms of heat we can write:

$$Q_{\text{gained}} = -Q_{\text{lost}}$$

Let's use the above equation to perform a simple calculation.

Example 5.2 DETERMINE THE HEAT GAINED

Lebogang mixes 100 g of 25 °C water with 75 g of 40 °C water. Show that the final temperature of the mixture is 31.4 °C.

1 ANALYSE

Given: Beaker one: $T_{\text{initial}} = 25\text{ °C}$, $m = 100\text{ g}$

Beaker two: $T_{\text{initial}} = 40\text{ }^{\circ}\text{C}$, $m = 75\text{ g}$

Prove: $T_{\text{final}} = 31,4\text{ }^{\circ}\text{C}$

2 SOLVE

Because we have two different masses of water mixed together we must equate the thermal energy gained by the cool water to the thermal energy lost by the warm water.

$$Q_{\text{net}} = 0$$

$$Q_1 + Q_2 = 0$$

$$Q_1 = -Q_2$$

Thermal energy gained by cool water = Thermal energy lost by warm water:

$$cm_1\Delta T = -(cm_2\Delta T_2)$$

Note: Thermal energy transfers from the warm water to the cool water. Because the cool water will absorb thermal energy, T_{final} will be greater than $25\text{ }^{\circ}\text{C}$ so:

$$\Delta T_1 = T_{\text{final}} - \Delta T_{\text{initial}} = \Delta T_{\text{final}} - 25\text{ }^{\circ}\text{C}$$

Because the warm water will release thermal energy, T_{final} will be less than $40\text{ }^{\circ}\text{C}$ so:

$$\Delta T_2 = T_{\text{final}} - \Delta T_{\text{initial}} = \Delta T_{\text{final}} - 40\text{ }^{\circ}\text{C}$$

As the system of units is homogenous, there is no need for unit conversion.

$$c(100\text{ g})(T_{\text{final}} - 25\text{ }^{\circ}\text{C}) = c[(75\text{ g})(T_{\text{final}} - 40\text{ }^{\circ}\text{C})]$$

$$100\text{ g}T_{\text{final}} - 2\,500\text{ }^{\circ}\text{C} = -75\text{ g}T_{\text{final}} = (3\,000 + 2\,500)\text{ g }^{\circ}\text{C}$$

$$175\text{ g}T_{\text{final}} + 75\text{ g}T_{\text{final}} = (3\,000 + 2\,500)\text{ g }^{\circ}\text{C}$$

$$T_{\text{final}} = 5\,500\text{ g }^{\circ}\text{C}$$

$$T_{\text{final}} = \frac{5\,500\text{ g }^{\circ}\text{C}}{175\text{ g}}$$

$$T_{\text{final}} = 31,4\text{ g }^{\circ}\text{C}$$

In the workshop, you submerge nails of a mass of 100 g at a temperature of $30\text{ }^{\circ}\text{C}$ in 200 g of water at a temperature of $20\text{ }^{\circ}\text{C}$. Equate the heat gained by the water to the heat lost by the nails and show that the final temperature of the water is about $23,3\text{ }^{\circ}\text{C}$.

5.4.1 Calorimetry

But how are the values for specific heat capacity of different substances determined? A device called a calorimeter is used in the laboratory to measure specific heat capacities of different substances. A calorimeter is a well-insulated container used to measure changes in thermal energy or heat transfer. To reduce the loss or gain of energy to or from the surroundings, a calorimeter should be well-insulated. Figure 5.13 shows a calorimeter used in the laboratory.

Energy always flows from an object with a higher temperature to an object with a lower temperature. The thermal energy gained by the

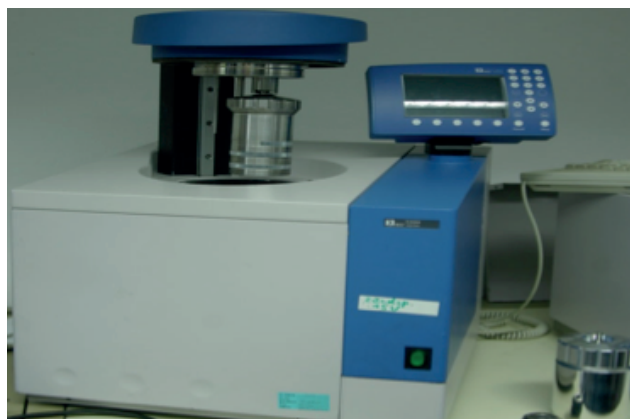


Figure 5.13 Calorimeter used in the laboratory

cooler substance equals the thermal energy lost by the warmer substance, if we assume no loss of thermal energy to the surrounding environment.

Thermal energy lost = Thermal energy results

A calorimeter operates on the principle of the law of conservation of energy. This is demonstrated in the practical activity that follows.



EXPERIMENT 13

In this experiment, you will determine the specific heat of a metal sample more specifically Lead (Pb). The metal sample is heated to a high temperature and then placed into a calorimeter containing a known quantity of water at a lower temperature. Having measured the mass of the water in the calorimeter, the temperature changes of the water (ΔT) and knowing the specific heat of water ($4,184 \text{ J}\cdot\text{g}^{-1}\cdot^\circ\text{C}^{-1}$) the heat gained by the water (heat lost by the metal) can be calculated as follows:

Heat gained by the water = mass of the water (g) $\times$ change in temperature (ΔT) $\times$ specific heat capacity of water ($4,184 \text{ J}\cdot\text{g}^{-1}\cdot^\circ\text{C}^{-1}$)

The specific heat of the metal will be calculated as follows:

Heat lost by the metal (heat gained by the water) = specific heat of the metal $\times$ mass of the metal (g) $\times$ change in temperature of the metal ($^\circ\text{C}$)

Specific heat of the metal = $\frac{\text{heat gained by the water}}{\text{mass of the metal} \times \Delta T \text{ of the metal}}$

Apparatus

For a makeshift calorimeter you will need:

- two polystyrene cups with a lid
- thermometer
- glass rod
- retort stand
- clamp for the thermometer

For experiment you will need:

- makeshift calorimeter (Figure 5.14)
- large beaker: heat resistant
- bunsen burner, stand and wire gauze
- small beaker
- digital scale
- test tube (heat resistant)
- retort stand with clamp
- thermometer

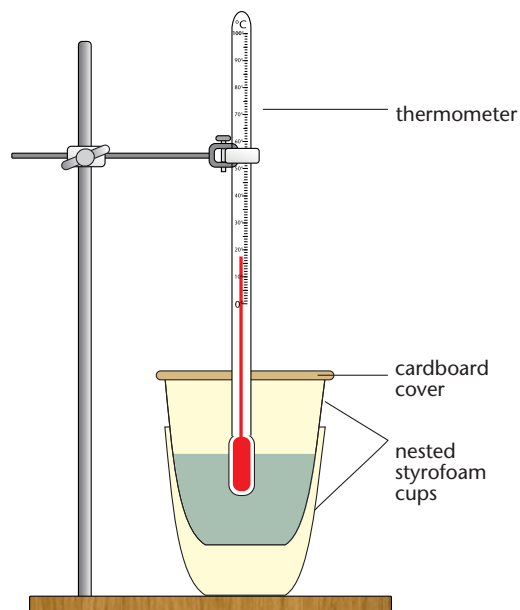


Figure 5.14 Makeshift calorimeter

Method

1. Fill the large beaker approximately half full of water. Place the beaker of water on the Bunsen burner with wire gauze. Heat the water to boiling point. Adjust the Bunsen burner so that the hottest part of the flame touches the bottom of the beaker through the gauze.
2. Weigh the small beaker (mass 1) and record its mass to two decimal places. Add a piece of metal to the small beaker. Weigh the beaker with the metal in it (mass 2) and subtract to find the mass of the metal (mass 2 – mass 1).
3. Weigh the empty makeshift calorimeter. Record the mass carefully to two decimal places.
4. Fill the calorimeter approximately half full with distilled water at room temperature and record the mass to two decimal places.
5. Measure the temperature of the water in the calorimeter cup and record to two decimal places.
6. Carefully transfer the metal into a large test tube. Clamp the test tube, suspending it in the beaker of water (from step 1). Boil at least for 10 minutes.
7. While the metal is still in the boiling water bath, measure the temperature of the water carefully with a thermometer and record to one decimal place. (It is assumed that the temperature of the metal is the same as that of the boiling water.)
8. After the metal has been heating 10 minutes, remove the test tube from the bath by its utility clamp. Immediately pour the metal into the calorimeter cup so that the metal is covered by the water. Cover the calorimeter with its cover. Turn off the Bunsen burner.
9. Carefully insert the thermometer through the small hole in the calorimeter lid. Stir very slowly by shaking, and record the highest temperature reached by the water.
10. Remove the calorimeter lid, retrieve and dry the metal. Return metal to its original place. Pour the water down the sink. Rinse and dry the calorimeter cup

Use the data obtained from the experiment to calculate the specific heat of the metal. Show all units in your calculations.

To determine the heat gained by water: use the first equation in the introduction

To determine the experimental specific heat of the metal: use the third equation in the introduction

Follow-up questions

1. Why is water an excellent material to use in the calorimeter?
2. What substance lost heat in this experiment?
3. What substance gained heat?
4. Metals have a lower specific heat than that of water. Was this true in what you observed?
5. Explain what a 'low specific heat' means in terms of heat retention and heat requirements.

5.5 Thermodynamics

‘Thermo’ means heat and ‘dynamics’ means change.

Thermodynamics refers to the study of processes through which thermal energy is transferred. The first law of thermodynamics is the law of conservation of energy adapted to thermodynamic systems.

Thermodynamics is one of the principle branches of Physics and engineering, which is the study and application of thermal energy of a system.

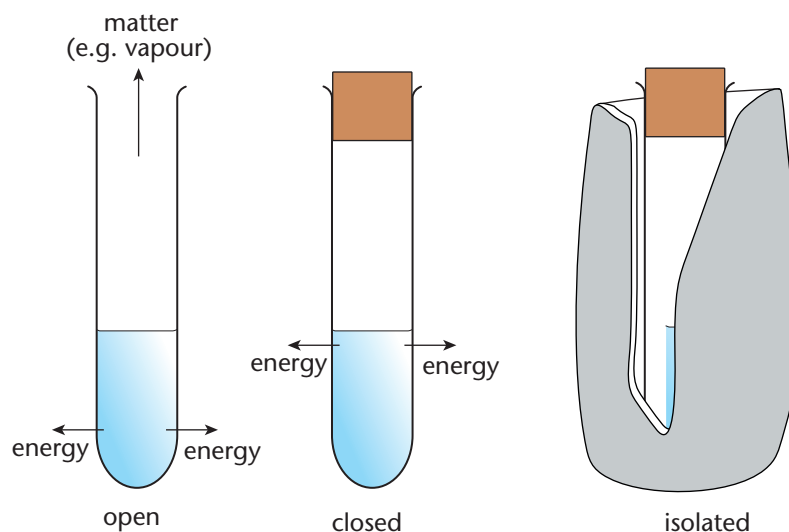


Figure 5.15 Three types of systems

5.5.1 Thermodynamics system

A thermodynamic system is the part of the world constituted by a significantly large number of particles (i.e., atoms and molecules).

A thermodynamic system is defined as a portion of matter for example, gas enclosed inside a cylinder fitted with a piston.

Figure 5.15 shows three types of systems, namely, isolated, closed and open systems. Figures 5.15 also illustrates the difference between the three systems.

In the study of thermodynamics, the term ‘system’ is often used to refer to a gas enclosed in some form of container. The term ‘surrounding’ is used to refer to anything outside the system which has some bearing on the behaviour of the system.

5.5.2 Thermodynamic variables

The thermal state of a thermodynamic system is defined by its temperature (T), pressure (P) and volume (V). These quantities are called thermodynamic variables.

Heat (Q) flowing in or out of the system can have two effects on the system:

1. It can increase or decrease the internal thermal energy of a system (ΔU)
2. It can enable the system to do work (W) on its surroundings

This statement sums up the first law of thermodynamics.

When a system changes from a given initial state to a given final state, both work (W) and heat (Q) depend on the nature of the process. BUT experimentally it has been proven that the quantity ($Q - W_{\text{system}}$) is the same for all processes, it depends only on the initial and final states.

The quantity $Q - W_{\text{system}}$ represents a change on an intrinsic property of the system called internal energy.

5.5.3 Internal energy

Internal energy is the sum of various kinds of energy that the atom or molecules of a substance possess. This include translational and rotational kinetic energy, vibrational energy and potential energy, chemical energy, and so on.

There are thermodynamic systems in which the thermal energy is considered as the internal energy because only the kinetic and potential energy of the particles are taken into consideration.

The internal thermal energy of a thermodynamic system is equal to the sum of the kinetic and potential energies of molecules within the system.

5.6 First law of thermodynamics

The change in the internal energy of a closed system is equal to the heat supplied to the system, minus the work done by the system: ($\Delta U = Q - W$)

This equation can be written as $Q = \Delta U + W$

W is the work done by the system

The first **law of thermodynamics** can also be stated as follows:

The heat given to a system is used to increase the internal energy of the system and to do work against the external pressure.

Alternatively:

Heat added = heat used to increase the internal thermal energy of the system + heat used by system to do work on its surroundings.

$$\Delta Q = \Delta U + \Delta W$$

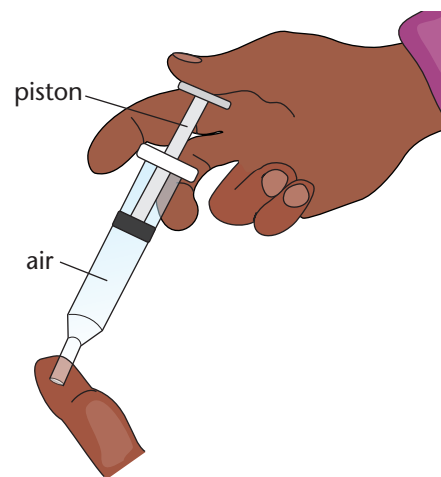
When the system does work the volume increases (expansion) and work done by the system is negative.

From the equation we can conclude that the internal energy of the system tends to increase if energy is added as heat and tends to decrease if energy is lost as work.

Work done on the system is always equal but with the opposite sign to the work done by the system, so we can write the equation of the first law of thermodynamics in terms of the work done on the system as: $\Delta U = Q + W$

This tells us that the internal energy of the system tends to increase if heat is absorbed /added or if positive work is done on the system.

The first law of thermodynamics can be observed when you apply pressure on the air inside a sealed syringe as shown alongside.



When you push down on the piston you decrease the space occupied by the air particles, that is, you do work on the air particles inside the syringe as shown in Figure 5.16.

This energy flowing into this system increases the internal thermal energy of the air molecules and enables the molecules to vibrate faster exerting pressure on the sides of the syringe.

Some of the energy entering the system is used to increase the internal energy of the air molecules and some is used to enable the air molecules to do work on its surrounding which is the container.

This is why the piston is automatically pushed back to its original position when you stop applying pressure as shown in Figure 5.17.

Note: Most of energy that is added onto the closed system will go into doing work than increasing the internal thermal energy of the air molecules. When the internal energy of the molecules decreases the temperature decreases. That is why the sides of the syringe will not feel warm. The temperature of enclosed air is lower when it does work than when work done on it. To demonstrate this point: Blow air on the back of your hand with your mouth wide open, your breath will feel warm. If you press your lips together and blow to get a fast stream of air, now your breath feels cold.

Another example: We are often warned not to throw aerosol cans into a fire or leave them in direct sunlight or exposed to direct heat even when they are empty. This is because the can is a closed system. Heating it will add thermal energy to the system. Some of the heat will go into increasing the internal energy of the molecules causing them to vibrate faster and vaporise. The molecules will use some of the thermal energy to do work by applying pressure on the sides of the canister causing it to expand and eventually explode. An aerosol can is shown in Figure 5.19

Visit the website below to view an illustration of what happens in the gas molecules in an aerosol can when it is heated:

<http://resources.schoolscience.co.uk/BAMA/14-16/aerosch4pg2.html>

Work done on the system

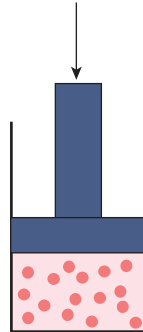


Figure 5.16 When the work is done on the system the volume decreases (compression) and work done is positive.

Work done by the system

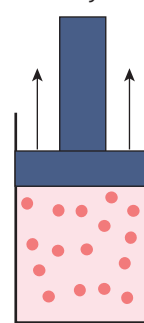


Figure 5.17 When the work is done by the system the volume increases (expansion) and work done is negative.

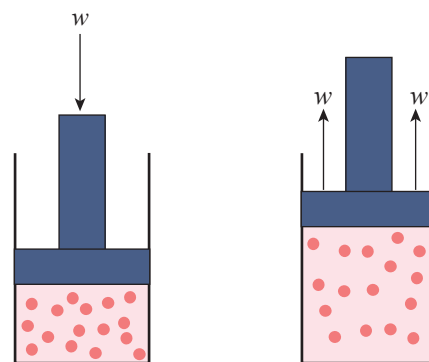


Figure 5.18 When the work is done by the system the volume increases (expansion) and work done is negative.



Figure 5.19 Example of aerosol can

Example 5.3

USE THE FIRST LAW OF THERMODYNAMICS EQUATION TO CALCULATE INTERNAL ENERGY, WORK DONE AND THE AMOUNT OF HEAT SUPPLIED

A gas enclosed in a container is heated which causes the lid of the container to rise. The enclosed gas performs 15 Joules of work to raise the lid, leaving the final energy of the system as 3 Joules. Calculate how much energy was added to the system through heating.

1 ANALYSE

Given: $W = 15$ Joules, $\Delta U = 3$ Joules

Unknown: $Q = ?$

2 SOLVE

Use the first law of thermodynamics equation to calculate the heat added to the system.

$$Q = \Delta U + W$$

$$Q = (3 + 15)$$

$$Q = 18 \text{ J}$$

OR

$$3 = Q - 15$$

$$Q = 18 \text{ J}$$

Of the 18 Joules of heat energy added to the system, 15 Joules of energy was used to perform work on the lid of the container and the rest (3 Joules) of the energy was used to increase the internal thermal energy of the system.

(Note: this is if we assume there is no exchange of heat with the surroundings, that all the heat added is used to do work and increase the internal energy of the system.)



Activity 5.3

Water enclosed in a cylinder with a piston is heated which causes the piston to move. The steam performs 20 Joules of work to move the piston, leaving the final energy of the system as 5 Joules. Calculate how much energy was added to the system through heating.

5.5.4 Heat engine

You may have probably seen a steam engine (train) in the movies or on an excursion as depicted in Figure 5.20. This was the type of train used in the past when there was no electricity or alternative fuels to coal. Engines have been used to power machines for many years. From coal-powered engines, petrol and diesel engines to jet engines in airplanes. The basic operation of an engine is based on the transfer of heat energy between high and low temperatures.

So what is an engine?

Engines that drive cars or industrial machines are examples of what scientists call heat engines. Heat engines transform heat put into the system into work consistent with the laws of thermodynamics.

A heat engine is a device designed to convert disordered energy into ordered energy. The net work done by an engine during one cycle is equal to the net heat that flow into the engine during the cycle ($\Delta U = 0$).

$$|W_{net}| = |Q_{net}|$$

Figure 5.21 illustrates how a heat engine works.

The basic mechanics of most heat engines follow the steps below. Figure 5.22 shows a diagrammatical representation of basic mechanisms for most heat engines.

An energy-rich fuel (coal, petrol, diesel, and so on) burns and supplies heat energy to the engine (heat is transferred from a high temperature burning source to the gas at low temperature in the engine)

The gas uses some of the heat energy to do work for example, push a piston, turn a wheel, and drive a machine. (Note: The gas or air in the engine is referred to as the working substance since it is the substance that absorbs the heat energy from the source and uses it to do work on the surrounding)

The rest of the input heat energy is transferred to some source at a lower temperature to bring the engine to its initial temperature (heat sink).



Figure 5.20 Steam engine (train running on steam powered engine)

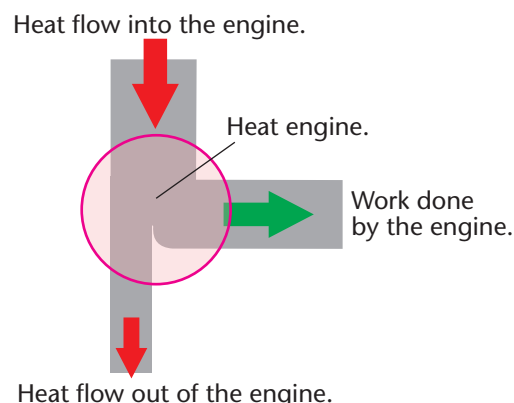


Figure 5.21 How heat engine works

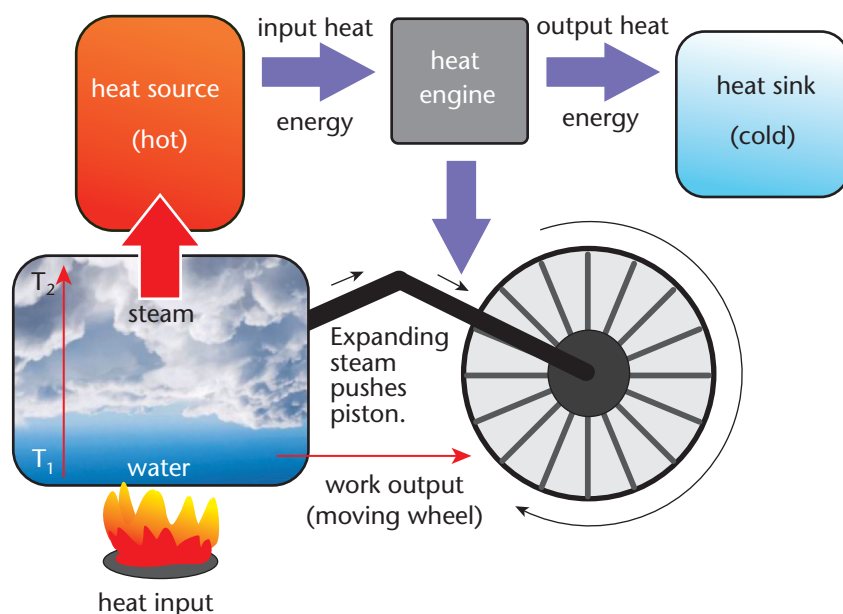


Figure 5.22 Mechanism of a heat engine

5.7 Efficiency of a heat engine

An efficient heat engine will be the one that absorbs heat from a hot body (source), converts a part of it into work and rejects the rest to a cold body (heat sink) with minimal energy lost to the environment.

The efficiency of a heat engine is defined as the ratio of the heat converted to work (W) to the total heat absorbed (Q_1).

$$\text{Efficiency} = \frac{\text{Heat converted to work}}{\text{Total heat absorbed}} = \frac{W}{Q}$$

The equation for efficiency of a heat engine can be written as follows if the engine does not lose any heat to the environment (which all engines do):

$$\text{Efficiency} = \frac{Q_1 - Q_2}{Q_1}$$

Commonly, efficiency is expressed as a percentage (%) then the equation becomes:

$$\text{Efficiency} = \frac{Q_1 - Q_2}{Q_1} \times 100\%$$

As a result, there is no machine with an efficiency of 100%. It is impossible to convert all the heat into work.

Note: It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than the lowest of its surroundings. According to the law of conservation of energy a perpetual motion machine cannot exist. No system can deliver a continuous supply of work without an external supply of energy.

5.8 Second law of thermodynamics

Thermal energy will flow spontaneously from a region of high temperature to a region of low temperature. In winter, heat flows from inside a warm house towards the cold air outside, which is why we try as much as possible to insulate our houses.

The second law of thermodynamics states:

Heat never spontaneously flows from a substance with low temperature to a substance with high temperature.

External work needs to be done on the system to force heat energy to flow from cold to hot. That is why your refrigerator at home will only work once you have plugged it in.

5.9 Refrigerators

The working substance in a heat engine is air, but in a refrigerator the substance that does the work is a coolant, which is usually a nontoxic gas CCl_2F_2 (Freon-12). The cooling effect of a refrigerator works on the principles of condensation and vaporisation of the coolant.

An electrically powered compressor does work on the Freon gas. Compressing the gas molecules results in a decrease in volume and an increase in pressure and temperature ($pV = nRT$).

The hot gas enters the coil at the back of the refrigerator.

As the hot gas travels up the coil, heat is transferred from the hot gas inside the coil to the cool air in the room outside the fridge. The loss in thermal energy cools down the Freon gas which causes it to slowly condense into a liquid with low temperature.

Prior to entering the inside of the refrigerator, the liquid Freon passes through an expansion valve which increases the volume and decreases the pressure and temperature of the liquid even further.

The low temperature liquid leaves the expansion valve and enters into the coil insulated inside the refrigerator.

The temperature difference between the liquid Freon in the coil and the air inside the refrigerator causes heat (thermal energy) to be transferred from the warmer air inside the fridge to the cooler liquid Freon in the coil. In this way heat is absorbed from inside the refrigerator by the liquid Freon in the coil, reducing the temperature inside the refrigerator.

The heat absorbed by the liquid Freon causes it to vaporise into the gaseous state.

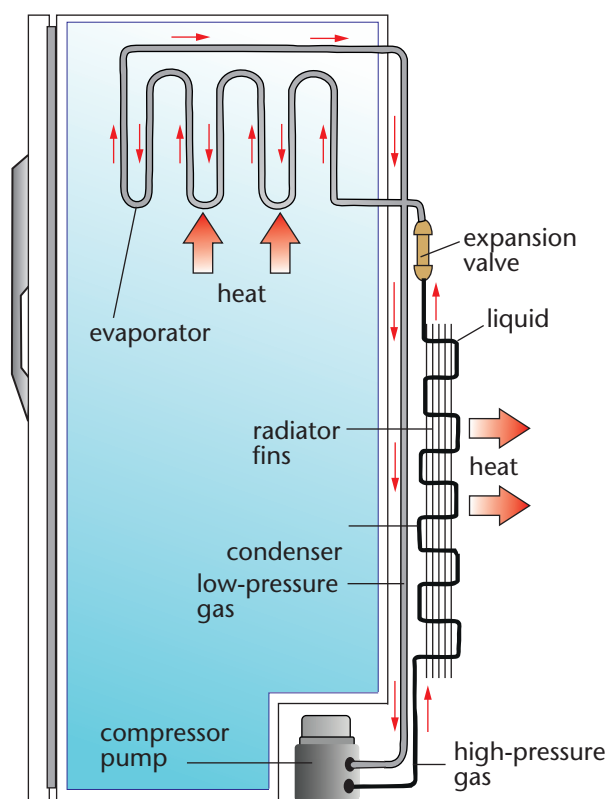


Figure 5.23 Mechanism of the engine in a refrigerator

The cycle starts all over again once all the liquid Freon changes to gas. Mechanism of the engine in a refrigerator is illustrated in Figure 5.23.

Note: The cycle described above does not run continuously. A thermostat regulates the process. The thermostat starts the compressor when the temperature inside the refrigerator rises above the set temperature. When the refrigerator cools below the set temperature, the thermostat turns off the compressor. This control mechanism allows the refrigerator to conserve electricity so that the process only takes place as much as is necessary to keep the refrigerator at the set temperature.

A refrigerator is the reverse of a heat engine. The working substance (coolant) absorbs heat from a cold body (freezer), with the help of an external agency (electrically-powered compressor), and rejects it to the hot body (atmosphere) as shown in Figure 5.25.

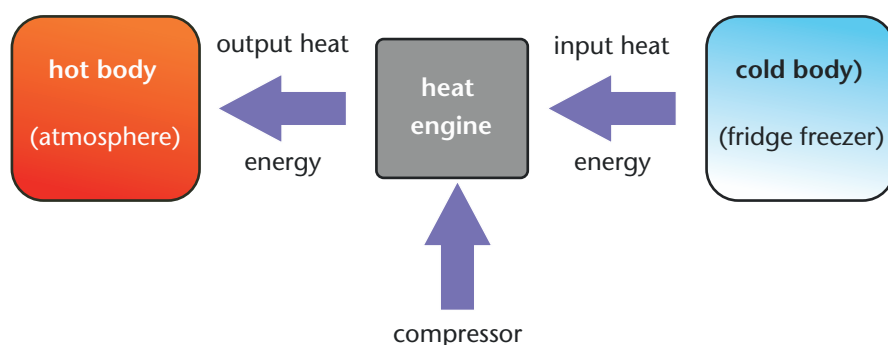


Figure 5.24 A refrigerator

Figure 5.25 Mechanism of a refrigerator (heat engine in reverse)

You can visit <http://home.howstuffworks.com/refrigerator.htm> to get an idea how a refrigerator works

5.9.1 Evaporative cooling

Long before refrigeration, evaporative cooling was used to keep foods cool. Sweating is our body's way of cooling itself down when it is overheated. This process works because as sweat evaporates, water molecules are converted from liquid to gas. Evaporation is always fueled by kinetic (heat) energy, and as more and more energy is expended, cooling will occur naturally and inevitably. This principle of heat loss is the secret behind evaporative coolers.

Evaporative coolers are able to cool any food or other objects placed inside of them by gradually draining away their heat until only a fraction of it remains. Refrigerators function in the same way, of course, but with evaporative coolers, no external electrical input is required.



Figure 5.26 A Zeer Pot

A Zeer Pot is an invention which works on the principle of evaporative cooling, which was created by a Nigerian pot-maker by the name of Mohammed Bah Abba who wanted to help Sudanese families to preserve their food. His invention won him the Rolex Award in 2000 and the World Shell Award for Sustainable Development in 2001.

Two different sized (small and large) unglazed Terra Cotta pots (clay pots) are placed one inside the other. A space is left between the pots and filled with wet sand. A wet cloth is used to cover the pots. Food that needs to be kept cool is placed inside the smaller pot. As the water in the wet sand and wet cloth evaporates, it pulls the warm air outward, causing the inside of the pot to be cooler than the outside air.

For detailed instructions on how you can make your own Zeer pot watch this youtube video:

<http://www.offthegridnews.com/grid-threats/how-to-keep-your-food-cold-without-a-refrigerator/>

Research project

Long before refrigeration was introduced what methods did our ancestors in Africa use to preserve foods such as fruit, meat and milk? Find out and present your findings in class.

Chapter summary

Temperature is a measure of the average kinetic energy of molecular particles that make up a substance.

Thermal energy is the total energy (kinetic and potential) of molecular particles that make up a substance possess.

Heat is thermal energy in transit.

Heat energy transfers in a direction from a warmer object to the cooler object.

Specific heat capacity is the amount of heat required to change the temperature of 1 kilogram of substance by 1 °C or 1 K (SI unit: J·kg⁻¹·K⁻¹ or J·kg⁻¹·°C⁻¹).

Heat capacity is the amount of heat required to raise the temperature of the whole substance by 1 K or 1 °C.

Law of conservation of energy (thermal energy) states that the amount of thermal energy lost equals the amount of thermal energy gained, when no thermal energy is transferred to the environment.

A calorimeter is a device used in the laboratory to experimentally determine the values of specific heat capacity for different substances.

The first law of thermodynamics states that the change in the internal energy of a closed system is equal to the heat supplied to the system, minus the work done by the system ($\Delta U = Q - W$).

A heat engine is a device that converts heat into mechanical work.

The efficiency of a heat engine is defined as the ratio of the heat converted to work to the total heat absorbed.

The second law of thermodynamics states that heat never spontaneously flows from a substance with low temperature to a substance with high temperature.

Refrigerators are heat engines in reverse.

Review exercise

Multiple choice questions

1. The specific heat capacity of aluminium is more than twice that of copper. If equal quantities of thermal energy are given to equal masses of aluminium and copper, the metal that rapidly increases in temperature is:
 - a) aluminium
 - b) copper
 - c) Both will increase at the same rate
 - d) none of these
2. A bimetallic strip used in thermostats relies on the fact that different metals have different:
 - a) specific heat capacities
 - b) thermal energies at different temperatures
 - c) rates of thermal expansion
 - d) all of the above
3. A gas in a closed container is heated with 10 Joules of energy, causing the lid to rise 2 metres with 3 N force. What is the total change in energy of the system?
 - a) 6 Joules
 - b) 10 Joules
 - c) 4 Joules
 - d) 4 Joules

Long questions

4. How does heat differ from thermal energy?
5. In which direction does thermal energy flow between hot and cold objects?
6. How does the specific heat capacity of water compare with the specific heat capacities of other common materials?
7. A hot water bottle is filled with 0.75 g of water at 80 °C. By morning, it has cooled down to 30 °C. How much energy has it given out?
8. A 100 g block of aluminum at 100.0 °C is placed in 100 g of water at 10.0 °C. The final temperature of the mixture is 25.0 °C. What is the specific heat of the aluminum as determined by the experiment?
9. In terms of thermal expansion, why is it important that a lock and its key be made of the same or similar materials?
10. In a certain process, 600 J of work is done on the system which gives off 250 J of heat. What is the change in internal energy for the process?
11. Heat is converted into mechanical energy in many different ways from steam engines to gas engines. Is this a violation of the second law of thermodynamics? Please explain.
12. On a hot day your air conditioner goes out of service so you decide to cool your room by opening the door of your refrigerator. Use the second law of thermodynamics to explain why this would not work. Devise a plan that might help make it work.



Objectives

By the end of this chapter you will gain a broad understanding and acquire skills relating to the following concepts:

- explain and describe concepts such as reduction, oxidation, a reducing agent, an oxidizing agent
- assign oxidation numbers to various compounds and ions
- explain and apply the concept of oxidation numbers in redox reactions
- describe the electrolysis process and its applications



Why chemical change matters

Oxidation-reduction reactions form the basis of many applications of chemistry in industry and in our daily lives. Some important applications include:

- extraction of metals
- electrochemical cells or batteries
- photosynthesis
- the supply of energy
- production of chemicals
- quantitative analysis.

A chemical property relates to a substance's ability to transform into different substances. Physical properties can be observed without changing the identity of a substance, but properties of chemical change are not easily observable.

Chemical properties are easiest to see when substances react to form new substances. One example of an observable property is the ability of (charcoal) carbon to burn in air. When charcoal burns, it combines with oxygen to become carbon dioxide gas.

After the chemical reaction occurs, the amounts of the original substances – that is the carbon and oxygen – are not less than before, but they have simply recombined to form different substances with different properties.

A change in which one or more substances are converted into different substances is called **chemical change** or a chemical reaction. The substances that react in a chemical change are called the **reactants**. The substances that are formed by chemical change are called the **products**.

In the case of burning charcoal, carbon and oxygen are the reactants. Carbon dioxide gas and ashes are products that are clearly different from reactants.

Figure 6.1 depicts a chemical reaction of carbon and oxygen to form carbon dioxide gas.

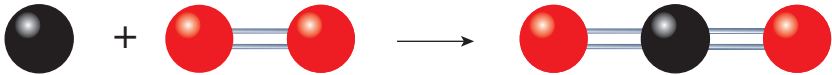
symbolic	$C(s) + O_2(g) \rightarrow CO_2(g)$
Model	 Carbon Oxygen Carbon Dioxide
Word notation	carbon + oxygen → carbon dioxide

Figure 6.1 Chemical change (reaction of carbon and oxygen)

Another example of chemical change is an industrial preparation of iron (Fe). Iron is very important in the manufacturing of various materials and in construction. It is usually produced from iron ores, which are minerals with high iron content.

Hematite, Fe_2O_3 is one of these and it is very similar to the usual iron rust. To produce iron, hematite is treated with carbon monoxide gas (CO) at high temperature to produce elemental iron (Fe) and carbon dioxide (CO_2) as shown in (Equation 1):



Oxidation describes a reaction in which a substance reacts with and gains oxygen atoms.

Reduction describes a reaction in which a substance loses oxygen atoms.

In the example, of Hematite, Fe has been 'reduced' because it has lost oxygen atoms and the carbon in CO has been oxidised because it has gained oxygen atoms to produce CO_2 . However, this definition of oxidation and reduction is too restrictive and insufficient, thus a broader definition would be: Oxidation is a reaction in which electrons are transferred from one element to another in a chemical reaction.

6.2 Using rules to assign oxidation numbers

Oxidation-reduction reactions is a special chemical reaction that involves the transfer of electrons. Oxidation involves the loss of electrons in a chemical reaction, whereas reduction involves the gain of electrons in a reaction. These processes can be identified through the use of **oxidation numbers** (oxidation states).

The oxidation number is the number of electrons that must be added or removed from an atom in a combined state to convert the atom into the elemental form.

The concept of oxidation numbers:

- is used to keep track of the number of electrons lost by the oxidised substance and gained by a reduced substance in a reaction.
- helps in classifying a chemical change as involving a transfer of electrons or not.
- will help in identifying substances that are either oxidised or reduced in a reaction by tracking the change in the oxidation number.

Figure 6.1 shows a summary of the rules on assigning oxidation numbers to monoatomic (consisting of only one atom type, for example, Cl^-) or polyatomic species (consisting of many atom types, for example, SO_4^{2-}).

Table 6.1 Rules for assigning oxidation numbers

Rule	Example
1. Oxidation number of any pure element is 0.	The oxidation number of Na(s) is 0
2. The oxidation number of monoatomic ions equals to the charge on the ion.	The oxidation Cl^- is -1
3. The more electronegative element in a binary compound is assigned the number equal to the charge it would have if it were an ion.	The oxidation number of O in NO is -2
4. The oxidation number of fluorine in a compound is always -1.	The oxidation number of F in NaF is -1

Rule	Example
5. Oxygen has an oxidation number of -2 , unless it is combined with F, (not always, only in O_2F_2) in which it is $+1$ or $+2$, or it is in a peroxide, in which it is -1	1. The oxidation number of O in NO_2 is -2 . Because oxygen is more electronegative than N. 2. The oxidation number of O in dioxygen difluoride O_2F_2 is $+1$. Because F is more electronegative than O. 3. The oxidation number of O in oxygen difluoride is $+2$ 4. The oxidation number of O in H_2O_2 is -1
6. Hydrogen oxidation state in most compounds is $+1$ unless it is combined with metal, in which case it is -1 . Only in metal hydrides.	The oxidation number of H in NaH is -1
7. In compounds, Group 1 and Group 2 and aluminium have oxidation number $+1$, $+2$ and $+3$ respectively.	The oxidation number Na in Na_2CO_3 is $+1$
8. The sum of oxidation numbers of all atoms in a neutral compound is zero. Check 1	The oxidation number of C in $CaCO_3$ is $+4$.
9. The sum of oxidation numbers of all atoms in a polyatomic ion equals charge of the ion.	The oxidation number of P in HPO_4^{2-} is $+5$.

Chromium provides a visual example of oxidation numbers. Different oxidation states of chromium have dramatically different colours.

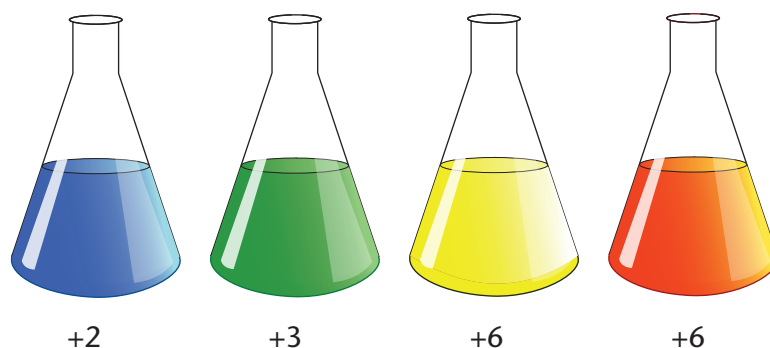
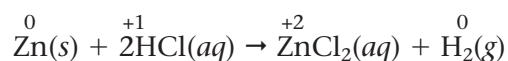


Figure 6.2 Oxidation state of chromium

6.2.1 Using oxidation number to identify redox reaction

Consider the chemical changes involving electron transfer (redox reactions) and apply these rules to identify substances undergoing oxidation or reduction in a reaction. Consider the reaction of Zn metal with hydrochloric acid (HCl) below:



We observe the following:

- the oxidation number of Zn increases from 0 to $+2$ in $ZnCl_2$. This increase in oxidation number means that Zn has lost electrons – it has been oxidised.

- the oxidation number of H has decreased from +1 in HCl to 0 in $\text{H}_2(\text{g})$. This decrease in oxidation number means that H^+ has gained electrons – it has been reduced.
- Chlorine has the oxidation number of –1 before and after the reaction, this means it has neither oxidised nor reduced; it is a **spectator ion**.

Example 6.1

CALCULATING THE OXIDATION NUMBERS

Determine the oxidation number of the atoms written in bold.

- a) H_2SO_4
b) NO_3^-

Analyse

Given: Oxidation number of H = 1
Oxidation number of O in H_2SO_4 = –2

Unknown: Oxidation number of S

Solve

- a) Assign the oxidation number of S to any variable (for example, x).
Since the overall charge is 0, it means that the sum of the oxidation numbers will add up to zero.
 $2(\text{oxidation number of H}) + x + 4(\text{oxidation number of O}) = 0$
 $2(1) + x + 4(-2) = 0$
 $2 + x - 8 = 0$
 $x - 6 = 0$
 $x = +6$
 $\therefore$ the oxidation number of S in H_2SO_4 is equal to 6
- b) Similarly, the oxidation number of O in NO_3^- is –2. Since the overall charge of NO_3^- is –1, we will equate the sum of the oxidation numbers to –1 as follows:
 $x + 3(-2) = -1$
 $x - 6 = -1$
 $\therefore x = +5$
 $\therefore$ the oxidation number of N in NO_3^- is equal to +5



Activity 6.1

- Consider the following redox reaction:
 $\text{CrO}_4^{2-}(\text{aq}) + \underline{\text{S}}^{2-}(\text{aq}) + \underline{\text{OH}}^- \rightarrow \underline{\text{Cr}}(\text{OH})_3(\text{s}) + \underline{\text{S}}(\text{s}) + \underline{\text{H}_2\text{O}}(\text{l})$
 - Determine the oxidation numbers of the underlined atoms in the reaction above
 - Identify both the oxidising and reducing agents. Justify your answer.
- Indicate, with reasoning, which of the following is an oxidation-reduction reaction:
 - $\text{MnO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{Mn}^{2+}(\text{aq}) + 2\text{H}_2\text{O} + \text{Cl}_2(\text{g})$
 - $\text{H}_2\text{PO}_4^-(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}$
- Write a net ionic equation to represent the reaction of iron (Fe) with hydrochloric acid (HCl) solution to produce $\text{H}_2(\text{g})$ and Fe^{2+} . Show both the oxidation and reduction half-reactions.

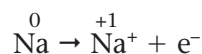
4. Identify, with justification, the oxidising and reducing agents in the following redox reaction:
 $2\text{NO}_2(\text{g}) + 7\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
5. Determine the oxidation number for the element underlined.
- a) $\text{Ca}\underline{\text{H}}_2$
 - b) $\text{Na}\underline{\text{I}}\text{O}_3$
 - c) $\underline{\text{C}}_4\text{H}_{12}$
 - d) $\text{Al}_2(\underline{\text{S}}\text{O}_4)^3$
 - e) $\underline{\text{Pb}}\text{SO}_4$
 - f) $\underline{\text{Cl}}\text{O}_3^-$
 - g) $\text{H}\underline{\text{P}}\text{O}_3^{2-}$
 - h) $\text{Na}_2\underline{\text{O}}_2$

6.2.2 Oxidation occurs when valence electrons are lost in a chemical reaction

Processes in which the atoms or ions of an element experience an increase in oxidation number (state) are oxidation processes. For example, in a chemical change between sodium (Na) and chlorine (Cl_2) in the formation of sodium chloride, the formation of sodium ions illustrate oxidation. The chemical equation for this reaction is written as follows:



The oxidation state is represented by placing an oxidation number above the symbol of an atom and the ion.

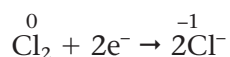


The oxidation state of sodium has changed from 0, its elemental state, to the +1 state of the ion (Rules 1 and 7, Table 6.1).

A chemical substance whose oxidation number increases is oxidised. A substance that undergoes oxidation is called **reducing agent**. In our example, the sodium atom is oxidised to a sodium ion.

6.2.3 Reduction occurs when valence electron is gained in a chemical reaction

Processes in which the atoms or ions of an element experience a decrease in its oxidation number (state) are reduction processes. Consider the behaviour of chlorine in its reaction with sodium once again.



The oxidation state of chlorine has decreased from 0, its elemental state, to the -1 state of the ion (Rules 1 and 2, Table 6.1). A chemical substance whose oxidation number increases is reduced. The chlorine atom is reduced to a chlorine ion.

6.2.4 Oxidation and reduction are paired reactions

Electrons are lost in oxidation and gained in reduction. Therefore, for oxidation to occur during a chemical reaction, reduction must also occur. The number of electrons transferred in oxidation must equal to the number of electrons gained in reduction.

Electrons are negatively charged, and for a charge to be conserved, the number of electrons lost must equal to the number of electrons gained. Mass is conserved in any chemical reaction. Therefore, the electrons exchanged during oxidation and reduction are conserved.

But why do we say substance is reduced when it gains electrons?

Remember, when electrons are gained, their electric negative charge will cause the overall oxidation number to decrease, that is, to be reduced.

A transfer of electrons causes changes in the oxidation states of one or more elements. Any chemical process in which elements undergo changes in oxidation number creates a reduction-oxidation reaction.

Did you know?

The name for the reduction-oxidation reaction, is often shortened to redox reaction.

An example of redox reaction can be seen in Figure 6.3. In this example, copper is being oxidised and NO_3^- from nitric acid is being reduced. The part of the reaction involving oxidation or reduction can be written as a half-reaction. The overall equation for a redox reaction is a sum of the half-reactions. Because the number of electrons involved is the same for oxidation and reduction, they cancel each other out and do not appear in the overall chemical equation.

Copper is oxidised and nitrogen dioxide (brown gas) is produced when this copper coin is placed in concentrated nitric acid solution

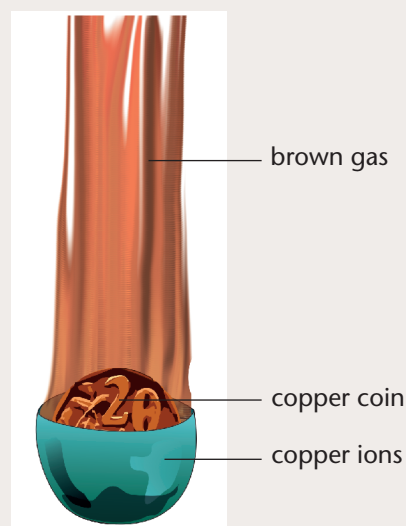
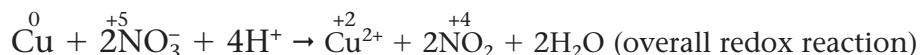
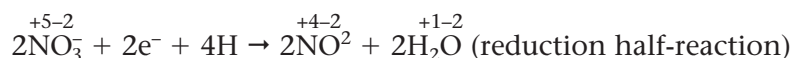


Figure 6.3 Oxidation of copper

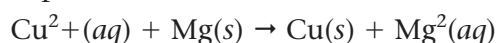
The equation for the reaction of copper and nitric acid illustrates the relationship between half-reactions and the overall redox reaction.



Notice that the electron lost in oxidation appear on the product side of the oxidation half-reaction. Electrons are gained in reduction and appear as reactants in the reduction half-reaction.

The procedure for identifying oxidising and reducing agents is outlined below:

- whenever reduction takes place, oxidation also takes place. Oxidation and reduction goes hand in hand. To clearly determine which substance is the oxidising agent, we break down this chemical reaction into half reactions, or reactions where one is the reduction component and the other is the oxidising component.



- break down the redox reaction into half-reactions as follows:
 - oxidation half reaction: $\text{Mg(s)} \rightarrow \text{Mg}^{2+} + 2\text{e}^-$
 - reduction half reaction: $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu(s)}$
- in the half reactions shown above, magnesium loses two electrons and the copper ion (Cu^{2+}) gains two electrons. Since the oxidising agent is the substance that is reduced and reduction is caused by a gain in electrons. We can deduce that, the oxidising agent is the copper ion and the reducing agent is magnesium.

Did you know?

To recall the definitions of oxidation and reduction the mnemonic OILRIG can be used as outlined below

The following mnemonic may be useful in recalling these reactions:

- OIL Oxidation I Loose (Oxidation is Loss of electrons)
- RIG Reduction I Gain (Reduction is Gain of electrons)

To summarise the key concepts we have covered in this unit, let's pause and look back:

- Oxidation:** loss of electrons by substance in a reaction; it is accompanied by an increase in oxidation number. A substance that undergo oxidation is called reducing agent
- Reduction:** gain of electrons by a substance in a reaction; it is accompanied by a decrease in oxidation number. A substance that undergo reduction is called oxidising agent.
- Oxidation and reduction must always occur together and the number of associated with oxidation must be the same as those associated with reduction.
- Sometimes it can get more confusing since we use similar words. The following mnemonics can be used to clear confusion

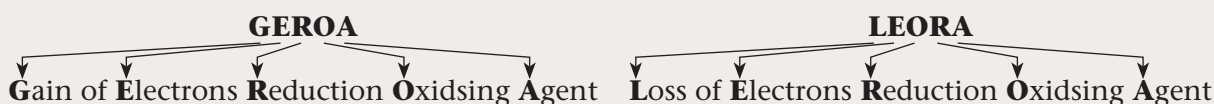


Figure 6.5 Summary

6.3 Application of redox reaction

Applications of oxidation-reduction reactions are vast.

One example, is the photochromic lenses shown in Figure 6.6.

Photochromic eyeglasses darken when exposed to ultraviolet light and become transparent again in the absence of ultraviolet light. This process is the result of oxidation-reduction reactions. Silver chloride (AgCl) and copper(I) chloride (Cu_2O) are embedded in the lenses.

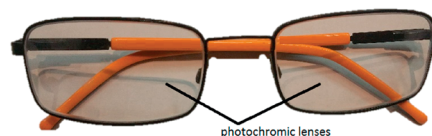


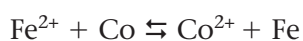
Figure 6.6 Photochromic lenses

The chloride ions absorb photons, and the silver chloride dissociates and form chlorine atoms and silver atoms. The elemental silver darkens the lenses. Chlorine ions are oxidised and silver atoms are reduced. Then the copper(I) ions reduce the chlorine atoms and form copper(II) ions. In the reverse process, the copper(II) ions oxidise to the silver atoms back to the transparent silver ions.



Activity 6.2

- Determine if each of the following changes is oxidation, reduction or neither.
 - $\text{SO}_3^{2-} \rightarrow \text{SO}_4^{2-}$
 - $\text{CaO} \rightarrow \text{Ca}$
 - $\text{CrO}_4^{2-} \rightarrow \text{Cr}_2\text{O}_7^{2-}$
 - $\text{CrO}_4^{2-} \rightarrow \text{Cr}^{3+}$
 - $\text{MnO}_4^- \rightarrow \text{Mn}^{2+}$
 - $\text{ClO}_2^- \rightarrow \text{ClO}^-$
- Write the oxidation and reduction reactions for each redox reaction. The first one has done for you.



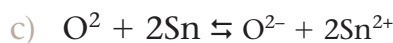
Oxidation:

Reduction:



Oxidation:

Reduction:



Oxidation:

Reduction:



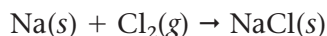
Activity 6.3

- Consider the following ionic reactions and determine the following:
 - substance oxidised
 - substance reduced
 - oxidising agent
 - reducing agent
 - $\text{Cr}_2\text{O}_7^{2-} + \text{Fe}^{2+} \rightarrow \text{Cr}^{3+} + \text{Fe}^{3+}$
 - $\text{IO}_3^- + \text{Re} \rightarrow \text{ReO}_4^- + \text{IO}^-$
 - $\text{SO}_4^{2-} + \text{Br}_2 \rightarrow \text{S}_2\text{O}_3^{2-} + \text{BrO}_3^-$
 - $\text{MnO}_4^- + \text{H}_2\text{S} \rightarrow \text{MnO}$
 - $\text{O}_2 + \text{Cr}^{3+} \rightarrow \text{H}_2\text{O}_2 + \text{Cr}_2\text{O}_7^{2-}$

6.4

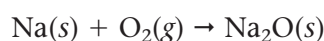
Nonspontaneous redox reactions occurs in electrolytic cells

We have learnt that sodium reacts violently with chlorine to produce sodium chloride.



Sodium also reacts violently with oxygen to produce sodium hydroxide. Chemists refer to such reactions as **spontaneous reactions**.

All the reactions we have studied so far in this chapter are spontaneous reactions. A **spontaneous reaction** is a reaction that doesn't require, for example, a catalyst to speed up the reaction, nor any heat to initiate the reaction. That is, it happens by itself. For example, when you expose sodium to air, it reacts spontaneously and produces sodium oxide. This is illustrated in the equation below.



So, in practice, sodium is placed under oil so that it doesn't react to air.

Some oxidation-reduction reactions do not occur spontaneously, but they can be driven by electrical energy. If electrical energy is required to produce a redox reaction and bring about chemical change, it is called an electrolytic cell.

You can split a compound (group of elements bounded together in a fixed ratio, for example, NaCl) using electricity. To explain what happens in an electrolytic cell, let's examine the decomposition of molten sodium chloride into sodium metal and chlorine gas as shown in Figure 6.7.

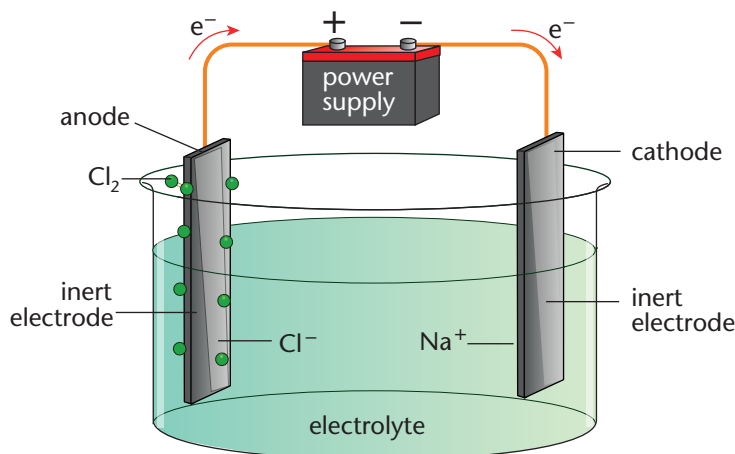


Figure 6.7 Electrolytic cell

The reaction is written below.



If molten NaCl is placed into the container and inert electrodes of carbon are attached to the positive and negative terminals of a battery, an electrolytic reaction will occur. Molten NaCl consists of negative (Cl⁻) and positive ions (Na⁺). The negative ions are called anions and the positive ions are called cations. The anions will be attracted to the electrode that is connected to the positive terminal of the power supply, and the cations will be attracted to the electrode connected to the negative terminal of the battery.

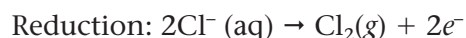
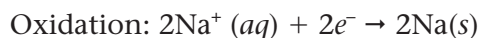
Recall that unlike charges attract each other. The electrode that attract the anions is called an anode and the electrode that attracts the cations is called a cathode. A cathode is the electrode where reduction takes place and anode is the electrode where oxidation takes place. Electrons from the negative terminal of a battery flow to the cathode and are used to reduce sodium ions into sodium atoms. The sodium will plate onto the cathode as it forms. The sodium ions are migrating towards the cathode.



The negative chlorine ions migrate towards the anode and release electrons as they oxidise to form chlorine atoms. The chlorine atoms will combine together to form chlorine gas which will bubble away.

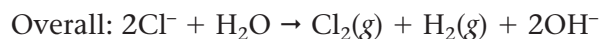
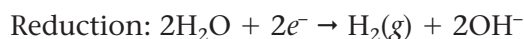
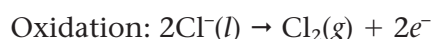
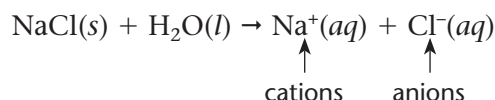


The conditions under which the electrolyte cell operates are very important. The substance that is the strongest reducing agent will undergo oxidation. The substance that is the strongest oxidising agent will be reduced. The overall redox reaction is obtained by combining the two half reactions as follows:

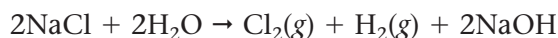


If an aqueous solution of sodium chloride were used in the above system, hydrogen would undergo reduction instead of sodium, because it is a stronger oxidising agent than sodium.

Sodium chloride will dissociate into negative (Cl^-) and positive ions (Na^+).



If we add in the sodium ions, then the overall reaction becomes:



Sodium ions are said to be spectator ions since they did not take part in the chemical reaction – there was no change in their oxidation state.

6.4.1 Electroplating

An electrolytic process in which a metal ion is reduced and solid metal is deposited on a surface is called electroplating. An electroplating cell contains a solution of a salt plating metal, an object to be plated (the cathode) and a piece of plating metal (anode). For example, a copper plating cell contains a solution of soluble copper(II), salt and a copper anode.

The cathode is the object to be plated. The copper anode is connected to the positive terminal of the battery or to some other source of direct current. The object to be plated is connected to the negative terminal.

Figure 6.10 shows how an object (bracelet) is being plated using copper.

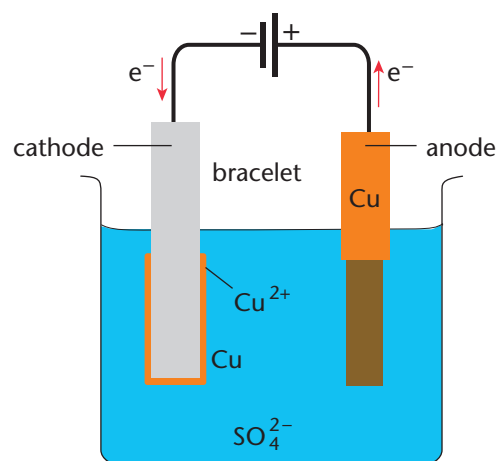
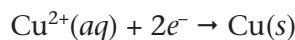
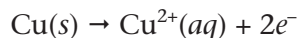


Figure 6.9 Electroplating of copper on a bracelet

Copper ions are reduced at the cathode according to the following half-reaction and deposited as metallic copper when electrons flow through the circuit.



At the anode, metallic copper is oxidised by the following half-reaction:



In fact, copper is transferred from the anode to the cathode of the cell.

6.4.2 Electrolysis

Electroplating is an example of electrolysis. Electrolysis is the decomposition of a substance when an electric current is passed. That is, electric energy is used to force a non-spontaneous reaction to occur. For this cell reaction to occur, the external voltage must be greater than the potential that would be produced by the spontaneous reverse reaction.

Electrolysis is important in industry. It is used to purify many metals, including the ores which are chemically combined in the Earth's crust. During the electrolysis of water, water is broken down into its elements, H_2 and O_2 .

The following experiment will demonstrate how electrolysis can be used to break NaCl down into its elements.



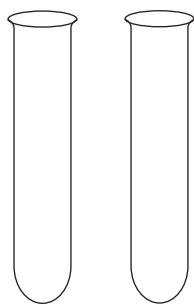
FORMAL EXPERIMENT

Aim: Electrolysis of an aqueous NaCl solution

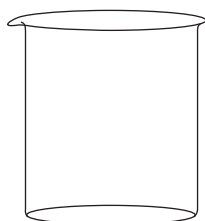
Aims

1. To identify both the cathode and the anode.
2. To identify reactions that occur at the cathode and the anode.

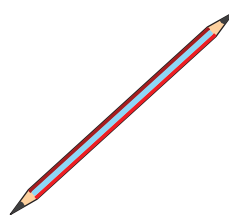
Apparatus and reagents



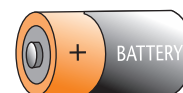
2 test tubes



1 Beaker



2 carbon electrodes
(you can use pencils
sharpened at both ends
for this)



6 or 9 V Battery/cell

- dilute NaCl solution
- concentrated NaCl solution (Brine)

Precautions

- Wear safety goggles
- Perform this experiment in a well ventilated area

Method

1. Fill the test tubes with the NaCl solution.
2. Insert the carbon electrodes into the test tubes each connected to a wire.
3. Invert the test tube into the beaker half-filled with the NaCl solution.
4. Add a few drops of the Universal indicator to this solution.
5. Connect the wires to the 6V or 9 V cell.
6. Observe what happens in the test tubes as well as noting the indicator colour change.

Questions

1. Justify the use of a safety precaution, other than wearing safety glasses, when carrying out this investigation.
2. Describe how the THREE products of this electrolysis could be identified.
3. Identify the anode and the cathode.
4. Write down the half-reactions taking place in each electrode.
5. Write down the overall redox reactions without spectator ions.
6. Write down the overall redox reactions with spectator ions.
7. Write down the name of spectator ion.
8. Write down TWO uses of the product identified in this experiment.

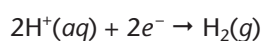
Chapter summary

Oxidation-Reduction Terminology

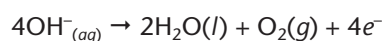
Term	Change in oxidation number	Change in electron population
Oxidation	In a positive direction	Loss of electrons
Reduction	In a negative direction	Gain of electrons
Oxidising agent	In a positive direction	Gains electrons
Reducing agent	In a negative direction	Loses electrons

Dilute NaCl solution

Reduction (cathode reaction)



Oxidation (Anode reaction)

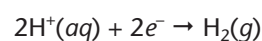


Products:

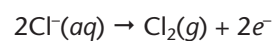


Concentration NaCl solution

Reduction (cathode reaction)



Oxidation (Anode reaction)



Products:



Selected answers

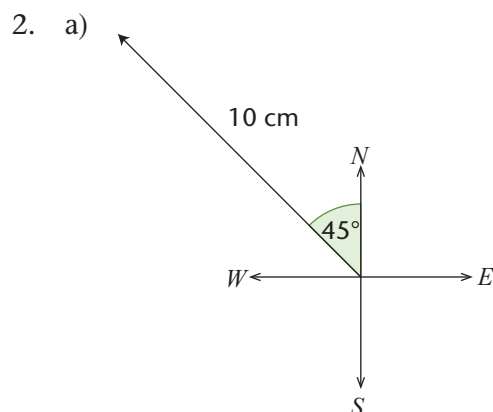
Chapter 1 Mechanics

Activity 1.1 The Cartesian Plane

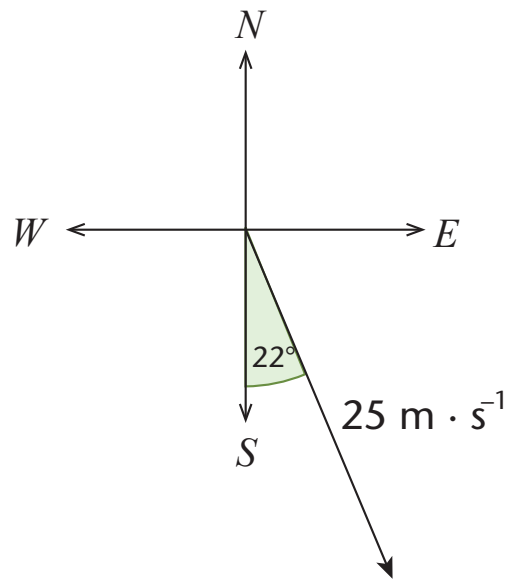
1.
 - a) Studying the graph shows that the maximum distance reached is 3 km away from the boy's home. Therefore, the tuck shop is 3 km away from the boy's home.
 - b) The total journey took 11 minutes, according to the graph. Therefore, the boy was away from home for 11 minutes.
 - c) The maximum distance, 3 km, is maintained between the time interval 3 – 7 minutes. During this time the boy the distance is not changing, meaning the boy must have stopped there during that time interval. Therefore, the boy was in the shop for 4 minutes (during the time interval 3 – 7 minutes).
 - d) 3 km away from home.
 - e) 1 km away from home.
 - f) The flatness means the distance from home is not changing. The boy has stopped.
 - g) C (2 minutes; 2 km) D (7 minutes; 3 km)

Activity 1.2 Sign Convention and Vectors

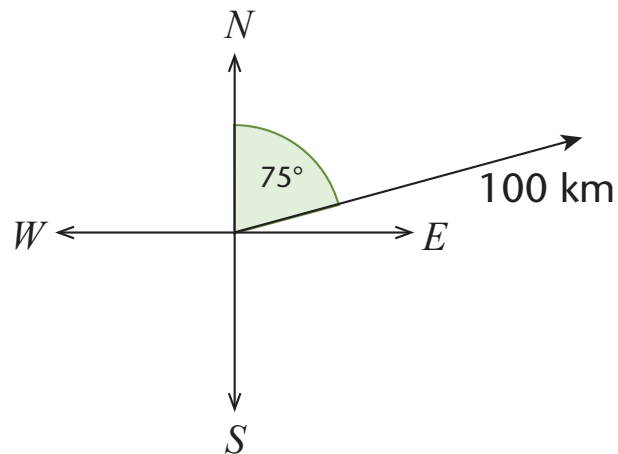
1.
 - a) Scalar quantity is the physical quantity that has only magnitude
 - b) Vector quantity is the physical quantity having magnitude and direction
 - c) Bearing is the degrees away from the true North, measured clockwise, of a distant point relative to the current (fixed) point



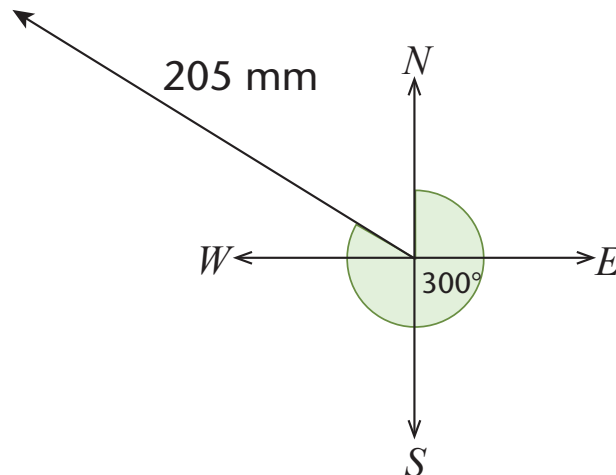
b) Using the scale 1 cm : 5 m.s⁻¹ such that 5 cm : 25 m.s⁻¹



c) Using the scale 1 cm : 20 km, we obtain that 100 km : 5 cm



d) Using the scale 1 cm : 25 mm, we get that 205 mm : 8,2 cm



Activity 1.3 Dependent and independent variables

1. For two variables to be directly proportional:

The ratio between the two variables must be constant

The graph representing the two variable must be a straight line passing through the origin

2. For two variables to be inversely proportional:

The product of the two variables must be a constant

The graph representing the variable must be a hyperbola, that doesn't intersect with the axes

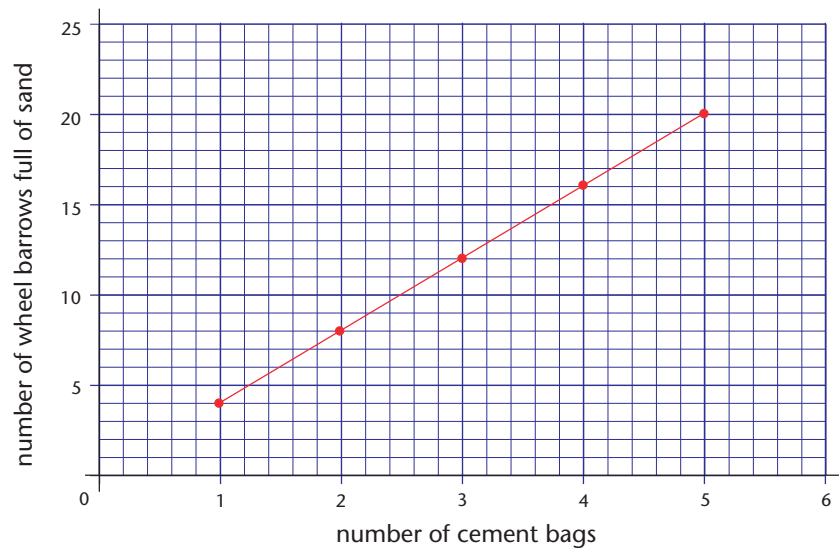
3. a)

Number of cement bags	Number of Wheel barrows	Ratio
1	4	4
2	8	4
3	12	4
4	16	4
5	20	4

- b) Independent variable: cement bags

Dependent variable: Cement

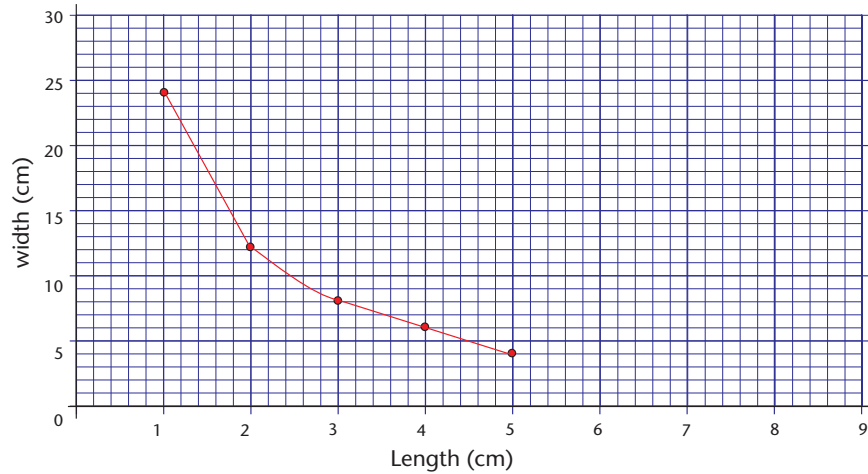
- c)



- d) The number of wheel barrows full of sand is directly proportional to the number of cement bags.

- e) Let x be number of cement bags, and y be the number of wheel barrows full of sand

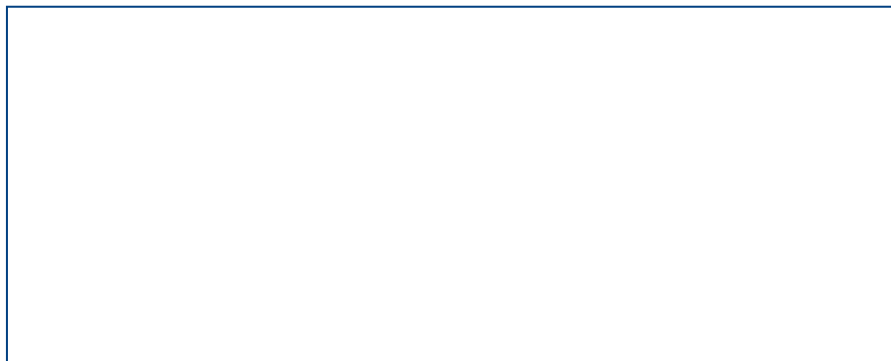
f) $y = 4x$



4. a)

Group	Length (cm)	Width (cm)	Area (cm ²)
A	1	24	24
B	2	12	24
C	3	8	24
D	4	6	24
E	5	4.8	24

b)



c) Since the product of length and width is the constant, therefore the width is inversely proportional to the length.

d) $A = W \times L$

$$W_a L_a = W_b L_b$$

e) $W \times L = 24$

$$W \times 10 \text{ cm} = 24 \text{ cm}^2$$

$$\therefore 2,4 \text{ cm}$$

Activity 1.4 Applications of the Pythagoras Theorem

3 – 4 – 5 The hypotenuse is the longest side in a right-angled triangle. We should prove that the sum of squares of 3 and 4 equals to the square of 5: $3^2 + 4^2$ $= 16 + 9$ $= 25$ $5^2 = 25$ $\therefore 3^2 + 4^2 = 5^2$	6 – 8 – 10 The hypotenuse is the longest side in a right-angled triangle. We should prove that the sum of squares of 6 and 8 equals to the square of 10: $6^2 + 8^2$ $= 36 + 64$ $= 100$ $10^2 = 100$ $\therefore 6^2 + 8^2 = 10^2$	9 – 12 – 15 The hypotenuse is the longest side in a right-angled triangle. We should prove that the sum of squares of 9 and 12 equals to the square of 15: $9^2 + 12^2$ $= 81 + 144$ $= 225$ $15^2 = 225$ $\therefore 9^2 + 12^2 = 15^2$
12 – 16 – 20 The hypotenuse is the longest side in a right-angled triangle. We should prove that the sum of squares of 12 and 16 equals to the square of 20 $12^2 + 16^2$ $= 144 + 256$ $= 400$ $20^2 = 400$ $\therefore 12^2 + 16^2 = 20^2$	15 – 20 – 25 The hypotenuse is the longest side in a right-angled triangle. We should prove that the sum of squares of 15 and 20 equals to the square of 25 $15^2 + 20^2$ $= 225 + 400$ $= 625$ $25^2 = 625$ $\therefore 15^2 + 20^2 = 25^2$	

Activity 1.5

- We can apply the theorem of Pythagoras to calculate the length of the zip line. Let the length of the zip line be x :

$$x^2 = 20^2 + 50^2$$

$$= 400 + 2500$$

$$x^2 = 2900$$

$$\therefore x = 53,85 \text{ m}$$
- The cable used must not be too tight to accommodate the mass to be suspended.

Activity 1.6

- $$AD^2 = AB^2 + BC^2 + CD^2$$

$$AD^2 = 42 + 52 + 62$$

$$AD^2 = 156$$

$$\therefore AD = 12,49 \text{ cm}$$

Activity 1.7

1. This is a rate problem. It is shown that 1 m of an object is reflected as 8 cm of that object's image. Therefore:

$$1 \text{ m} : 8 \text{ cm} = x : 24 \text{ cm}$$

$$\frac{1 \text{ m}}{8 \text{ cm}} = \frac{x}{24 \text{ cm}}$$

$$x = \frac{1 \text{ m}}{8 \text{ cm}} \times 24 \text{ cm}$$

$$x = 3 \text{ cm}$$

2. We can apply trigonometric ratios that we have learned in Grade 10 Mathematics. Let the height of the tree be x

$$\tan 44^\circ = \frac{x}{90 \text{ m}}$$

$$\therefore x = 90 \text{ m} \times \tan 44^\circ$$

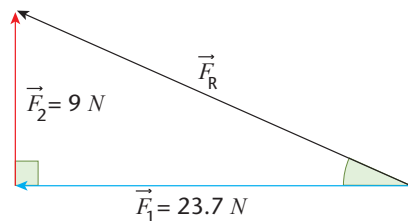
$$x = 86,91 \text{ m}$$

Therefore, the height of the tree is 86,91 m.

Activity 1.8 Pythagoras Theorem

1. The resultant force is a single force which has the same effect as all the forces combined together.
2. Collinear vectors are vectors that act along the same line of action.
3. Calculating resultant force of perpendicular forces.

a)



$$F_R^2 = F_1^2 + F_2^2$$

$$F_R^2 = (23,7)^2 + 9^2$$

$$F_R^2 = 642,69$$

$$\therefore F_R = 25,35 \text{ N}$$

We know the magnitude of the resultant force, now we must determine the angle to find the direction of the resultant force.

$$\sin \theta = \frac{F_y}{F_R} = \frac{9}{25,35} = 0,36^\circ$$

$$\theta = 20,80^\circ$$

$$\vec{F}_R = 25,35 \text{ N at } 20,80^\circ \text{ to the negative } x\text{-direction}$$

OR

$$\cos \theta = \frac{F_x}{F_R} = \frac{23,7}{25,35} = 0,93^\circ$$

$$\theta = 20,79^\circ$$

$$\vec{F}_R = 23,35 \text{ N at } 20,79^\circ \text{ to the negative } x\text{-direction}$$

OR

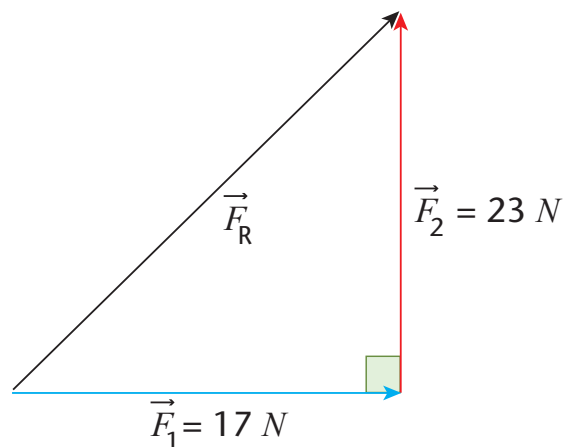
$$\tan \theta = \frac{F_y}{F_x} \quad \text{OR} \quad \theta = \tan^{-1} \left(\frac{F_y}{F_x} \right)$$

$$\tan \theta = \frac{9}{23,7} \quad \text{OR} \quad \theta = \tan^{-1} \left(\frac{9}{23,7} \right)$$

$$\theta = 20,79^\circ$$

$$\vec{F}_R = 25,35 \text{ N at } 20,79^\circ \text{ to the negative } x\text{-direction}$$

b)



$$F_R^2 = F_1^2 + F_2^2$$

$$F_R^2 = (17)^2 + (23)^2$$

$$F_R^2 = 818$$

$$\therefore F_R = 28,60 \text{ N}$$

We know the magnitude of the resultant force, now we must determine the angle to find the direction of the resultant force.

$$\sin \theta = \frac{F_y}{F_R} = \frac{23}{28,60} = 0,8042^\circ$$

$$\theta = 53,53^\circ$$

$$\vec{F}_R = 28,60 \text{ N at } 53,53^\circ \text{ to the negative } x\text{-direction}$$

OR

$$\cos \theta = \frac{F_x}{F_R} = \frac{17}{28,60} = 0,5944^\circ$$

$$\theta = 53,53^\circ$$

$$\vec{F}_R = 28,60 \text{ N at } 53,53^\circ \text{ to the positive } x\text{-direction}$$

OR

$$\tan \theta = \frac{F_y}{F_x} \quad \text{OR} \quad \theta = \tan^{-1} \left(\frac{F_y}{F_x} \right)$$

$$\tan \theta = \frac{23}{17} \quad \text{OR} \quad \theta = \tan^{-1} \left(\frac{23}{17} \right)$$

$$\theta = 53,53^\circ$$

$$\vec{F}_R = 28,60 \text{ N at } 53,53^\circ \text{ to the positive } x\text{-direction}$$

4. a) $\vec{F}_x = \vec{F}_1 + \vec{F}_3$

$$\vec{F}_x = 2,3 \text{ N} + (-2,1 \text{ N})$$

$$\vec{F}_x = +0,2 \text{ N} \quad \text{OR} \quad \vec{F}_x = 0,2 \text{ N in the positive } x\text{-direction}$$

b) $\vec{F}_y = \vec{F}_2 + \vec{F}_4$

$$\vec{F}_y = 4 \text{ N} + (-3,3 \text{ N})$$

$$\vec{F}_y = +0,7 \text{ N} \quad \text{OR} \quad \vec{F}_y = 0,7 \text{ N in the positive } x\text{-direction}$$

$$\begin{aligned}
 \text{c) } F_R^2 &= F_x^2 + F_y^2 \\
 F_R^2 &= (0,2)^2 + (0,7)^2 \\
 F_R^2 &= 0,53 \\
 \therefore F_R &= 0,73 \text{ N}
 \end{aligned}$$

We know the magnitude of the resultant force, now we must determine the angle to find the direction of the resultant force.

$$\begin{aligned}
 \sin\theta &= \frac{F_y}{F_R} = \frac{0,7}{0,73} = 0,96^\circ \\
 \theta &= 73,52^\circ \\
 \vec{F}_R &= 0,73 \text{ N at } 73,52^\circ \text{ to the positive } x\text{-direction}
 \end{aligned}$$

OR

$$\begin{aligned}
 \cos\theta &= \frac{F_x}{F_R} = \frac{0,2}{0,73} = 0,27^\circ \\
 \theta &= 73,4^\circ \\
 \vec{F}_R &= 0,73 \text{ N at } 73,4^\circ \text{ to the positive } x\text{-direction}
 \end{aligned}$$

OR

$$\begin{aligned}
 \tan\theta &= \frac{F_y}{F_x} \quad \text{OR} \quad \theta = \tan^{-1}\left(\frac{F_y}{F_x}\right) \\
 \tan\theta &= \frac{0,7}{0,2} \quad \text{OR} \quad \theta = \tan^{-1}\left(\frac{0,7}{0,2}\right) \\
 \theta &= 74,05^\circ \\
 \vec{F}_R &= 0,73 \text{ N at } 74,05^\circ \text{ to the positive } x\text{-direction}
 \end{aligned}$$

5. a) First calculate the resultant of forces in the x - and y -direction:

$$\begin{aligned}
 \vec{F}_x &= \vec{F}_1 + \vec{F}_3 \\
 \vec{F}_x &= (-2,3 \text{ N}) + (3,3 \text{ N}) = +1 \text{ N} \\
 \vec{F}_y &= \vec{F}_2 + \vec{F}_4 \\
 \vec{F}_y &= (4 \text{ N}) + (2,1 \text{ N}) = +6,1 \\
 F_R^2 &= F_x^2 + F_y^2 \\
 F_R^2 &= (1)^2 + (6,1)^2 \\
 F_R^2 &= 38,21 \\
 \therefore F_R &= 6,18 \text{ N}
 \end{aligned}$$

We know the magnitude of the resultant force, now we must determine the angle to find the direction of the resultant force.

$$\begin{aligned}
 \sin\theta &= \frac{F_y}{F_R} = \frac{6,1}{6,18} = 0,99^\circ \\
 \theta &= 80,77^\circ \\
 \vec{F}_R &= 6,18 \text{ N at } 80,77^\circ \text{ to the positive } x\text{-direction}
 \end{aligned}$$

OR

$$\cos\theta = \frac{F_x}{F_R} = \frac{1}{6,18} = 0,1618^\circ$$

$$\theta = 80,67^\circ$$

$$\vec{F}_R = 6,18 \text{ N at } 80,67^\circ \text{ to the positive } x\text{-direction}$$

OR

$$\tan\theta = \frac{F_y}{F_x} \quad \text{OR} \quad \theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

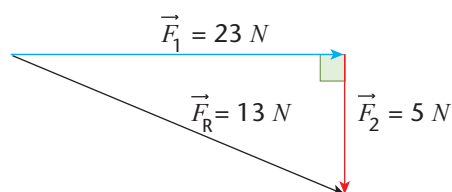
$$\tan\theta = \frac{6,1}{1} \quad \text{OR} \quad \theta = \tan^{-1}\left(\frac{6,1}{1}\right)$$

$$\theta = 80,69^\circ$$

$$\vec{F}_R = 6,18 \text{ N at } 80,69^\circ \text{ to the positive } x\text{-direction}$$

Activity 1.9 Forces in 2D (Head-to-Tail Method)

1. a) Using a scale 1 cm : 1 N, we can draw diagram from which we can determine the resultant of the two forces:

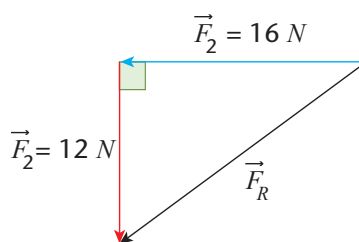


Measuring the length of the vector representing $\vec{F}_R$ we get 13 cm. This is exactly an equivalent of 13 N, according to our scale.

- b) Using the scale 1 cm : 2 N, we can convert our forces as follows:

$$16 \text{ N} : 8 \text{ cm}$$

$$12 \text{ N} : 6 \text{ cm}$$

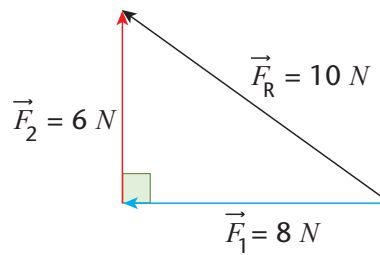


Measuring the length of the vector representing $\vec{F}_R$ we obtain 10 cm. according to our scale, this is exactly equivalent to 20 N.

c) Using the scale 1 cm : 1 N, we can convert our forces as follows:

$$8 \text{ N} : 8 \text{ cm}$$

$$6 \text{ N} : 6 \text{ cm}$$



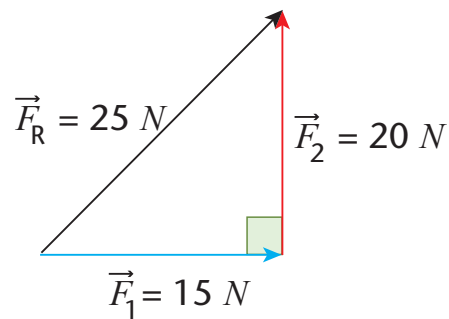
Measuring the length of the vector representing $\vec{F}_R$ we obtain that $F_R = 10 \text{ cm}$. This is exactly an equivalent of 10 N, according to the defined conversion scale

d) We can use the scale, 1 cm : 2,5 N, such that the forces can be converted as follows:

$$15 \text{ N} : 6 \text{ cm}$$

$$20 \text{ N} : 8 \text{ cm}$$

Then the scale diagram will be as shown below:



Measuring the length of the vector representing $\vec{F}_R$ we obtained 10 cm. According to the defined conversion scale, this is an equivalent of 25 N

2. Using the theorem of Pythagoras we can verify the correctness of the answers we obtained graphically in number 1 above

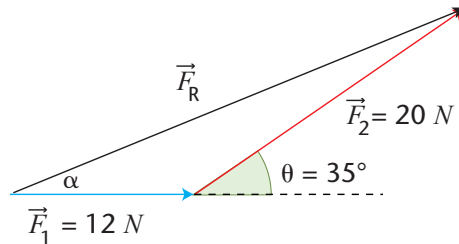
$$\begin{aligned} \text{a)} \quad F_R^2 &= F_1^2 + F_2^2 \\ F_R^2 &= (12)^2 + (5)^2 \\ F_R^2 &= 169 \\ \therefore F_R &= 13 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{b)} \quad F_R^2 &= F_1^2 + F_2^2 \\ F_R^2 &= (16)^2 + (12)^2 \\ F_R^2 &= 400 \\ \therefore F_R &= 20 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{c)} \quad F_R^2 &= F_1^2 + F_2^2 \\ F_R^2 &= (8)^2 + (6)^2 \\ F_R^2 &= 100 \\ \therefore F_R &= 10 \text{ N} \end{aligned}$$

$$\begin{aligned}
 \text{d) } F_R^2 &= F_1^2 + F_2^2 \\
 F_R^2 &= (15)^2 + (20)^2 \\
 F_R^2 &= 400 \\
 \therefore F_R &= 20 \text{ N}
 \end{aligned}$$

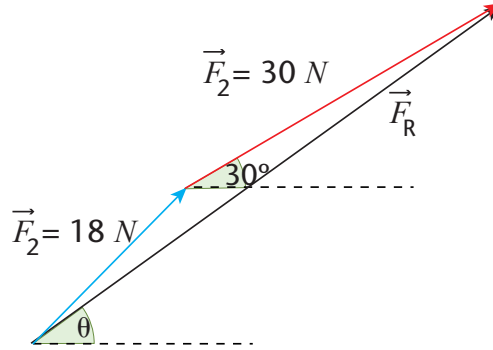
3. Let 1 cm : 4 N, such that 3 cm : 12 N and 5 cm : 20 N



Measuring the length of the vector representing $\vec{F}_R$ we get 7,7 cm. According to the scale this is an equivalent of 30,8 N. And angular direction of $\vec{F}_R$ is 22° .

$$\therefore \vec{F}_R = 30,8 \text{ N at } 22^\circ$$

4. Let 1 cm : 6 N such that 3 cm : 18 N and 5 cm : 30 N.

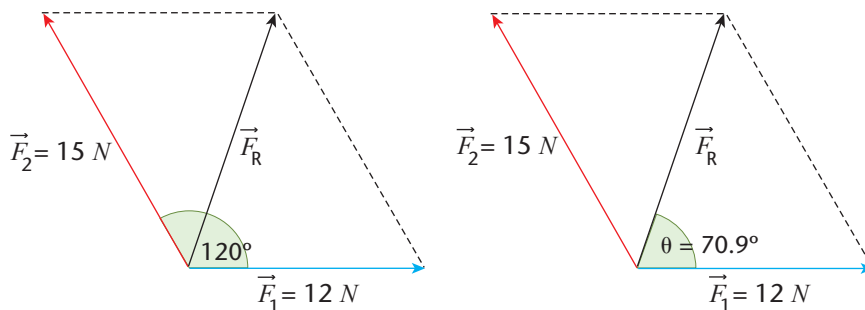


Measuring the length representing $\vec{F}_R$ we get 7,9 cm. Using the conversion scale this is an equivalent of 47,4 N and $\theta = 35,6^\circ$.

$$\therefore \vec{F}_R = 47,4 \text{ N at } 35,6^\circ \text{ to the horizontal/to positive } x\text{-direction}$$

Activity 1.10 Parallelogram Law of Forces

- The Parallelogram Law of Forces states that if two forces acting at a point can be represented by the adjacent sides of a parallelogram both in magnitude and direction, then the diagonal from the point gives the resultant of the two forces.
- Resultant of 2 forces acting at an angle using the parallelogram of forces
 - We can use the scale 1 cm : 3 N to find the resultant, such that, F_1 is represented by 4 cm : 12 N and F_2 by 5 cm : 15 N



Measuring the length representing FR we obtain 4,6 cm. Using the defined scale, this is an equivalent of 13,8 N. The angle made by the resultant is $70,9^\circ$.

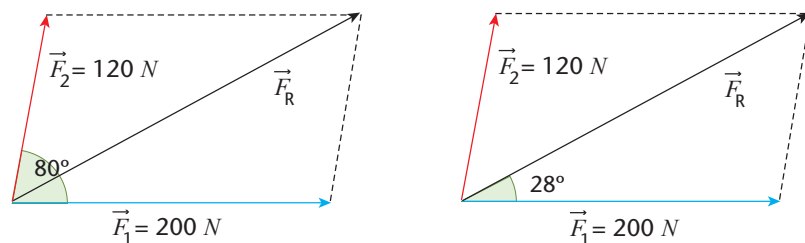
$\therefore FR = 13,8 \text{ N}$ at an angle of $70,9^\circ$

Note: If the $\vec{F}_2$ is the one drawn horizontal, then the direction of the resultant force will be $120^\circ - 70,9^\circ = 49,1^\circ$

- b) Using the scale 1 cm : 40 N, we obtain 5 cm : 200 N and 3 cm : 120 N

The length of the vector representing FR = 6,3 cm According to the scale, this is an equivalence of 252 N. The resultant makes an angle of 28° .

$\therefore FR = 252 \text{ N}$ at an angle of 28°



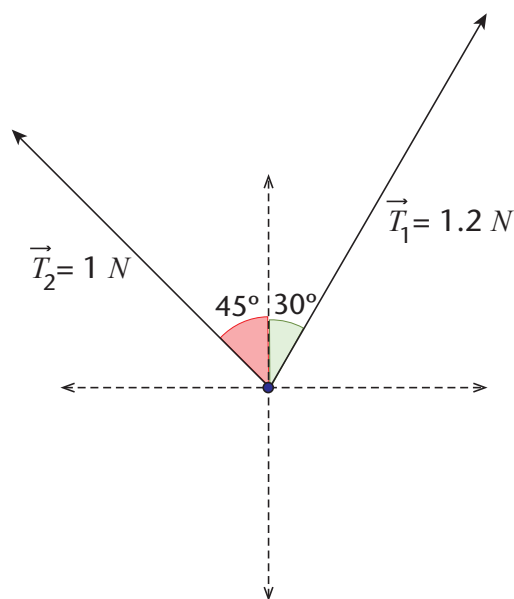
3. To simplify the problem, let's take $g = 10 \text{ m.s}^{-2}$. The tension on the string attached to m_2 is the same as the weight of m_2 . Same applies to m_1 . By applying some simple geometry, we can see that the angle between drawn vertical line that separates the two ropes and the rope connected to m_2 is 30° . The same applies to m_1 . The angle between the two ropes, where they meet is, therefore 75° .

$$T_1 = m_1 g$$

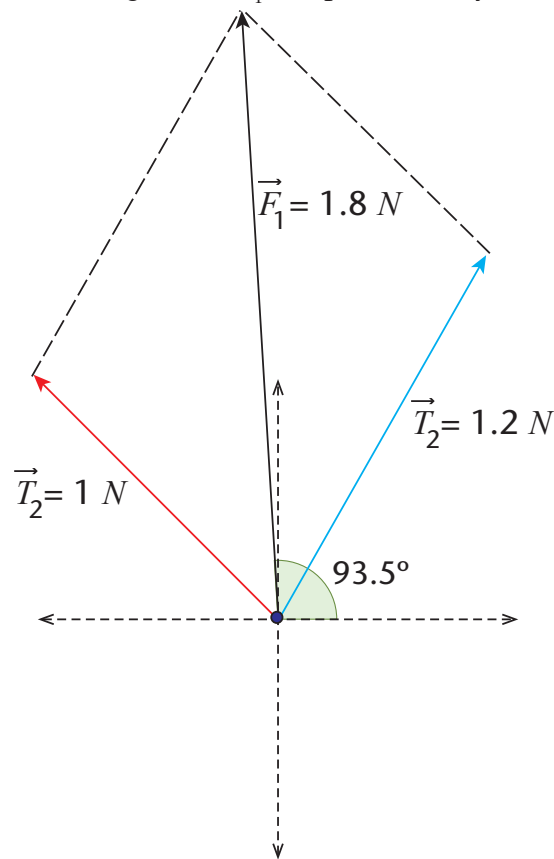
$$T_1 = (0,1)(10) = 1 \text{ N}$$

$$T_2 = m_2 g$$

$$T_2 = (0,12)(10) = 1,2 \text{ N}$$



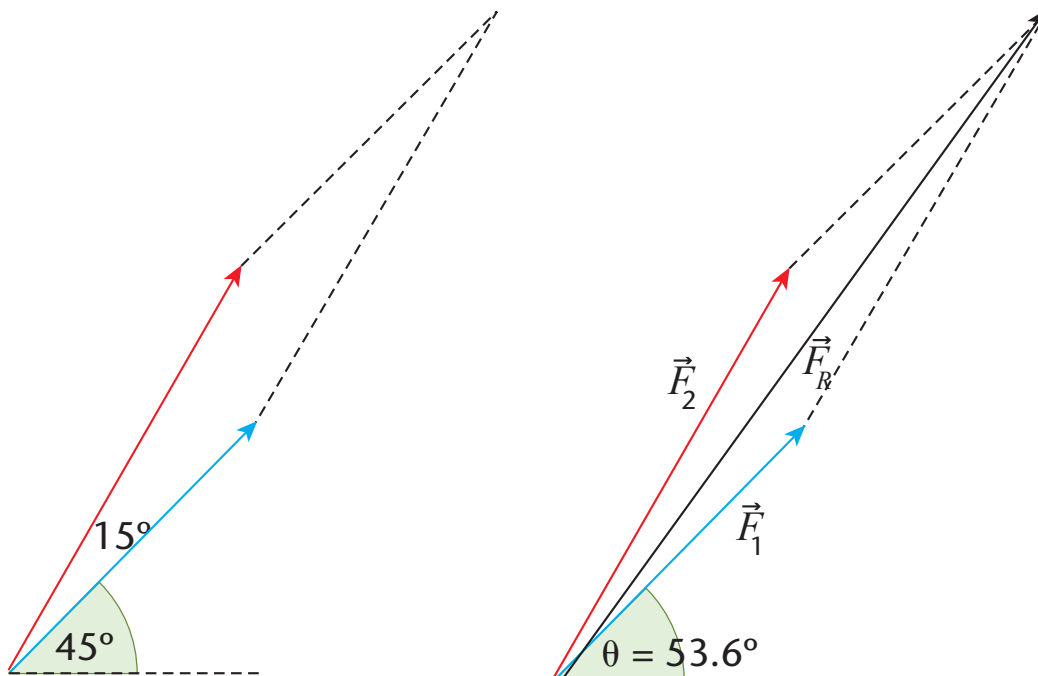
Using the scale 1 cm : 0,2 N, we get that $\vec{T}_1$ is represented by 5 cm and $\vec{T}_2$ is represented by 6 cm.



Measuring the length of the vector representing $\vec{F}_R$ we get 8,8 cm, which is an equivalent of 1,8 N according to the defined scale. The angle made by the resultant is $93,5^\circ$.

$\therefore FR = 1,76^\circ$ at an angle of $93,5^\circ$.

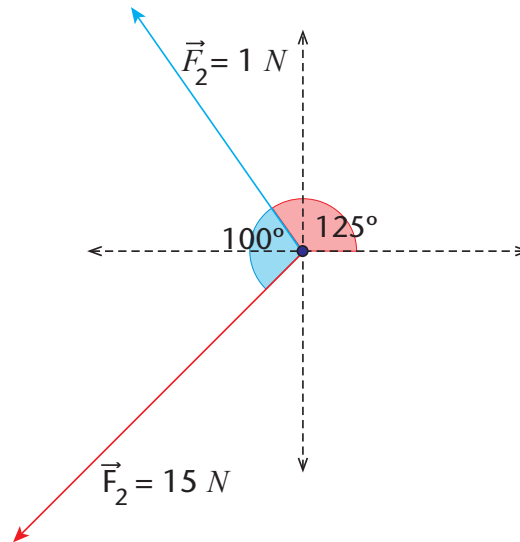
4. The problem can be represented in a form of a sketch to help us see the situation we are talking about



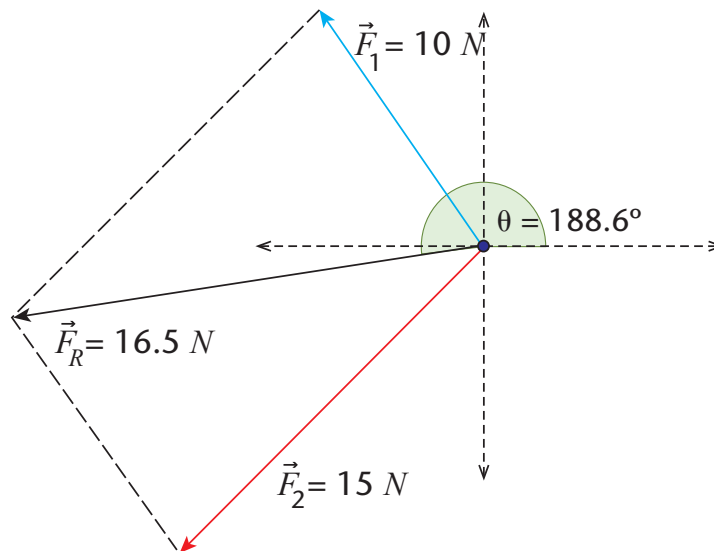
Measuring the length and the angle representing we obtain 13,9 cm at $53,6^\circ$. Using the scale defined, this is an equivalent of 41,7 N.

$\therefore \vec{F}_R = 41,7 \text{ N}$ at $53,6^\circ$ to the horizontal/to the positive x -direction.

5. This is the problem situation in a sketched drawing



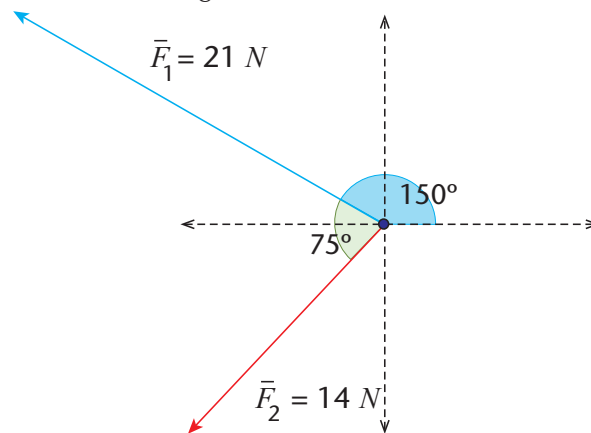
Using the scale 1 cm : 2,5 N, we get that 4 cm : 10 N and 6 cm : 15 N.



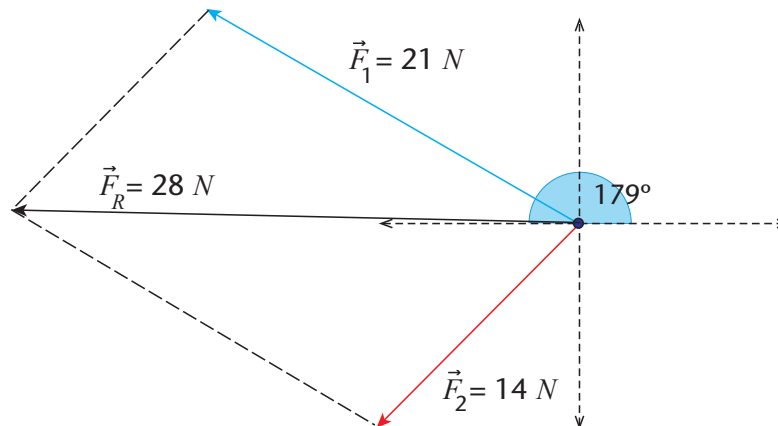
Measuring the length and the angle representing $\vec{F}_R$ we get: 6,6 cm at an angle of $188,6^\circ$. According to the scale this is an equivalent of 16,5 N.

$\therefore \vec{F}_R = 16,5 \text{ N}$ at $188,6^\circ$ to the positive x -direction.

6. The problem situation in sketched diagram



Using the scale 1 cm : 3,5 N, we get that 6 cm : 21 N and 4 cm : 14 N. Such that the resultant can be obtained from the scale drawing:

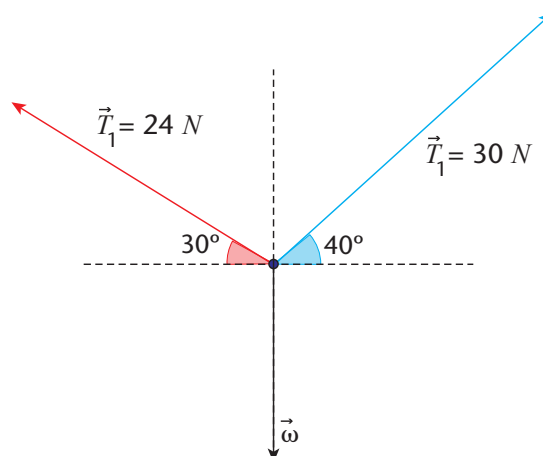


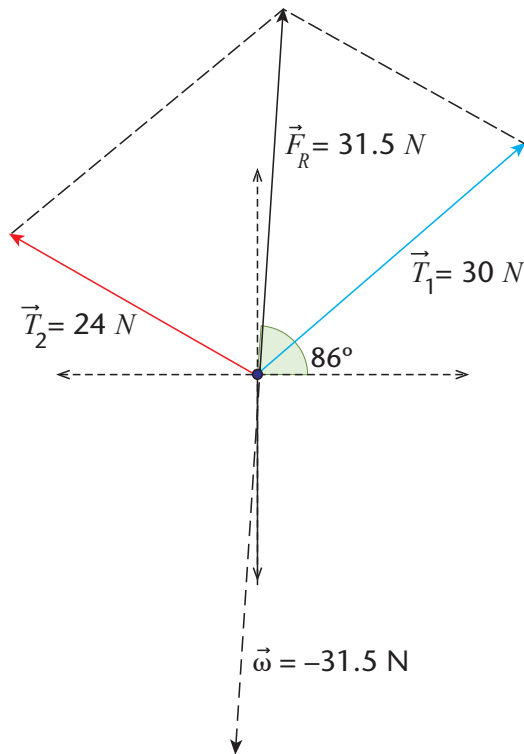
Measuring the length and the angle representing the resultant, we obtain 8 cm at an angle of 179° . According to the scale this is an equivalent of:

$\vec{F}_R = 29,75\text{ N}$ at an angle of 179° to the positive x -direction.

7. This is the direct application of the law of parallelograms. Hence we know that, since the system is in equilibrium, then the resultant of the forces has the same magnitude as the third force; that is the unknown weight.

Using the scale 1 cm : 6 N we get that 4 cm : 24 N and 5 cm : 30 N. This then in a scale drawing gives:





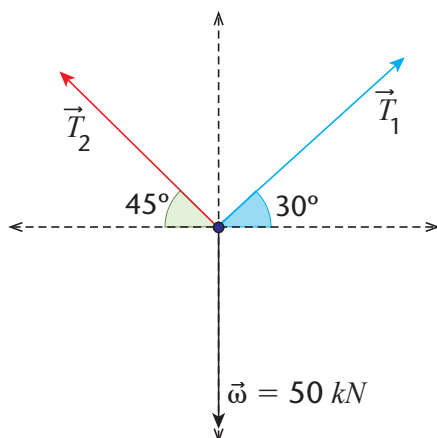
Measuring the length of the vector representing $\vec{F}_R$ we get 10,5 cm. According to the defined scale, this is equivalent to $\vec{F}_R = 31,5 \text{ N}$. The equilibrant, which has the same magnitude as $\vec{F}_R$, but in the opposite direction, has the same magnitude as the unknown weight.

$$\therefore \vec{w} = -31,5 \text{ N}$$

OR

$$\therefore \vec{w} = 31,5 \text{ N downwards}$$

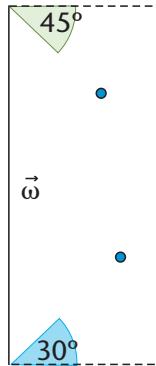
8. We can use the scale 1 cm : 10 kN such that 5 cm : 50 kN.



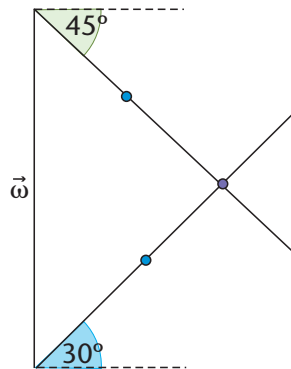
Step 1: Draw the vertically downward vector $\vec{w}$.

$$\vec{w} = 50 \text{ kN}$$

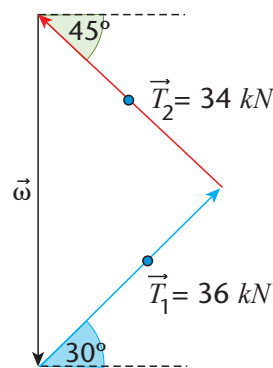
Step 2: From the head measure an angle of 30° anticlockwise, and from an angle of 45° clockwise. Put the dots to indicate where your angles are formed. {Note that, even when done in reversed order this will not have any impact on the final answer.}



Step 3: Draw a line segment from joining the head of the vector $\vec{w}$ and point formed by the angled measured from the head. Do the same with the tail of the vector $\vec{w}$. Your long line segments must be long enough that they cross each other. Where your lines intersect put a point.



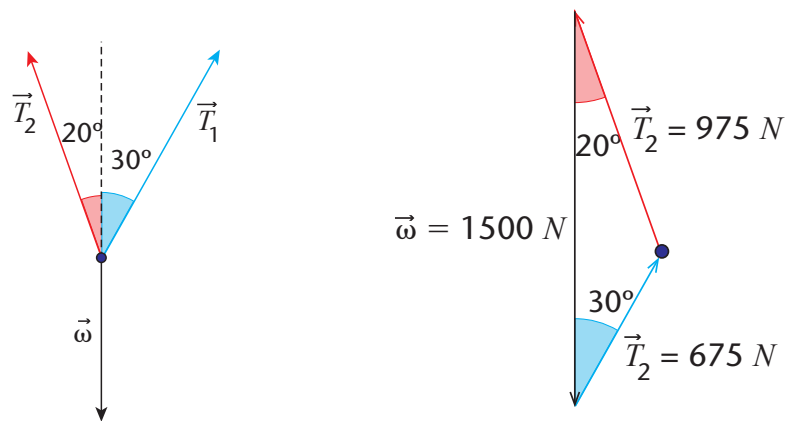
Step 4: Draw an arrow which points to the intersection point from the head of the vector $\vec{w}$, and another arrow pointing to the tail of $\vec{w}$ from the intersection point. Erase the part where the lines cross each other from the intersection point.



Measuring the length of the vectors representing $\vec{T}_1$ and $\vec{T}_2$ we get 3,6 cm and 4,5 cm respectively. This according to our scale drawing means:

$$T_1 = 36 \text{ kN and } T_2 = 45 \text{ kN}$$

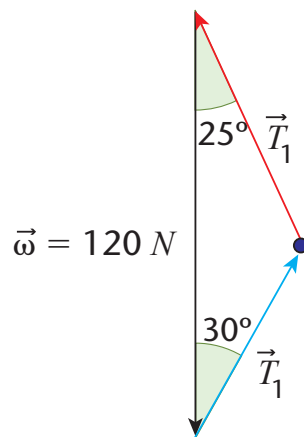
9. Follow the same procedure outlined in the 8. Using the scale 1 cm : 300 N, we get that 5 cm : 1 500 N. The only difference is with the orientation of the angles, but the problem is still the same as the previous.



Measuring the length of the vectors representing $\vec{T}_1$ and $\vec{T}_2$ we get 2,3 cm and 3,3 cm respectively. This according to our scale drawing means:

$$T_1 = 660 \text{ N and } T_2 = 990 \text{ N}$$

10. The problem situation presented here is exactly the same as the previous one. Using the scale 1 cm : 30 N we get that 4 cm : 120 N. Hence the scale diagram:



Measuring the length of the vectors representing $\vec{T}_1$ and $\vec{T}_2$ we get 2,1 cm and 2,5 cm respectively. This according to our scale drawing means:

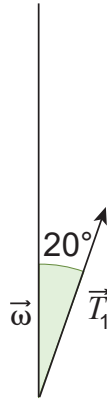
$$T_1 = 63 \text{ N and } T_2 = 75 \text{ N}$$

11. This problem is more or less the same as the previous. The only difference is that magnitude if the weight is unspecified. Use a scale 1 cm : 500 N, such that 8 cm : 4 000 N.

Step 1: Draw a vector facing downward with no specified magnitude. This vector represent the unknown weight of the load.

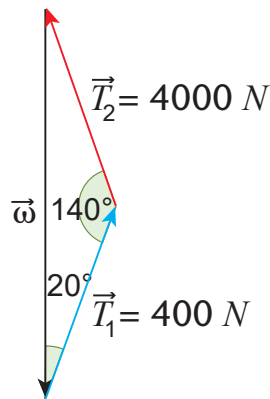


Step 2: At the head of the vector, measure the angle of 20° clockwise from the vertical. Draw the tension T_1



Step 3: with the aid of geometry, we can show that the angle formed between the vectors, when they joined from head-to-tail without changing their angular orientation, is 140° . Measure this angle clockwise, relative to the head of T_1 and draw T_2 in that direction.

{Note that if done correctly, the head T_2 should lie exactly on w }



Step 4: Erase the part of w that extends beyond the head of T_2 , and measure the length of w . In this case, the length of the vector representing w is about 15 cm. Using the defined scale: $w = 7\,500$

Activity 1.11 Resolving forces

- We know the formulas to calculate the components of the force, that is:

$$\vec{F}_x = \vec{F}\cos\theta$$

$$\vec{F}_y = \vec{F}\sin\theta$$

$$\text{a) } \vec{F}_x = \vec{F}\cos\theta$$

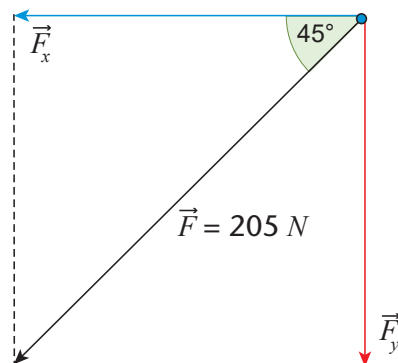
$$\vec{F}_x = 205 \cos 45^\circ$$

$$\vec{F}_x = 144,96 \text{ N to the left}$$

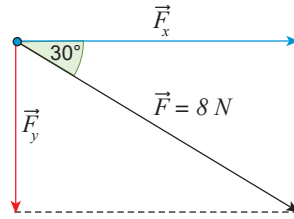
$$\vec{F}_y = \vec{F}\sin\theta$$

$$\vec{F}_y = 205 \sin 45^\circ$$

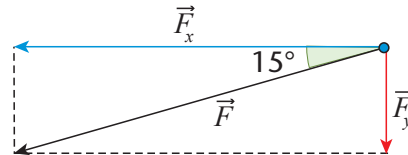
$$\vec{F}_y = 144,96 \text{ N downwards}$$



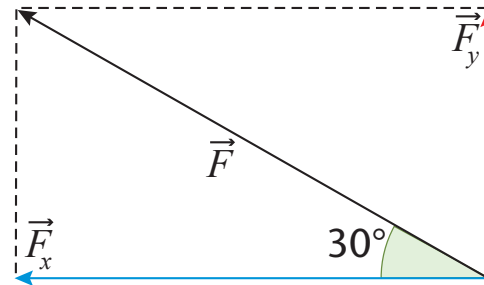
b) $\vec{F}_x = \vec{F} \cos \theta$
 $\vec{F}_x = 8 \cos 30^\circ$
 $\vec{F}_x = 6,93 \text{ N to the right}$
 $\vec{F}_y = \vec{F} \sin \theta$
 $\vec{F}_y = 8 \sin 30^\circ$
 $\vec{F}_y = 4 \text{ N downwards}$



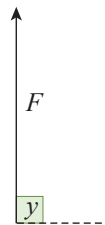
c) $\vec{F}_x = \vec{F} \cos \theta$
 $\vec{F}_x = 400 \cos 15^\circ$
 $\vec{F}_x = 386,37 \text{ N to the left}$
 $\vec{F}_y = \vec{F} \sin \theta$
 $\vec{F}_y = 400 \sin 15^\circ$
 $\vec{F}_y = 103,53 \text{ N downwards}$



d) $\vec{F}_x = \vec{F} \cos \theta$
 $\vec{F}_x = 1\,500 \cos 30^\circ$
 $\vec{F}_x = 1\,299,04 \text{ N to the left}$
 $\vec{F}_y = \vec{F} \sin \theta$
 $\vec{F}_y = 1\,500 \sin 15^\circ$
 $\vec{F}_y = 750 \text{ N upwards}$

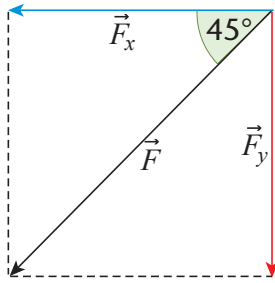


e) $\vec{F}_x = \vec{F} \cos \theta$
 $\vec{F}_x = 90 \cos 90^\circ$
 $\vec{F}_x = 0 \text{ N}$
 $\vec{F}_y = \vec{F} \sin \theta$
 $\vec{F}_y = 90 \sin 90^\circ$
 $\vec{F}_y = 90 \text{ N upwards}$



2. Scale drawing to resolve forces into their perpendicular components

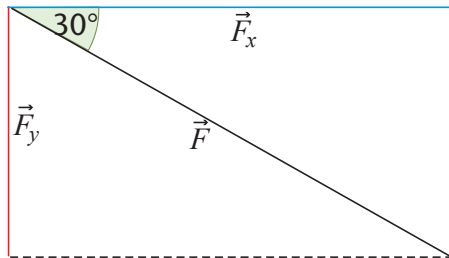
- a) Using the scale 1 cm : 25 N, so that 205 N : 8,2 cm



Measuring the length representing $\vec{F}_x$ and $\vec{F}_y$ we obtained that they are both equals to 5,8 cm
Using the specified conversion scale we found that these are an equivalent of 145 N.

$\therefore \vec{F}_x = 145 \text{ N}$, to the left $\vec{F}_y = 145 \text{ N}$ downwards

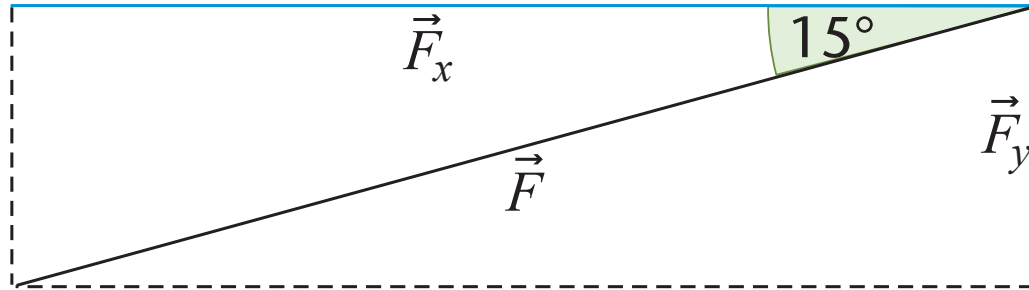
- b) We can use the scale 1 cm : 1 N



Measuring length representing $\vec{F}_x$ and $\vec{F}_y$ we obtained 6,9 cm, and 4 cm, respectively. Use the defined conversion scale, we can see that:

$\therefore \vec{F}_x = 6,9 \text{ N}$, to the right, and $\vec{F}_y = 4 \text{ N}$ downwards

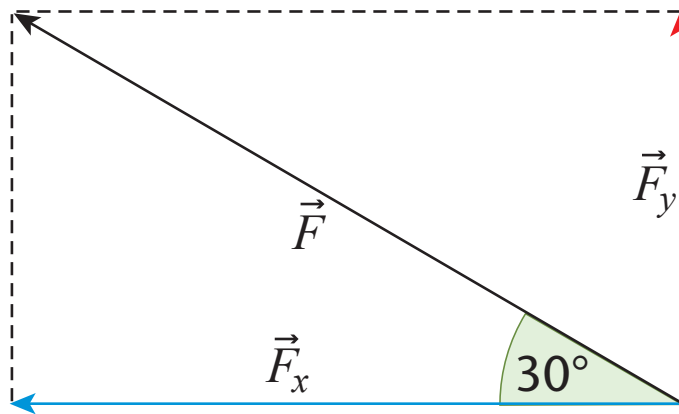
- c) Use the scale 1 cm : 50 N such that 8 cm : 400 N



Measuring the lengths representing $\vec{F}_x$ and $\vec{F}_y$ we obtain that:

$\vec{F}_x = 7,7$ cm and $\vec{F}_y = 2,1$ cm. These are equivalent to $\vec{F}_x = 385$ N, to the left, and $\vec{F}_y = 105$ N downwards

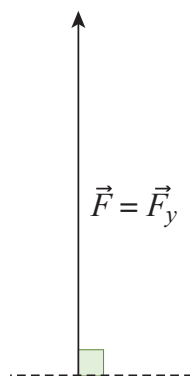
- d) We can use the scale 1 cm : 250 N, such that 1 500 N : 6 cm.



The lengths of $\vec{F}_x$ and $\vec{F}_y$ were measured and obtained to be $\vec{F}_x = 5,2$ cm and $\vec{F}_y = 3$ cm. According to the scale we can see that:

$\vec{F}_x = 1\,300$ N, to the left, and $\vec{F}_y = 750$ N upwards

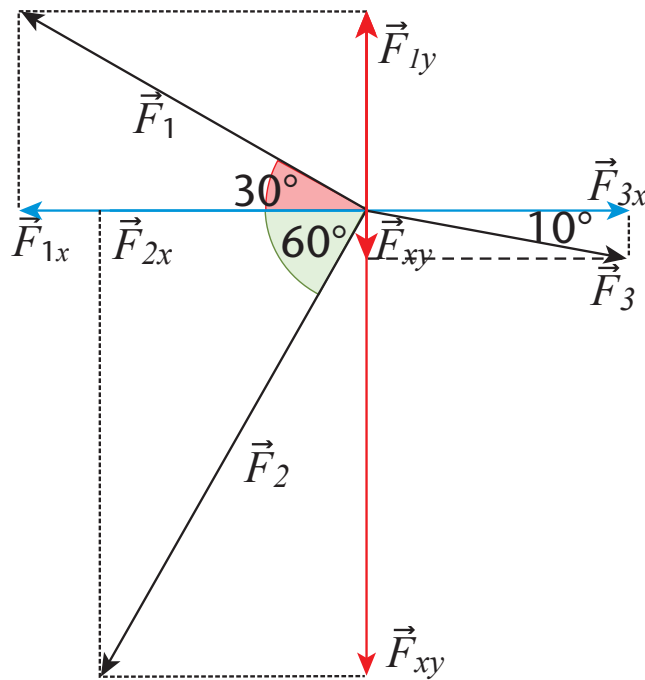
- e) Use the scale 1 cm : 10 N such that 9 cm : 90 N



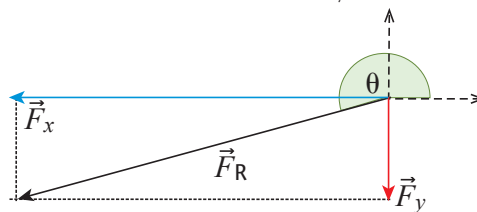
From the diagram above, $\vec{F}_x = 0$ N, while $\vec{F}_y = F_y = 90$ N upwards

3. All the three forces can be resolved into their horizontal and vertical components.

The diagram above shows the horizontal components of each of the three forces and their directions. Let's take direction to the right as positive, and the direction upward as positive:



- a) $\vec{F}_x = \vec{F}_{1x} + \vec{F}_{2x} + \vec{F}_{3x}$
 $\vec{F}_x = 15 \cos 150^\circ + 20 \cos 240^\circ + 10 \cos 350^\circ$
 $\vec{F}_x = -13,14 \text{ N}$
- b) $\vec{F}_y = \vec{F}_{1y} + \vec{F}_{2y} + \vec{F}_{3y}$
 $\vec{F}_y = 15 \sin 150^\circ + 20 \sin 240^\circ + 10 \sin 350^\circ$
 $\vec{F}_y = -11,56 \text{ N}$
- c) The simplified diagram showing only $\vec{F}_x$ and $\vec{F}_y$:



$$F_R^2 = F_x^2 + F_y^2$$

$$F_R^2 = (-13,14)^2 + (-11,56)^2$$

$$F_R^2 = 306,2932$$

$$\therefore F_R = 17,50 \text{ N}$$

$$\tan \theta = \frac{F_y}{F_x}$$

$$\tan \theta = \frac{11,56}{13,14}$$

$$\therefore \theta = 41,33^\circ$$

$$\therefore F_R = 17,50 \text{ N at } 41,33^\circ \text{ below the horizontal to the left}$$

4. Let the vertical component of the force be $\vec{F}_y$.
- $$\vec{F}_y = F \sin 60^\circ$$
- $$\vec{F}_y = 1\,000 \sin 60^\circ$$
- $$\vec{F}_y = 866 \text{ N vertically up}$$
5. http://www.physicsforarchitects.com/Sailing_against_the_wind.php

Activity 1.12 Friction

- Advantages of friction:
 - » It is difficult to move on slippery floor because of low friction. For example, walking on ice is very difficult because of low friction.
 - » Friction enables object, such as cars, to stop over a short distance. The more friction there is the shorter the stopping distance.
 - » Friction between a match and a box causes fire
 - » Friction enables to pen to be gripped on to the paper when writing. it would be impossible to write on a paper if there was no friction between the pen (or pencil) and the paper.
 - » Friction keeps objects in their positions. If it was not for friction object would easily slide away from their (fixed) positions.

- The coefficient of friction is the ratio between the frictional and the normal force.

$$\mu = \frac{f}{F_N}$$

- The force required must at least be equal to the maximum static frictional force, otherwise the box won't be displaced.

$$f_s^{\max} = \mu_s F_N$$

$$f_s^{\max} = \mu_s mg$$

$$f_s^{\max} = 0,72 \times 85 \times 9,8$$

$$f_s^{\max} = 599,76 \text{ N}$$

- The force required is equals to the maximum static frictional force.

$$f_s^{\max} = \mu_s F_N$$

$$f_s^{\max} = \mu_s mg$$

$$f_s^{\max} = 0,8 \times 80 \times 9,8$$

$$f_s^{\max} = 627,20 \text{ N}$$

Review exercise

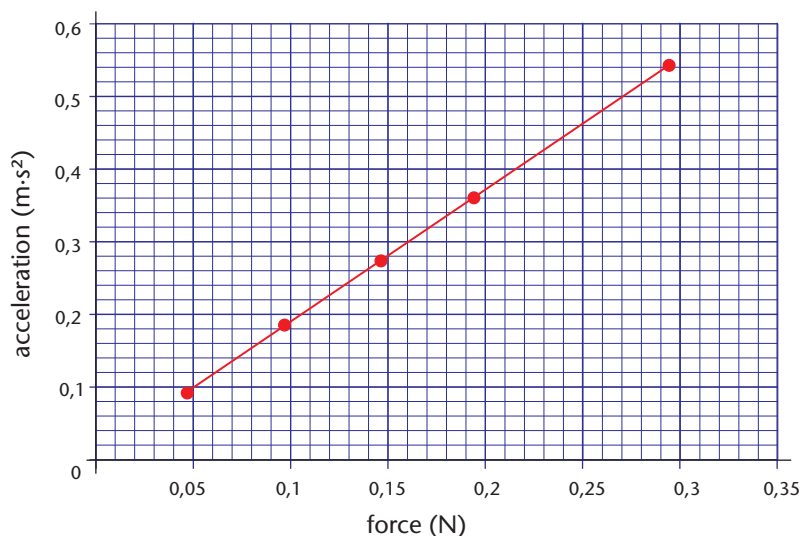
Multiple Choice Questions:

1. A 2. C 3. D 4. C 5. D

Long Questions:

6. a) (i) Total mass of the trolley and the hanging mass.
(ii) Pulling force.
(iii) Acceleration.

b)

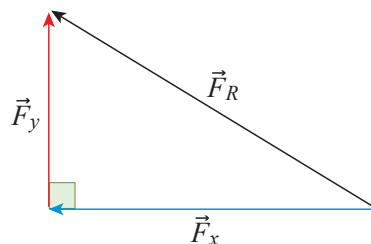


- c) The acceleration is directly proportional to the pulling force.

7. a) $\vec{F}_x = \vec{F}_2 + \vec{F}_4$
 $\vec{F}_x = -10 \text{ N} - 15 \text{ N}$
 $\vec{F}_x = -25 \text{ N}$
 $\therefore \vec{F}_x = 25 \text{ N to the left}$

b) $\vec{F}_y = \vec{F}_1 + \vec{F}_3$
 $\vec{F}_y = 25 \text{ N} - 10 \text{ N}$
 $\vec{F}_y = 15 \text{ N}$
 $\therefore \vec{F}_y = 15 \text{ N to the right}$

- c) Scale 1 cm : 5 N
 25 N : 5 cm
 15 N : 3 cm
 The length representing $F_R = 5,8 \text{ cm}$
 This is an equivalent of 29 N

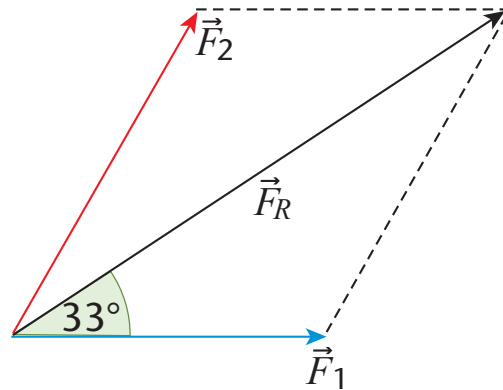


d) $F_R^2 = F_x^2 + F_y^2$
 $F_R^2 = (-25)^2 + (15)^2$
 $F_R^2 = 850$
 $\therefore F_R = 29,15 \text{ N}$

8. Let 1 cm : 3 N

18 N : 6 cm

15 N : 5 cm



Measuring the length representing F_R we obtain 9,54 cm. Using the conversion scale, this is an equivalent of 28.5 N. The angle made by the resultant force is 33° . Therefore, $\vec{F}_R = 28,5 \text{ N}$ at 33° measured anticlockwise from the positive horizontal axes.

9. a) $\vec{F}_x = \vec{F} \cos 40^\circ$

$$\vec{F}_x = 100 \cos 40^\circ$$

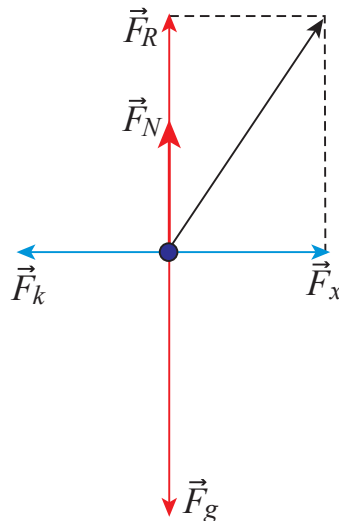
$$\vec{F}_x = 76,60 \text{ N to the left}$$

b) $\vec{F}_y = \vec{F} \sin 40^\circ$

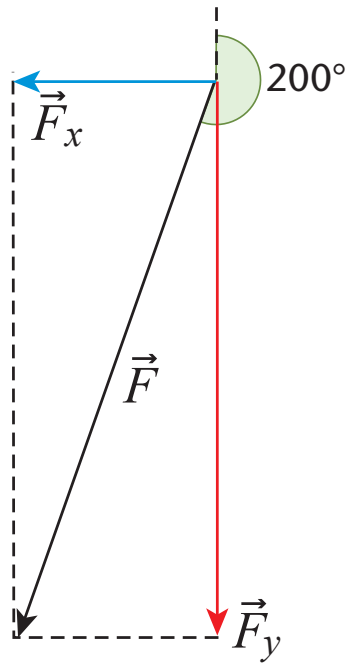
$$\vec{F}_y = 100 \sin 40^\circ$$

$$\vec{F}_y = 64,28 \text{ N upwards}$$

c) Looking at the free-body diagram



10. Since the resultant forces is zero, taking the direction up as positive, we get:



Measuring the lengths of $\vec{F}_x$ and $\vec{F}_y$ we obtain that $\vec{F}_x = 2,1$ cm and $\vec{F}_y = 5,6$ cm. Using the conversion factor, we get that:

$$\vec{F}_x = 52,5 \text{ N to the left}$$

$$\vec{F}_y = 140 \text{ N downwards}$$

Chapter 2 Magnetism

Experiment 1 Determining the north pole of the Earth using a bar magnet

Results

Magnet always come to rest in the same direction

Conclusion and discussion

1. The bar magnet always points towards the north pole of the earth.
2. Yes, magnets always come to rest in the same direction.
3. No, the other materials don't always come to rest in the same direction.

Practical investigation: Making a simple electromagnet

Observations – the pins or paper clips stick to the nail.

Conclusion – The results show that in general the more batteries you add to the electromagnets, the more weight it can hold. The more wire you wrap around the nail, the stronger your electromagnet will be.

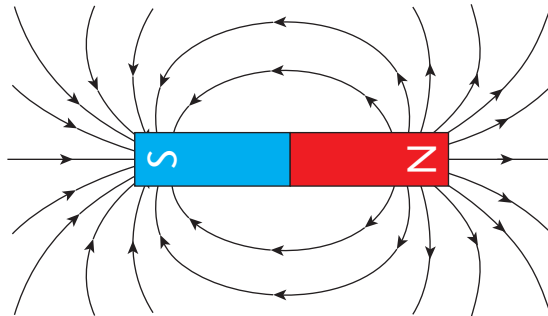
Activity 2.1

1. A magnet always has two poles, namely, the north and the south pole
2. The like poles of a magnet repel each other when brought closer to one another, whereas the unlike poles will attract one another when brought closer to each other.
3. The force of a magnet is strongest where the magnetic field lines are closest to one another.
4. A permanent magnet is one that retains its magnetic properties for a long period of time. A temporary magnet only maintains its magnetism while in the magnetic field produced by a permanent magnet or an electric current.
5. By coiling a thin coated copper wire around an and connected the ends of the wire to a battery (or a cell). To verify if the electromagnet works, it can be used to pick paper clips.
6. An electromagnet is a temporary magnet because it only retains its magnetic properties when it is within the magnetic field create by the electric current.
7. Differences between a bar magnet and an electromagnet:

Permanent magnet	Electromagnet
A permanent magnet is an object made from a material that is magnetized and creates its own persistent magnetic field	An electromagnet is made from a coil of wire which acts as a magnet when an electric current passes through it.
Permanent magnet strength depends upon the material used in its creation	The strength of an electromagnet can be adjusted by the amount of electric current allowed to flow into it

Similarities between a bar magnet and an electromagnet:

The two are similar in that while the electromagnet is magnetised it acts as a magnet in that it can attract magnetic materials, just like a bar magnet. And like a bar magnet, an electromagnet also has the north and the south poles.



Experiment 2 Magnetic field lines

Results

Redraw your magnetic field map here

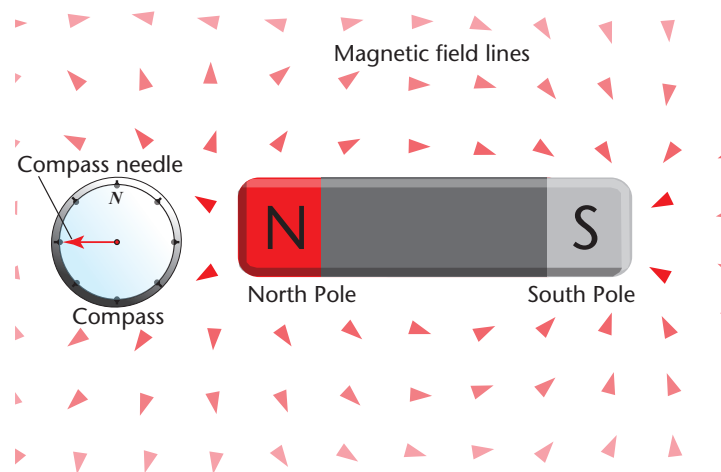


Image adapted from Phet simulations

Discussion and conclusion

The field lines should be somewhat symmetric and balanced and never cross. Magnetic field lines move from north to south pole.

Questions?

1. Yes, the lines are more concentrated in some areas than in others.
2. The relative strength is high.
3. If two field lines crossed, then that is saying that the magnetic field points in two different directions, at one place. There's only one direction to the magnetic field at any place at any time, which is north to south pole, so this doesn't happen.

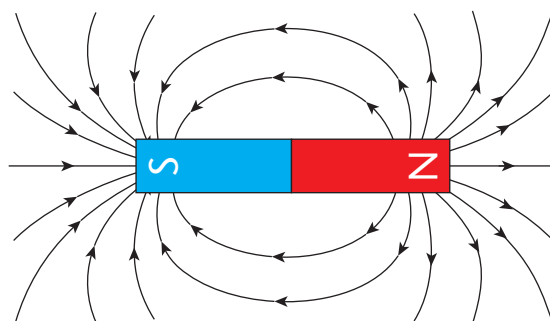
Review exercise

Multiple choice questions

1. D
2. D
3. E
4. B
5. B
6. E

Long questions

7. A magnet is a piece of metal that pulls other magnetic metal objects towards it.
8. A magnetic field is the region of space within which the magnetic materials will experience the magnetic force.
9. Permanent magnets have regions, called domains, which have a magnetic field aligned in a certain direction. These regions give rise to a magnetic field by aligning themselves towards the same direction when magnetised by another magnet, or an electric current.
10. Ferromagnetic materials include iron, nickel and cobalt.
11. When a magnet is cut into two pieces two new magnets will be formed. The cut out end of one magnet will be a new south pole, while the other cut out end will be the new north pole. The old poles will be retained as they in the old, uncut, magnet.
12. The like poles of a magnet will repel each when brought closer to one another.
13. The opposite poles of a magnet will attract one another when brought closer to one another.
14. Magnetic field lines have the following properties:
 - » The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line
 - » The strength of the field is proportional to the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines (called the areal density).
 - » Magnetic field lines can never cross, meaning that the field is unique at any point in space.
 - » Magnetic field lines are continuous, forming closed loops without beginning or end. They go from the north pole to the south pole.
15. Magnetic field of a bar magnet:



16. The needle of a compass when placed in a magnetic field will point away from the north pole, and towards the south pole.
17. The Earth's magnetic field is similar to that of a bar magnet tilted 11 degrees from the spin axis of the Earth. The north pole of a compass needle is a magnetic north pole. It is attracted to the geographic North Pole, which is a magnetic south pole (opposite magnetic poles attract).
18. A compass is always attracted towards the south pole of a magnet. Oppositely, it is attracted to the earth's north pole. So the geographic north pole is actually a magnetic south pole.
19. Aurora, solar winds
20. Earth's magnetic field

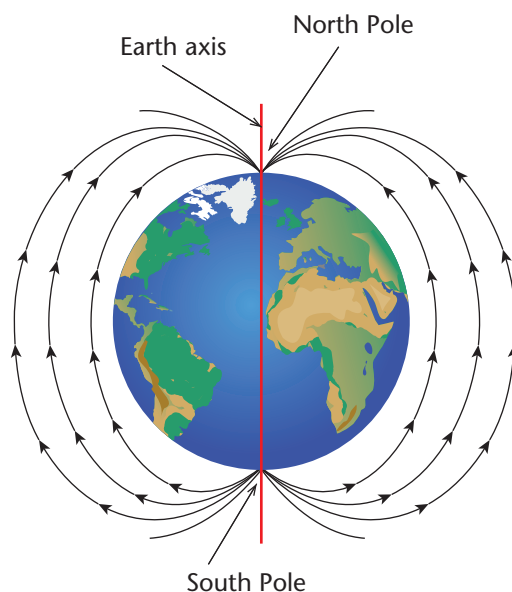


Image adapted from: Easy Science for Kids. <http://easyscienceforkids.com/all-about-earths-magnetism/> 09 September 2016

21. Compare the geographic North Pole with the magnetic north pole.
22. Explain the difference between the geographical North pole and the magnetic North pole of the Earth.
23. Discuss qualitatively how the Earth's magnetic field provides protection from solar winds.

Chapter 3 Waves and sound

Practical investigation Demonstrate a single vibration in different media

1. The pattern produced in the water by the coin is circular.
2. The energy comes from the gravitational potential energy of the stones.
3. An object that moves downwards has a lot of energy when it hits the water. The energy from its downward motion changes when it hits the water and turns in part into energy that pushes outward from the center where the object has landed. The energy from the object moves out equally in all directions. As the energy moves out from the object, it makes little waves. These waves are called ripples. Since the energy moves out equally in all directions, the ripples are always in a circle.

Practical investigation Generate a longitudinal wave in a slinky or spring

1. A pulse is a single disturbance in a medium.
2. The pulse moves forward.
3. The particle in the medium moves back and forth.
4. The particles move parallel to the particles of the medium.
5. A series of repeating or periodic disturbances that move through a medium from one location to another is called waves.

Activity 3.1

1. A medical imaging device produces ultrasound by oscillating with a period of 0,400 ms. What is the frequency of this oscillation?
2. The frequency of middle D on a typical musical instrument is 294 Hz. What is the time for one complete oscillation?
3. Identify an event in your life (such as receiving a monthly salary) that occurs regularly. Identify both the period and frequency of this event.

Activity 3.2 The relationship between speed, frequency, period and wavelength

1.
 - a) wave speed – is a distance travelled by a wave in one second
 - b) frequency – is the number of waves passing a point per second
 - c) period – is the time taken to complete one wave.
 - d) wave velocity – is a wave speed in a particular direction
2.
 - a) $c = f\lambda$
 $340 = f \times 0,77$
 $f = 441,56 \text{ Hz}$
 - b) $T = \frac{1}{f}$
 $T = \frac{1}{221,56}$
 $T = 2,26 \times 10^{-3} \text{ s}$

Practical activity (Project) **How to make a string telephone (project)**

Questions

1. If the string hangs loose, you can hardly hear your friend.
2. If you pinch the string, you stop the movement of particle and your friend will not hear you.
3. If you connect three or four string telephones together you can hardly hear your friend.

Conclusion

The phone works best when the string is tight, in line, and free of contact with any other object.

Formal Experiment **Determining the difference between pitch and loudness using an oscilloscope**

Conclusion

Frequency is directly proportional to the pitch.

Amplitude is directly proportional to the loudness.

Activity 3.3 **Transversal waves**

- a) Transverse pulse is a pulse in which the particles of the medium vibrate at right angles to the direction of propagation of the pulse.
- b) Points that are in phase move exactly at the same time in the same direction.
- c) B and C; G and H; C and D; F and G
- d) B and C; G and H; C and D; F and G
- e) Rest position/ position of rest/ equilibrium line
- f) amplitude = 1 cm
- g) $T = \frac{1}{f}$, but $f = \frac{3}{0,3} = 10 \text{ Hz}$

$$\therefore T = \frac{1}{10} = 0,1 \text{ s}$$

OR

$$T = \frac{\text{time}}{\text{number of waves}} = \frac{0,3}{3} = 0,1 \text{ s}$$

h) $f = \frac{\text{number of waves}}{\text{time}}$

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

$$f = 10 \text{ Hz}$$

i) $\lambda = \frac{\text{distance AE}}{\text{number of waves}} = \frac{120}{3} = 40 \text{ cm}$
 $v = f \times \lambda = 10 \times 40 = 400 \text{ m.s}^{-1}$

Practical demonstration **Make a pulse on s string and on a rope**

Questions

1. The coloured string moves back and forth as the pulse passes.
2. The particles of the medium move back and forth as the longitudinal wave propagates through the slinky spring

Activity 3.4 Calculations involving the wave equation

1. Using the wave equation

a) $v = f \times \lambda$

$$345 = f \times 25$$

$$\therefore f = \frac{345}{25} = 13,8 \text{ Hz}$$

b) $v = f \times \lambda$

$$345 = 790 \times \lambda$$

$$\therefore \lambda = \frac{345}{790} = 0,44 \text{ m}$$

c) $v = f \times \lambda$

$$v = 3 \times 10 = 30 \text{ m}\cdot\text{s}^{-1}$$

d) $v = f \times \lambda$

$$100 = 3 \times \lambda$$

$$\lambda = \frac{100}{3} = 33,33 \text{ m}$$

e) $v = f \times \lambda$

$$v = 345 \times 1 = 345 \text{ Hz}$$

2. $v = f \times \lambda$

$$300\,000\,000 = 97\,100\,000 \times \lambda$$

$$\therefore \lambda = \frac{300\,000\,000}{97\,100\,000} = 3,09 \text{ m}$$

3. Assuming the speed of the air in whistle to be, then we can calculate the wavelength.

$$v = f \times \lambda$$

$$343 = 320 \times \lambda$$

$$\lambda = \frac{343}{320} = 1,49 \text{ m}$$

We have been told that the length of the whistle must be exactly $\frac{1}{4}$ of the wavelength.

$$\therefore \text{length} = \frac{1}{4} \times 1,49 \text{ m} = 0,37 \text{ m}$$

4. C_4 note:

$$v = f \times \lambda$$

$$343 = 261,6 \times \lambda$$

$$\therefore \lambda = \frac{343}{261,6} = 1,31 \text{ m}$$

D_4 note:

$$\lambda = \frac{343}{293,6} = 1,17 \text{ m}$$

E_4 note:

$$\lambda = \frac{343}{323,6} = 1,06 \text{ m}$$

F_4 note:

$$\lambda = \frac{343}{349,2} = 0,98 \text{ m}$$

G_4 note:

$$\lambda = \frac{343}{392} = 0.875 \text{ m}$$

A_4 note:

$$\lambda = \frac{343}{440} = 0.78 \text{ m}$$

B_4 note:

$$\lambda = \frac{343}{493.9} = 0.69 \text{ m}$$

C_5 note:

$$\lambda = \frac{343}{523.2} = 0.66 \text{ m}$$

Practical activity Interference of pulses

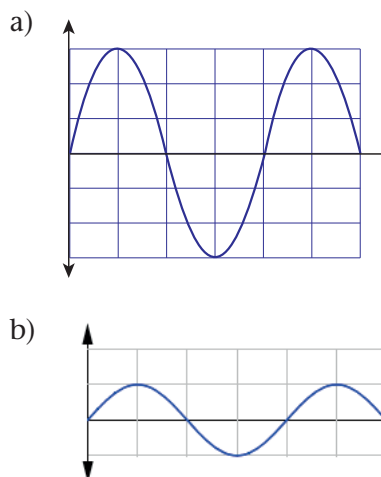
- In the situation of figure a, the displacements of the two pulses are in **out of phase** directions. When the two pulses meet, there is a large / **small** / no displacement of the medium. It seems that when the two pulses meet we can find the total displacement by **subtracting** (fill in: the right mathematical operation) the displacements of the individual pulses.
- In the situation of figure b, the displacements of the two pulses are in the **in phase** direction. When the two pulses meet, there is a **large** / small / no displacement. It seems that when the two pulses meet, we can find the total displacement by **adding** (fill in: the correct mathematical operation) the displacements of the individual pulses.

Activity 3.5 The ripple tank experiment

- To be recorded as observed during performing the experiment.
- To be recorded as observed during performing the experiment.
- Because of the waves overlapping one another. The type of interference responsible for this is the destructive interference.
- When the crest of one pulse coincides with a trough of another pulse, it results in the **destruction** of the pulse as they move over each other. If the pulses are of equal amplitude, the result will be _____ at that point. We call this **destructive** interference.

When the trough of one pulse coincides with the trough of another, it results in a **bigger** trough. This is visible on the paper as a region of lighter bands. This is known as **constructive** interference

Activity 3.6 Superposition of waves



- c) In the top example, **constructive** interference produces a **louder** sound.
- d) In the bottom example, destructive interference produces a **softer** sound

Activity 3.7

1. Define echo and mention its application.
2. A SONAR receives a strong echo of ultrasonic signal it sent downwards into the sea 3,6 seconds after the transmission. Calculate the depth of the sea-bed if the speed of the ultrasonic waves in sea-water is $1\,250\text{ m}\cdot\text{s}^{-1}$.

$$\text{speed (v)} = \frac{\text{distance travelled } (\Delta x)}{\text{time travelled } (\Delta t)}$$

Note that we have been given the total time (to and fro), so to determine the depth of the sea we only use half the time (i.e. $\frac{3,6}{2} = 1,8\text{ s}$).

$$\therefore 1250 = \frac{\text{depth of the sea}}{1,8}$$

$$\therefore \text{depth of the sea} = 2250\text{ m}$$

3.
 - a) pitch
 - b) frequency
 - c) loudness
4. You hook up a stereo system. When you test the system, you notice that in one corner of the room, the sounds seem dull. In another area, the sounds seem excessively loud. Describe how the sound moving about the room could have resulted in this.
5. You observe two musical instruments that you cannot identify. One plays high-pitched sounds and the other plays low-pitched sounds.
How could you determine which is which without hearing either of them play?
6. Imagine that you observe two fireworks displays. You hear the explosion of one as soon as you see it. However, you see the other display several milliseconds before you hear the explosion. Explain why this is so.

Review exercise

Multiple choice questions

1. A
2. C
3. A
4. C
5. A
6. B
7. D
8. D
9. A
10. B

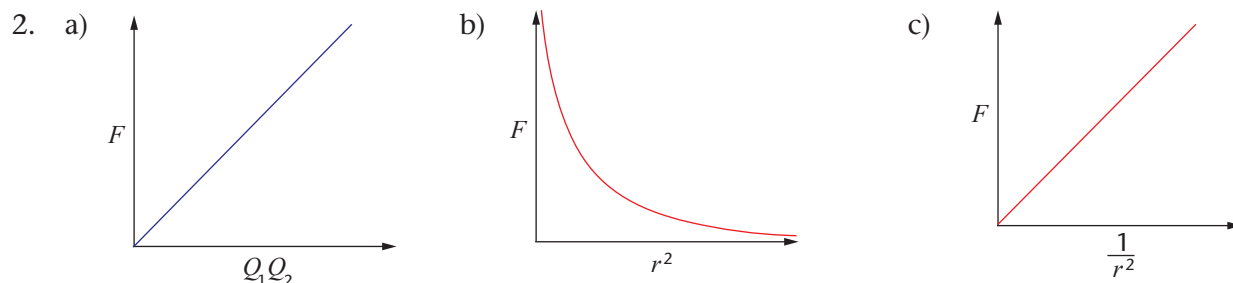
Long questions

11. There are no atoms to vibrate to carry the sound waves. It needs a medium to travel through.
12. The speed of a sound wave depends on what type of medium it is traveling through, and if that medium is a gas or liquid, a significant change in temperature can also affect its speed. It does not depend on the frequency or wavelength of the sound wave.
13. Bats: higher frequency means shorter wavelength.
14. With headphones and louder personal mp3 players our ears are generally more stressed than they used to be.
15. No change in speed – speed is determined by the material through which the wave travels, not its frequency. The wavelength will decrease by a factor of 2.
16. $v = f \times \lambda$
 $v = 0,100 \times 15$
 $v = 0,15 \text{ m}\cdot\text{s}^{-1}$
17. $v = f \times \lambda$
 $v = 94\,500\,000 \times 3,17$
 $v = 3,00 \times 10^8 \text{ m}\cdot\text{s}^{-1}$
18. $v = f \times \lambda$
 $343 = 20 \times \lambda$
 $\lambda = \frac{343}{20} = 17.15 \text{ m}$
 $\lambda = \frac{343}{20\,000} = 0.01715 \text{ m} = 17.15 \text{ m}$

Chapter 4 Electrostatics Solutions-part 1

Activity 4.1: Application of Coulomb's Law

- Coulomb's law states that the magnitude of the electrostatic force that a charged particle exert on another charged particle is directly proportional to the product of the two charges, and inversely proportional to the square of the distance between them.



$$3. \text{ a) } F = \frac{kQ_1Q_2}{r^2}$$

$$F_{\text{new}} = \frac{k(2Q_AQ_B)}{(2r)^2}$$

$$F_{\text{new}} = \frac{2kQ_AQ_B}{4r^2}$$

$$F_{\text{new}} = \frac{1}{2} \left(\frac{kQ_AQ_B}{r^2} \right)$$

$$\therefore F_{\text{new}} = \frac{1}{2}F$$

Hence the new force will be decreased by the factor of 2

$$\text{b) } F_{\text{new}} = \frac{k2Q_AQ_B}{r^2}$$

$$F_{\text{new}} = 4 \left(\frac{kQ_AQ_B}{r^2} \right)$$

$$\therefore F_{\text{new}} = 4F$$

Therefore, doubling the charges on the two spheres increases the force by the factor of 4.

$$\text{c) } F_{\text{new}} = \frac{kQ_AQ_B}{r^2}$$

$$F_{\text{new}} = \frac{kQ_AQ_B}{\left(\frac{1}{3}r\right)^2}$$

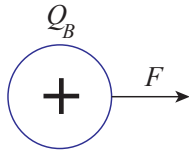
$$F_{\text{new}} = \frac{kQ_AQ_B}{\frac{1}{9}r^2}$$

$$F_{\text{new}} = 9 \left(\frac{kQ_AQ_B}{r^2} \right)$$

$$\therefore F_{\text{new}} = 9F$$

Decreasing the distance by the factor of 3, increases the force by the factor of 9.

4. a) The charges are like, both positively charged, and by the very nature they repel each other. So, Q_B will be pushed away from Q_A by force F .



- b) Like charges will repel each other, as depicted in the force diagram in (a) above.
 c) The force the charges exert on each other is equal in magnitude. The force depends on the product of the charges, as well as the distance between the charges

$$\begin{aligned} \text{d) } F &= \frac{kQ_A Q_B}{r^2} \\ F &= \frac{(9 \times 10^9)(2,6 \times 10^{-6})(3,2 \times 10^{-6})}{(0,05)^2} \\ F &= 29,952 \text{ N} \end{aligned}$$

$$\begin{aligned} 5. \text{ a) } F &= \frac{kQ_m Q_n}{r^2} \\ F &= \frac{(9 \times 10^9)(2,5 \times 10^{-6})(3,5 \times 10^{-6})}{(0,045)^2} \\ F &= 38,89 \text{ N} \end{aligned}$$

- b) Doubling the distance will result in the new force being:

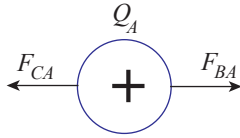
$$\begin{aligned} F &= \frac{kQ_m Q_n}{(2r)^2} \\ F &= \frac{kQ_m Q_n}{4r^2} \\ \therefore F &= \frac{1}{4}F \\ F_{\text{new}} &= \frac{1}{4}(38,89 \text{ N}) \\ F_{\text{new}} &= 9,72 \text{ N} \end{aligned}$$

6. The spheres are carrying equal charges. Therefore, we have $Q_1 = Q_2 = Q$:

$$\begin{aligned} F &= \frac{kQ_1 Q_2}{r^2} \\ F &= \frac{kQ^2}{r^2} \\ 3,6 \times 10^{-4} &= \frac{9 \times 10^9 Q^2}{(0,04)^2} \\ Q^2 &= 6,4 \times 10^{-17} \\ \therefore Q &= 8 \times 10^{-9} \text{ C or } Q = 8 \text{ nC} \end{aligned}$$

7. a) There are three charges in the system. Each will experience a force due to the two charges within its vicinity
 (i) Two Forces
 (ii) Two Forces
 (iii) Two Forces

- b) Sphere A will experience the attractive force due to sphere B, and the repulsive force due to the sphere C. The following is the force diagram, showing the forces acting on sphere A:



$$F_{BA} = \frac{kQ_A Q_B}{r^2}$$

$$F_{BA} = \frac{(9 \times 10^9)(3 \times 10^{-6})(5 \times 10^{-6})}{(0,12)^2}$$

$$F_{BA} = 9,375 \text{ N}$$

$$F_{CA} = \frac{kQ_A Q_C}{r^2}$$

$$F_{CA} = \frac{(9 \times 10^9)(3 \times 10^{-6})(2 \times 10^{-6})}{(0,07 + 0,12)^2}$$

$$F_{CA} = 1,50 \text{ N}$$

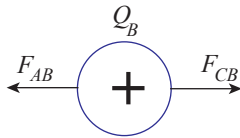
Take the direction to the right as positive:

$$\vec{F}_{\text{net}} = 9,375 \text{ N} - 1,50 \text{ N}$$

$$\vec{F}_{\text{net}} = +7,875$$

$$\therefore \vec{F}_{\text{net}} = 7,875 \text{ N to the right}$$

c)



$$F_{BA} = \frac{kQ_A Q_B}{r^2}$$

$$F_{BA} = \frac{(9 \times 10^9)(3 \times 10^{-6})(5 \times 10^{-6})}{(0,12)^2}$$

$$F_{BA} = 9,375 \text{ N}$$

$$F_{CB} = \frac{kQ_B Q_C}{r^2}$$

$$F_{CB} = \frac{(9 \times 10^9)(5 \times 10^{-6})(2 \times 10^{-6})}{(0,07)^2}$$

$$F_{CB} = 18,39 \text{ N}$$

Let the direction to the right be positive

$$\vec{F}_{\text{net}} = \vec{F}_{BA} + \vec{F}_{CA}$$

$$\vec{F}_{\text{net}} = 17,367 \text{ N} + (-9,375 \text{ N})$$

$$\vec{F}_{\text{net}} = +8,992$$

$$\therefore \vec{F}_{\text{net}} = 8,992 \text{ N to the right}$$

8. a) Identical spheres will equally share their when brought into contact. So the new charge will be:

$$Q_{\text{new}} = \frac{Q_{\text{total}}}{2}$$

$$Q_{\text{new}} = \frac{+4,8 \times 10^{-9} \text{ C} + (-3,2 \times 10^{-9} \text{ C})}{2}$$

$$Q_{\text{new}} = +8,0 \times 10^{-10} \text{ C}$$

b) $F = \frac{k Q_A Q_B}{r^2}$

$$F = \frac{(9 \times 10^9)(8,0 \times 10^{-10})(8,0 \times 10^{-10})}{(0,05)^2}$$

$$F = 2,304 \times 10^{-6} \text{ N}$$

Activity 4.2: Calculating the electric field strength

1. a) Electric field is a region of space in which an electric charge experiences a force.
b) The electric field strength at a point is defined as the magnitude of the force experienced by a Coulomb of charge, divided by the charge.

2. a) $E = \frac{F}{Q}$

$$E = \frac{4 \times 10^{-6}}{5 \times 10^{-9}}$$

$$E = 800 \text{ N} \cdot \text{C}^{-1}$$

- b) The charge of an electron is $Q_e = 1,6 \times 10^{-19} \text{ C}$.
The force experienced by an electron due to the field will be:

$$F = QE$$

$$F = 1,6 \times 10^{-19} \times 800$$

$$F = 1,28 \times 10^{-16} \text{ N}$$

3. The charge of an alpha particle is: $Q_\alpha = 2 \times 1,6 \times 10^{-19} = 3,2 \times 10^{-19} \text{ C}$

The force that an alpha particle will experience due to the given field, assumed to uniform, and the alpha particle assumed to be behaving like a point charge:

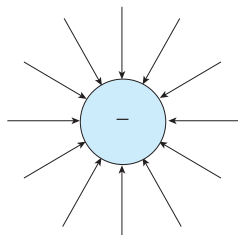
$$F = QE$$

$$F = (300)(3,2 \times 10^{-19})$$

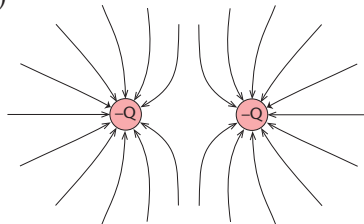
$$F = 9,6 \times 10^{-17} \text{ N}$$

Activity 3: Application of Electric Field Strength

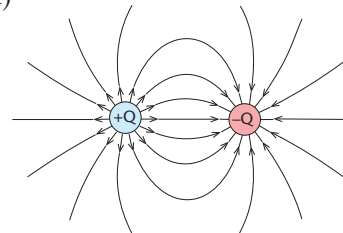
1. a)

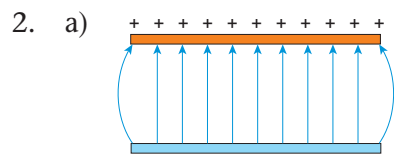


- b)



- c)





b) $E = \frac{V}{d}$

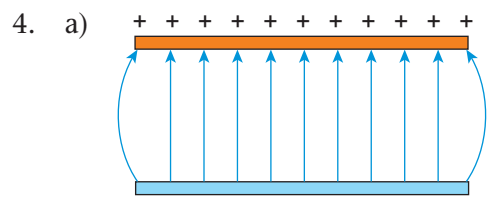
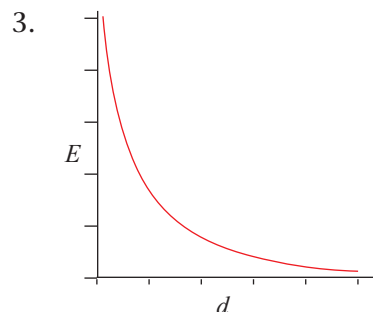
$$E = \frac{15}{0,02}$$

$$E = 750 \text{ N} \cdot \text{C}^{-1}$$

- c) Since the electric field between two parallel plates is inversely proportional to the distance between the plates, doubling the distance will half the electric field of the two plates.

$$E_{\text{new}} = \frac{1}{2} \times 750 \text{ N} \cdot \text{C}^{-1}$$

$$E_{\text{new}} = 375 \text{ N} \cdot \text{C}^{-1}$$



b) $E = \frac{V}{d}$

$$E = \frac{1\,000}{(3,2 \times 10^{-2})}$$

$$E = 3,125 \times 10^4 \text{ N} \cdot \text{C}^{-1}$$

- c) (i) The charge is positively charged. It is being pushed away from the positive terminal of the parallel plates, while simultaneously attracted to terminal A.

(ii) $F = QE$

$$F = (3,2 \times 10^{-12}) (3,125 \times 10^4)$$

$$F = 1,00 \times 10^{-7} \text{ N}$$

Activity 4.4 Electric circuits

1. A circuit will only work if it is complete. This means that it must make a complete loop, otherwise the electrical energy be transferred. A circuit is a path that allows charges to pass through it. The conventional direction of the electric current is from the positive terminal to the negative terminal.

- When the switch is closed a path for electrons to flow is created. The battery, which stores chemical energy, acts as the 'electron-pump', converts the chemical energy to electrical energy. The evidence of this is the light given off by the bulb. The electron pressure will start to accumulate at the negative terminal. As a result; they will start to flow towards the positive terminal through the wires. By convention, the electrical current flows from the positive terminal through to the negative terminal



EXPERIMENT 10

Variables

Independent: current

Dependent: Potential difference (voltage)

Results

Trial No.	Ammeter reading (A)	Voltmeter reading (V)
1	0,02	6
2	0,04	12
3	0,06	18
4	0,08	24
5	0,10	30

Graph of potential difference versus current

The graph is a straight line, which is a graph of a linear function with the following linear equation:

$$y = mx + c$$

Making

$$y = \Delta V$$

$$x = \Delta I$$

Extrapolating we get $c = 0$

$$m = \text{gradient} = \frac{\Delta V}{\Delta I}$$

The gradient of the graph represent the resistance of the resistor

Calculating gradient (slope) of the graph:

$$\text{gradient} = \frac{\Delta V}{\Delta I}$$

$$\text{gradient} = \frac{30 - 6}{0,10 - 0,02} = \frac{24}{0,08}$$

$$\text{gradient} = 300$$

Therefore, the resistance of the resistor is $R = 300 \Omega$

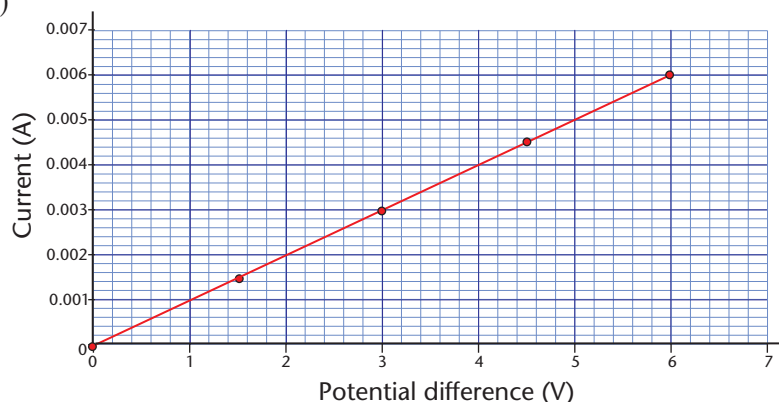
Conclusion

The graph is a straight line that extends through the origin. Therefore, the potential difference across a resistor is directly proportional to strength of the electric current through it, provided that the temperature remains constant (resistance is constant).

$$\text{Hence } R = \frac{\Delta V}{\Delta I} = \text{constant}$$

Activity 4.5 Ohms Law

1. a)



b) The gradient of the graph is $m = \text{gradient} = \frac{\Delta V}{\Delta I} = \frac{1}{R}$. Therefore, the resistance will be the reciprocal of the gradient of the graph

$$\text{c) } m = \frac{I_2 - I_1}{V_2 - V_1}$$

$$m = \frac{1,5 - 0,375}{12 - 3}$$

$$m = \frac{1,125}{9}$$

$$\therefore R = \frac{1}{m}$$

$$R = \frac{9}{1,125}$$

$$R = 8\Omega$$

d) The graph is a straight line that extends through the origin. Therefore, the current is directly proportional to the voltage.

$$2. \quad R = \frac{V}{I}$$

$$R = \frac{3}{0,4}$$

$$R = 7,5\Omega$$

$$3. \quad \text{a) } R = \frac{V}{I}$$

$$10 = \frac{V}{0,4}$$

$$V = 2,1 \text{ V}$$

$$\begin{aligned}
 \text{b) } Q &= I\Delta t \\
 Q &= (0,21)(10) \\
 Q &= 2,1 \text{ C} \\
 V &= \frac{W}{Q} \\
 2,1 &= \frac{W}{2,1} \\
 W &= (2,1)(2,1) \\
 W &= 4,41 \text{ J}
 \end{aligned}$$

$$\begin{aligned}
 4. \text{ a) } I &= \frac{V}{R} \\
 I &= \frac{4,5}{15} \\
 I &= 0,3 \text{ A}
 \end{aligned}$$

$$\begin{aligned}
 \text{b) } V &= IR \\
 V &= (3)(12) \\
 V &= 36 \text{ V}
 \end{aligned}$$

$$\begin{aligned}
 \text{c) } R &= \frac{V}{I} \\
 R &= \frac{9}{0,5} \\
 R &= 18\Omega
 \end{aligned}$$

$$\begin{aligned}
 \text{d) } V &= IR \\
 V &= (2,5)(3) \\
 V &= 7,5 \text{ V}
 \end{aligned}$$

$$\begin{aligned}
 \text{e) } I &= \frac{V}{R} \\
 I &= \frac{220}{80} \\
 I &= 2,75 \text{ A}
 \end{aligned}$$

Activity 4.6 Series and parallel combination

1. a) R_1 and R_2 are connected in parallel.

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_{12} = \frac{(3)(6)}{3+6}$$

$$R_{12} = \frac{18}{9}$$

$$R_{12} = 2\Omega$$

$$\therefore R_{\text{total}} = R_{12} + R_3$$

$$R_{\text{total}} = 2\Omega + 2\Omega$$

$$R_{\text{total}} = 4\Omega$$

- b) The ammeter A_1 measures the total current of the circuit.

$$I_{\text{total}} = \frac{V}{R_{\text{total}}}$$

$$I_{\text{total}} = \frac{12}{4}$$

$$I_{\text{total}} = 3 \text{ A}$$

- c) The voltmeter V_2 measures the potential difference across resistor R_3 . Through that resistor flows the total current of the circuit.

$$\therefore V_2 = I_{\text{total}} R_3$$

$$V_2 = (3)(2)$$

$$V_2 = 6 \text{ V}$$

- d) The reading on the voltmeter V_1 will be:

$$V_1 = V - V_2$$

$$V_1 = 12 \text{ V} - 6 \text{ V}$$

$$V_1 = 6 \text{ V}$$

This reading will be the same across both the resistors connected in parallel, that is R_1 and R_2 .

Therefore, the current flowing through the resistor R_2 will be:

$$I_2 = \frac{V_1}{R_2}$$

$$I_2 = \frac{6}{6}$$

$$I_2 = 1 \text{ A}$$

- e) Decrease.

If R_1 burns out, the total resistance of the circuit will decrease. According to Ohm's Law, the current flowing in the circuit is inversely proportional to the resistance of the circuit. Therefore, the total current, measured by the ammeter A_1 will decrease.

2. a) The potential difference across the resistor R_1 is:

$$V_1 = I_1 R_1$$

$$V_1 = (0,5)(5)$$

$$V_1 = 2,5 \text{ V}$$

- b) The series combination of the resistors R_1 and R_2 is connected in parallel to the resistor R_3 . The current flowing through the resistor R_1 is the same as the current flowing through the resistor R_2 , and is calculated as follows:

$$I_1 + I_3 = I_{\text{total}}$$

$$I_1 + 1,5 \text{ A} = 2 \text{ A}$$

$$I_1 = 0,5 \text{ A}$$

- c) $I_2 = I_1 = 0,5 \text{ A}$

- d) The resistance of the resistor R_2 is:

$$R_2 = \frac{V_2}{I_2}$$

$$R_2 = \frac{3,5}{0,5}$$

$$R_2 = 7\Omega$$

- e) The potential difference across the resistor R_3 is the same as the combined potential difference across the resistors R_1 and R_2 :

$$V_3 = V_1 + V_2$$

$$V_3 = 2,5 \text{ V} + 3,5 \text{ V}$$

$$V_3 = 6 \text{ V}$$

- f) The resistance of the resistor R_3 is:

$$R_3 = \frac{V_3}{I_3}$$

$$R_3 = \frac{6}{1,5}$$

$$R_3 = 4\Omega$$

- g) The resistors R_4 and R_5 are connected in parallel. We now the current flowing through the resistor R_5 , we can calculate the current flowing through the resistor R_4 :

$$I_{\text{total}} = I_4 + I_5$$

$$2 \text{ A} = I_4 + 1 \text{ A}$$

$$\therefore I_4 = 1 \text{ A}$$

- h) The resistance of the resistor R_4 will be:

$$R_4 = \frac{V_4}{I_4}$$

$$R_4 = \frac{4}{1}$$

$$R_4 = 4\Omega$$

- i) The potential difference across the resistor R_5 will be the same as that across the resistor R_4 , the resistors are connected in parallel.

$$\therefore V_5 = 4 \text{ V}$$

- j) The resistance of the resistor R_5 will be same as that of the resistor R_4 , because the two resistors are equally sharing their current and are connected in parallel:

$$\therefore R_5 = R_4 = 4\Omega$$

- k) The potential difference across the resistor R_6 is:

$$V_6 = I_6 R_6$$

$$V_6 = (2)(2)$$

$$V_6 = 4 \text{ V}$$

- l) The current flowing through the resistor R_6 is the total current of the circuit.

$$\therefore I_6 = 2 \text{ A}$$

- m) The emf of the battery, which is the total potential difference of the circuit will be:

$$V_T = V_5 + V_6 + V_3$$

$$V_T = 4 \text{ V} + 4 \text{ V} + 6 \text{ V}$$

$$V_T = 14 \text{ V}$$

n) The effective resistance of the circuit will be:

$$R_T = \frac{V_T}{I_T}$$

$$R_T = \frac{14}{2}$$

$$R_T = 7\Omega$$

Activity 4.7 Ohmic and non-Ohmic conductors

1.
 - a) Ohm's law states that the current flowing through the conductor is directly proportional to the potential difference across the ends of the conductor, given that the temperature of the conductor stays constant.
 - b) An ohmic conductor is the conductor that obeys Ohm's law in all aspects.
 - c) Potential difference is the work done (or energy transferred) per unit charge
 - d) Electric current is the rate at which charges flow in the circuit
 - e) Resistance is the opposition to the flow of charges in the electric circuit
2. ohmic conductors: Copper, Nichrome, platinum, graphite
Non-ohmic conductors: acid battery, semiconductors, ionized gases, vacuum tubes

Review activity

Multiple Choice Questions

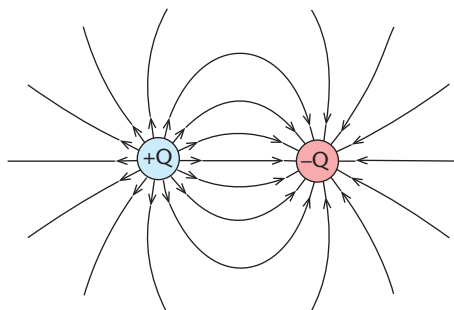
1. D 2. B 3. D

Long Questions

4.
$$F = \frac{kQ_1Q_2}{r^2}$$
$$F = \frac{(9 \times 10^9)(3 \times 10^{-9})(5 \times 10^{-9})}{(0,4)^2}$$
$$F = 8,44 \times 10^{-7} \text{ N}$$

5. a) Coulomb's law states that the electrostatic force between two charged objects is directly proportional to the product of the charges, and inversely proportional to the square of the distance separating the two charges.

b)



c) $F = \frac{kQ_1Q_2}{r^2}$

$$F = \frac{(9 \times 10^9)(6 \times 10^{-9})(1,10 \times 10^{-8})}{(0,02)^2}$$

$$F = 1,35 \times 10^{-3} \text{ N}$$

d) During this physical process, the two spheres will equally share their total charge, such the new charge on each sphere will be:

$$Q_{\text{new}} = \frac{Q_1 + Q_2}{2}$$

$$Q_{\text{new}} = \frac{6 \times 10^{-9} + (-1,0 \times 10^{-8})}{2}$$

$$Q_{\text{new}} = -2 \times 10^{-9} \text{ C}$$

e) The new force after separating the two charges will then be:

$$F = \frac{kQ_{\text{new}}^2}{r^2}$$

$$F = \frac{(9 \times 10^9)(2 \times 10^{-9})^2}{(0,06)^2}$$

$$F = 1 \times 10^{-5} \text{ N}$$

6. a) $V = \frac{W}{Q}$

$$V = \frac{5\,000}{2,5 \times 10^{-6}}$$

$$V = 2 \times 10^9 \text{ V}$$

$$E = \frac{V}{d}$$

$$E = \frac{2 \times 10^9}{5 \times 10^{-3}}$$

$$E = 4,00 \times 10^{11} \text{ N} \cdot \text{C}^{-1}$$

b) $F = QE$

$$F = (1,6 \times 10^{-19})(4,00 \times 10^{11})$$

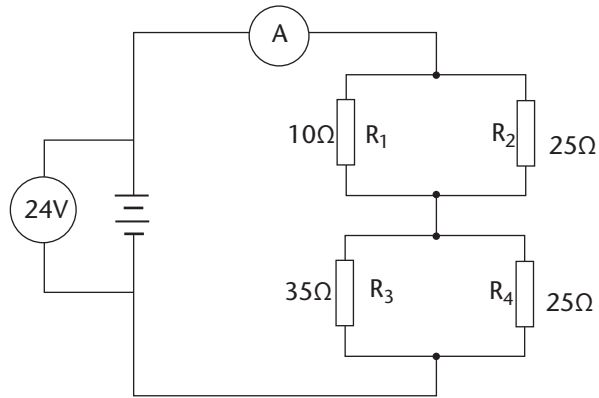
$$F = 6,4 \times 10^{-8} \text{ N}$$

7. $E = \frac{V}{d}$

$$E = \frac{300}{0,02}$$

$$E = 1,5 \times 10^4 \text{ N} \cdot \text{C}^{-1} \text{ from positive plate to negative plate.}$$

8.



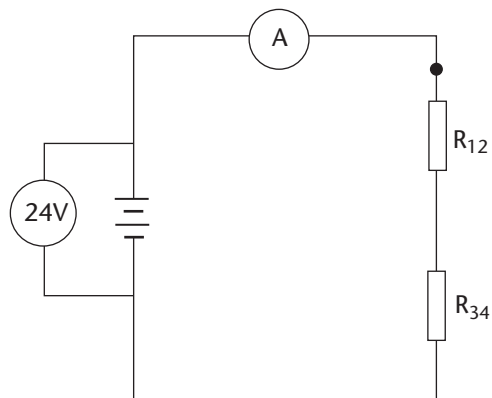
Note in the diagram above, we can combine R_1 and R_2 and treat them as one resistor whose effective resistance is given by:

$$R_{(12)} = \frac{R_1 R_2}{R_1 + R_2}$$

We can also do the same with R_3 and R_4 :

$$R_{(34)} = \frac{R_3 R_4}{R_3 + R_4}$$

Now the circuit looks like a simple series circuit with two resistors R_{12} and R_{34}



$$a) \quad R_{(12)} = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_{(12)} = \frac{25 \times 10}{25 + 10}$$

$$\therefore R_{(12)} = 7,14\Omega$$

$$R_{(34)} = \frac{R_3 R_4}{R_3 + R_4}$$

$$R_{(34)} = \frac{35 \times 20}{35 + 20}$$

$$\therefore R_{(34)} = 12,72\Omega$$

$$R_T = R_{(12)} + R_{(34)}$$

$$R_T = 7,14 + 12,72$$

$$\therefore R_T = 19,86\Omega$$

- b) To calculate the total current, we need to know what the total resistance of the circuit is, and also what is the total voltage supplied to the external circuit. In this case we know both the quantities. So:

$$I_T = \frac{V_T}{R_T}$$

$$I_T = \frac{24}{19,86}$$

$$\therefore I_T = 1,21 \text{ A}$$

- c) (i) For R_{12} , R_1 and R_2 the voltage is the same. If the current and the voltage that passes through either one of the 3 quantities are known, we can with ease calculate the voltage of the three (which has the same value). The current passing through R_{12} and R_{34} is the same as the total current, (resistors in series have the same current).

$$V_{12} = IR_{12}$$

$$V_{12} = (1,21)(7,14)$$

$$\therefore V_{12} = 8,63 \text{ V}$$

Now that we know the voltage of R_1 , we can easily calculate three flowing through R_1 .

$$I_1 = \frac{V_1}{R_1}$$

$$I_1 = \frac{8,63}{10}$$

$$\therefore I_1 = 0,86 \text{ A}$$

- (ii) V_{34} and V_{12} are in series. Therefore:

$$V_{34} + V_{12} = V_T \text{ and } I_{34} = I_{12} = I_T = 1,21 \text{ A}$$

$$V_{34} + 8,63 = 24$$

$$\therefore V_{34} = 15,37 \text{ V}$$

$$I_3 = \frac{V_3}{R_3}$$

$$I_3 = \frac{15,37}{25}$$

$$I_3 = 0,44 \text{ A}$$

Resistors R_3 and R_4 are connected in parallel to each other. Their voltages have the same value as V_{34} .

$$\therefore V_3 = 15,37 \text{ V}$$

Alternative solution

$$V_3 = I_{34} R_{34}$$

$$V_3 = (1,21)(12,72)$$

$$\therefore V_{34} = 15,39 \text{ V}$$

Resistors R_3 and R_4 are connected in parallel to each other. Their voltages have the same value as V_{34} .

$$\therefore V_3 = 15,39 \text{ V}$$

$$I_3 = \frac{V_3}{R_3}$$

$$I_3 = \frac{15,39}{35}$$

$$I_3 = 0,44 \text{ A}$$

(iii) We have already established that $V_1 = V_2 = V_{12}$

$$\therefore V_2 = 8,63 \text{ V}$$

And we also know that for resistors in parallel:

$$I_1 + I_2 = I_{12}$$

$$\therefore I_2 + 0,86 = 1,21$$

$$\therefore I_2 = 0,35 \text{ A}$$

Alternative solution

We have already established that:

$$V_1 = V_2 = V_{12}$$

$$\therefore V_2 = 8,63 \text{ V}$$

$$I_2 = \frac{V_2}{R_2}$$

$$I_2 = \frac{8,63}{25}$$

$$\therefore I_2 = 0,345 \text{ A}$$

(iv) We have already established that: $V_3 = V_4 = V_{34}$

$$\therefore V_4 = 15,37 \text{ V}$$

And we also know that for resistors in parallel:

$$I_3 + I_4 = I_{34}$$

$$\therefore I_4 + 0,44 = 1,21$$

$$\therefore I_4 = 0,77 \text{ A}$$

Alternative solution

We have already established that:

$$V_3 = V_4 = V_{34}$$

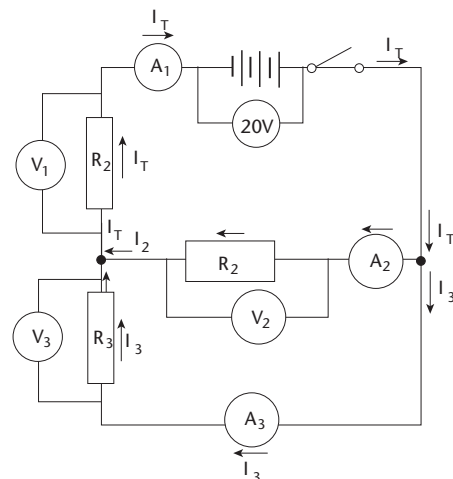
$$\therefore V_4 = 15,37 \text{ V}$$

$$I_4 = \frac{V_4}{R_4}$$

$$I_4 = \frac{15,39}{20}$$

$$\therefore I_4 = 0,77 \text{ A}$$

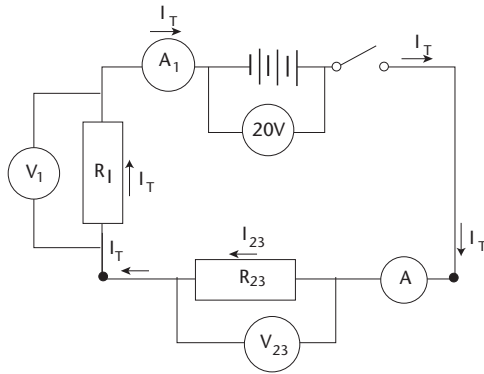
9. This question can best be understood by tracing the path of the electric current. Consider the diagram alongside:



We can see by following the arrows that the total current is divided at the junction, such that I_3 flows towards R_3 , and I_2 flows towards R_2 . At the second junction we see the currents diverting and combining again, such I_T flows through R_1 .

From this statement, it is evident that the resistors R_2 and R_3 are parallel to each other, at their junction the current divides. Therefore, we can combine R_2 and R_3 , and represent them with their effective resistance R_{23} . Obviously:

$$R_{23} = \frac{R_2 R_3}{R_2 + R_3}$$



Now that there is no junction, it should be clear that $I_{23} = I_T$. Since R_2 and R_3 are parallel to each other, it can be established that $V_2 = V_3 = V_{23}$.

$$a) \quad R_{23} = \frac{R_2 R_3}{R_2 + R_3}$$

$$R_{23} = \frac{10 \times 8}{10 + 8}$$

$$R_{23} = 4,44\Omega$$

$$\therefore R_T = R_{23} + R_1$$

$$R_T = 4,44 + 5$$

$$R_T = 9,44\Omega$$

b) The ammeter A_1 measures the total current flowing in the external circuit.

$$I_T = \frac{V_T}{R_T}$$

$$I_T = \frac{20}{9,44}$$

$$I_T = 2,12 \text{ A}$$

c) Across the end of the potential difference (voltage) is given by:

$$V_1 = IR_1$$

$$V_1 = (2,12)(5)$$

$$V_1 = 10,6\text{V}$$

d) We have already established that $V_2 = V_3 = V_{23}$

From the second diagram above, it is clear that $I_{23} = I_1 = I_T$

$$I_{23} \text{ and } I_1 \text{ are connected in series } \therefore V_{23} = IR_{23}$$

$$V_{23} = (2,12)(4,44)$$

$$V_{23} = 9,41 \text{ V}$$

$$\therefore V_2 = 9.41 \text{ V}$$

Alternative solution

$$V_{23} + V_1 = V_T$$

$$V_{23} + 10.6 = 20$$

$$\therefore V_{23} = 9.4 \text{ V}$$

- e) The ammeter A3 measures the current that flows through the resistor R3.

$$I_3 = \frac{V_3}{R_3}$$

$$I_3 = \frac{9.41}{8}$$

$$I_3 = 1.18 \text{ A}$$

- f) $V_3 = V_{23} = 9.41 \text{ V}$

- g) A₂ measures the current flowing through R₂.

$$I_2 = \frac{V_2}{R_2}$$

$$I_2 = \frac{9.41}{10}$$

$$I_2 = 0.941 \text{ A}$$

Alternative solution

Since R₂ and R₃ are in series, therefore:

$$I_2 + I_3 = I_T$$

$$I_2 + 1.18 = 2.12$$

$$I_2 = 0.94 \text{ A}$$

10. Brightness of a bulb is associated to the current strength flowing the bulb. The higher the current, the brighter the bulb

- a) The bulbs are identical and have the same current strength flowing through them. Their brightness will be the same. But, because of increased resistance, they will glow dimmer.

$$A = B = C$$

- b) The current is divided at the junction, such that, a certain portion goes toward C and the another portion towards A and B. But, since the resistance of the branch C, is higher than that of A and B, the current at C is higher that of A and B branch. Therefore, A and B will be dimmer, but have the same dimness, and B will be the brightest.

$$A = B, C$$

- c) All three bulbs are identical and connected parallel to each other. This reduces their effective resistance, thereby increasing the total current strength. The bulbs will equally share the current. Therefore, they will glow equally brighter, and very brighter, relative to the bulbs is 3.1.

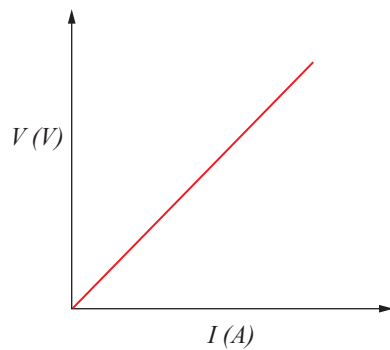
$$A = B = C$$

- d) The connection of the wire between the two bulbs means the bulbs are short-circuited. This is because electric current will take the route with the lower resistance, in this case the wire has a comparable lower resistance.

Therefore, the bulbs will not glow at all

10. Ohm's law states that the current flowing through the conductor is directly proportional to the potential difference across the ends of the conductor, given that the temperature of the conductor stays constant.

11.



12. The main difference between an ohmic and a non-ohmic conductor is whether they follow Ohm's law. An Ohmic conductor would have a linear relationship between the current and the voltage. With non-Ohmic conductors, the relationship is not linear.

More information; follow the link below:

<http://www.differencebetween.net/technology/difference-between-ohmic-and-non-ohmic-conductors/#ixzz489W82boh>

13. ohmic conductors: Copper, Nichrome, platinum, graphite

Non-ohmic conductors: acid battery, semiconductors, ionized gases, vacuum tubes

14. Length of the conductor

Thickness of the conductor

Temperature

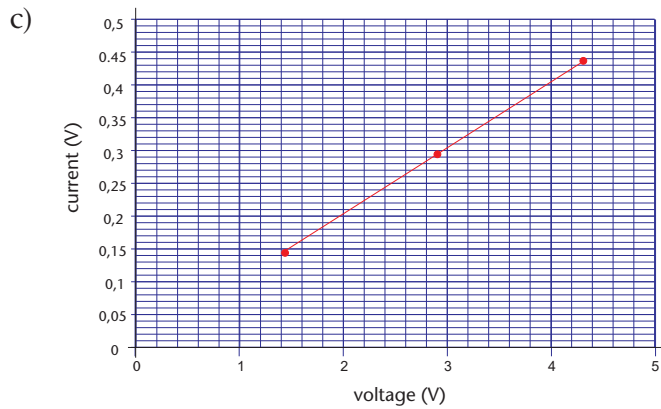
Nature of the material

15. a)

Number of Cells	V (V)	I (A)	$R = \frac{V}{I}(\Omega)$
1	1.44	0.14	$R = \frac{1,44}{0,14}$ $R = 10,3\Omega$
2	2.88	0.29	$9,9\Omega$
3	4.33	0.43	$10,1\Omega$

b) $R_{\text{avg}} = \frac{10,3 + 9,9 + 10,1}{3}$

$R_{\text{avg}} = 10,1\Omega$



d)

$$m = \frac{V_2 - V_1}{I_2 - I_1}$$

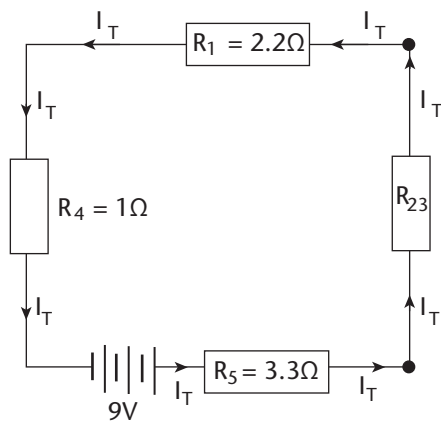
$$m = \frac{0,43 - 0,14}{4,33 - 1,44}$$

$$m = 0,100 \text{ A} \cdot \text{V}^{-1}$$

$$\therefore R = \frac{1}{m} = 10\Omega$$

e) The answers are approximately the same. Due to some experimental errors, they are not exactly the same.

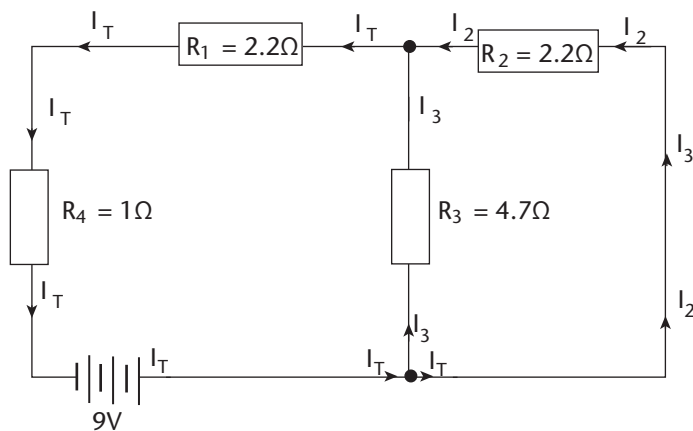
16. Where the current branches, that's where we find resistors connected in parallel. In our case that's R_2 and R_3 . Combining the two resistors gives us the following diagram:



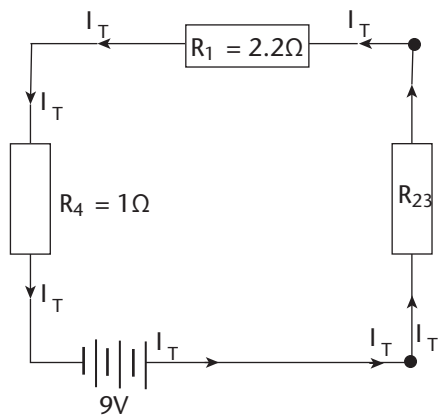
	V	I	R
R_1	$V_1 = I_1 R_1$ $V_1 = 1,02 \times 2,2$ $V_1 = 2,244 \text{ V}$	$\therefore I_1 = 1,02 \text{ A}$	$2,2\Omega$

	V	I	R
R_2	$V_{23} = V_2 = V_3$ $V_{23} + V_1 + V_4 + V_5 = V_T$ $V_{23} + 2,244 + 1,02 + 3,366 = 12$ $\therefore V_{23} = 2,39 \text{ V}$ $\therefore V_2 = 2,39 \text{ V}$	$I_2 = \frac{V_2}{R_2}$ $I_2 = \frac{2,39}{4,7}$ $I_2 = 0,51 \text{ A}$	$4,7\Omega$
R_3	$\therefore V_3 = 2,39 \text{ V}$	$I_3 = \frac{V_3}{R_3}$ $I_3 = \frac{2,39}{4,7}$ $I_3 = 0,51 \text{ A}$	$4,7\Omega$
R_4	$V_4 = I_4 R_4$ $V_4 = 1,02 \times 1$ $V_4 = 1,02 \text{ V}$	$I_4 = 1,02 \text{ A}$	1Ω
R_5	$V_5 = I_5 R_5$ $V_5 = 1,02 \times 3,3$ $V_5 = 3,366 \text{ V}$	$I_5 = 1,02 \text{ A}$	$R_{23} = \frac{R_2 R_3}{R_2 + R_3}$ $R_{23} = \frac{4,7 \times 4,7}{4,7 + 4,7}$ $R_{23} = 2,35\Omega$ $R_T = R_1 + R_{23} + R_4 + R_5$ $R_T = 2,2 + 2,35 + 1 + 3,3$ $R_T = 8,85\Omega$

17.



From the sketch, it is evident that the current is divided at the branch of R_2 and R_3 . Therefore, these are the two resistors which are parallel. We then combine the represent them with their effective resistance, as shown in the sketch below:



The circuit is now reduced to a circuit with three resistors, R_1 , R_{23} and R_4 , connected in series.

To complete the table, it is clear that the easiest quantity to calculate is the total resistance of the circuit, followed by the total current flowing in the circuit. But first we need to calculate the effective resistance of R_2 and R_3 .

	V	I	R
R_1	$V_1 = I_1 R_1$ $V_1 = 2,01 \times 2,2$ $V_1 = 4,42 \text{ V}$	$\therefore I_1 = 2,01 \text{ A}$	$2,2\Omega$
R_2	$V_{23} + V_1 + V_4 = V_T$ $V_{23} + 4,42 + 2,01 = 12$ $\therefore V_{23} = 5,57 \text{ V}$ $\therefore V_2 = 5,57 \text{ V}$	$I_2 = \frac{V_2}{R_2}$ $I_2 = \frac{5,57}{6,8}$ $I_2 = 0,82 \text{ A}$	$6,8\Omega$
R_3	$V_3 = 5,57 \text{ V}$	$I_3 = \frac{V_3}{R_3}$ $I_3 = \frac{5,57}{4,7}$ $I_3 = 1,19 \text{ A}$ Alternatively $I_2 + I_3 = I_T$ $0,82 + I_3 = 2,01$ $\therefore I_3 = 1,19 \text{ A}$	$4,7\Omega$
R_4	$V_4 = I_T \times R_4$ $V_4 = 2,01 \times 1$ $V_4 = 2,01 \text{ V}$	$I_4 = 2,01 \text{ A}$	1Ω

	V	I	R
Total	12 V	$I_T = \frac{V_T}{R_T}$ $I_T = \frac{12}{5,98}$ $I_T = 2,01 \text{ A}$	$R_{23} = \frac{R_2 R_3}{R_2 + R_3}$ $R_{23} = \frac{4,7 \times 6,8}{4,7 + 6,8}$ $R_{23} = 2,78\Omega$ $R_T = R_1 + R_{23} + R_4$ $R_T = 2,2 + 2,78 + 1$ $R_T = 5,98\Omega$

18. a) emf (electromotive force) is the potential difference across the battery when there is no current flowing in the circuit.
b) Internal resistance is the resistance within a battery, or other voltage source, that causes a drop in the source voltage when there is a current.
c) The electrical resistance of an electrical conductor is a measure of the difficulty to pass an electric current through that conductor.
d) The energy transferred to an electrical device per unit charge
e) Electric current is the flow of electric charges through a conductor.
- Or
- Electric current is a flow of charge carriers through a conducting media.
19. a) In a series circuit, voltage is divided between the resistors as the current flows.
b) In a series circuit, current flowing through the resistors is the same
c) In a series circuit, resistance increases as more resistors are added
20. a) In a parallel circuit, voltage across all the resistors is the same.
b) In a parallel circuit, current is divided between the resistors
c) In a parallel circuit, resistance decreases as more resistors are added.

Chapter 5 Heat and thermodynamics

Activity 5.1 Calculations for the amount of heat

$$Q = cm\Delta T$$

$$Q = 450 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1} \times 10 \text{ kg} \times (100-0)\text{K}$$

$$Q = 450\,000 \text{ J}$$

Experiment 1

1. Water is an excellent material to use in a calorimeter because it has a very high specific heat, making it very hard for water to raise its temperature even by 1 degree Celsius, but as hard as it was to raise the temperature of the water, it is equally as hard to lower the temperature of the water-making it able to effectively retain heat and allowing the other material inside of the calorimeter to absorb that heat.
2. Metal (Pb)
3. Water
4. Yes
5. Substances with a low specific heat capacity heat up quickly - but then they lose their heat quickly. Substances with a high specific heat capacity require a large amount of heat to be added to change their temperature – but then they hold their heat much longer. This should be the case in this experiment.

Activity 5.2

$$Q = \Delta U + W$$

$$Q = 5 + 20$$

$$Q = 25 \text{ J}$$

Review exercise

Multiple choice questions

1. B
2. C
3. D

Long questions

4. Heat is thermal energy in transit and thermal energy is the average kinetic energy of molecules in a substance. is the total energy (kinetic and potential) that molecular particles that which make up a substance possess.
5. Thermal energy flows from hot to cold objects
6. The specific heat capacity of water is higher than most substances
7. $Q_{\text{released}} = cm\Delta T = \left(\frac{4,184 \text{ J}}{\text{g}\cdot^{\circ}\text{C}}\right)(0,75 \text{ g})(80 - 30)^{\circ}\text{C} = 156,9 \text{ J}$
8. $Q_{\text{gained by water}} = c_{\text{water}} \times m_{\text{water}} \times \Delta T_{\text{water}} = \left(\frac{4,184 \text{ J}}{\text{g}\cdot^{\circ}\text{C}}\right)(100 \text{ g})(25,0 - 10,0)^{\circ}\text{C} = 6\,276 \text{ J}$
 $C_{Al} = \frac{Q_{\text{gained by water}}}{m_{Al} \times \Delta T_{Al}} = \frac{6276 \text{ J}}{(100 \text{ g})(100,0 - 25,0)} = 0,8368 \approx 0,84 \text{ J}\cdot\text{g}^{-1}\cdot^{\circ}\text{C} = \frac{0,84 \text{ J}}{\text{g}\cdot^{\circ}\text{C}}$

9. It is important that a lock and its key be made of the same or similar materials so that both materials can contract and expand at the same rate with changing temperature conditions. Otherwise, the key would not open the lock if one expands or contracts more than the other.
10. $\Delta U = Q - W = 250 \text{ J} - 600 \text{ J} = -350 = 350 \text{ J}$
11. This is not a violation of the second law of thermodynamics. The second law of thermodynamics states that heat can never spontaneously flow from a substance with low temperature to a substance with high temperature. In steam engines, thermal energy from the heat source transfers to the water molecules at low temperature. The thermal energy enables the molecules now in gaseous phase to do work on the piston which produces motion.
12. According to the second law of thermodynamics thermal energy can never spontaneously flow from the refrigerator with low temperature to your room at a higher temperature. An external device would have to be used to force the cool air to move from the refrigerator into your room.

Activity 6.1

1. a) Let the unknown oxidation number be x

The oxidation number of Cr in CrO_4^{2-}

$$x + 4(-2) = -2$$

$$x - 8 = -2$$

$$x = +6$$

Therefore, the oxidation number of Cr in CrO_4^{2-} is +6

The oxidation number of Cr in $\text{Cr}(\text{OH})_3$ is 3, knowing that the charge of the OH^- is -1:

$$x + 3(-1) = 0$$

$$x = +3$$

Therefore, the oxidation number of Cr in $\text{Cr}(\text{OH})_3$.

The oxidation number of sulphur in S^{2-} is -2

Sulphur in $\text{S}(\text{s})$ has the oxidation number of zero

The oxidation state of hydrogen in OH^- is:

$$-2 + x = -1$$

$$x = +1$$

Therefore, the oxidation number of H in OH^- is +1

Hydrogen in H_2O :

$$2x + (-2) = 0$$

$$x = +1$$

Therefore, hydrogen on H_2O has the oxidation number +1

- b) From the calculations above, we can conclude that Cr has been reduced from +6 in CrO_4^{2-} to +3 in $\text{Cr}(\text{OH})_3$. Therefore CrO_4^{2-} is an oxidising agent, because it has undergone reduction.

The oxidation number of S has increased from -2 in S^{2-} to 0 in $\text{S}(\text{s})$. This indicates that S^{2-} has undergone oxidation, and therefore, is an oxidising agent.

2. a) The oxidation number of Mn in MnO_2 is:

$$x + 2(-2) = 0$$

$$x = +4$$

While in Mn^{2+} , the oxidation number of Mn is +2.

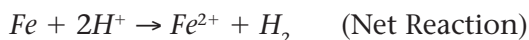
This indicates that MnO_2 has undergone reduction. And so, this is a redox reaction.

OR

The oxidation number of Cl in Cl^- is -1, while in Cl_2 , the oxidation number of Cl is zero. Again the change in oxidation of a species in a chemical reaction indicates that such a chemical reaction is a redox reaction.

3. In this chemical reaction, all the species maintain their oxidation states. And for that reason this is not a redox reaction.

Starting the half reactions, we have:



4. The oxidation number of N in NO_2 :

$$x + 2(-2) = 0$$

$$x = +4$$

While in NH_3 the oxidation number of N is:

$$x + 3(-1) = 0$$

$$x = +3$$

The calculation reveals that NO_2 has undergone reduction because the N atom has been reduced from +4 to +3. Hence, NO_2 is the oxidising agent.

On the other hand, H in H_2 has an oxidation number of zero. While in H_2O , the oxidation number of H is:

$$2x + (-2) = 0$$

$$x = +1$$

Indicating that the hydrogen atom has been oxidised. Therefore H_2 is a reducing agent.

5. a) H in CaH_2 has an oxidation number calculated as follows:

$$2 + 2x = 0$$

$$x = -1$$

Therefore, in CaH_2 hydrogen has an oxidation number of -1

- b) I in $NaIO_3$ has an oxidation number calculated as follows:

$$1 + x + 3(-2) = 0$$

$$x = +5$$

Therefore, the oxidation number of I in $NaIO_3$ is +5

- c) C in C_4H_{12}

$$4x + 12(1) = 0$$

$$x = -3$$

Carbon in C_4H_{12} has the oxidation number of -3

- d) Sulphur in $Al_2(SO_4)_3$:

$$2(+3) + 3x + 12(-2) = 0$$

$$3x = 18$$

$$x = +6$$

So, sulphur in C_4H_{12} has an oxidation state of +6

e) Lead in PbSO_4 :

$$x + 6 + 4(-2) = 0$$

$$x = +2$$

In, PbSO_4 has the oxidation state of +2

f) Cl in Cl_3^- :

$$x + 3(-2) = -1$$

$$x = +5$$

g) P in HPO_3^{2-} :

$$1 + x + 3(-2) = -2$$

$$x - 5 = -2$$

$$x = +3$$

h) O in Na_2O_2

$$2(1) + 2x = 0$$

$$x = -1$$

Activity 6.2

1. a) S in SO_3^{2-}

$$x + 3(-2) = -2$$

$$x = +4$$

In SO_4^{2-}

$$x + 4(-2) = -2$$

$$x = +6$$

Sulfur has been oxidised, and so this is an oxidation half reaction

b) Ca in CaO :

$$x + (-2) = 0$$

$$x = +2$$

But the oxidation number of Ca atom, in Ca, is zero.

c) Cr in Cr_4^{2-}

$$x + 4(-2) = -2$$

$$x = +6$$

While in $\text{Cr}_2\text{O}_7^{2-}$

$$2x + 7(-2) = -2$$

$$2x = +12$$

$$x = +6$$

No change oxidation number for Cr atom. Hence, this is not a redox reaction

d) In Cr_4^{2-} , the oxidation number of Cr is:

$$x + 4(-2) = -2$$

$$x = +6$$

While in Cr^{3+} the oxidation number of Cr is +3, indicating that Cr has been reduced. So this is reduction half reaction.

e) Mn in MnO_4^{2-}

$$x + 4(-2) = -2$$

$$x = +6$$

Mn is reduced. Hence this is reduction half reaction

f) Cl in ClO_2^-

$$x + 2(-2) = -1$$

$$x = +3$$

while in ClO^-

$$x + (-2) = -1$$

$$x = +1$$

Therefore, this is a reduction half reaction

2. a) $3\text{Ag}^+ + \text{Ni} \rightarrow \text{Ni}^{3+} + 3\text{Ag}$

Reduction: $3\text{Ag}^+ + 2e^- \rightarrow 3\text{Ag}$

Oxidation: $\text{Ni} \rightarrow \text{Ni}^{3+} + 3e^-$

b) $\text{Cu}^{2+} + \text{Pb} \rightarrow \text{Pb}^{2+} + \text{Cu}$

Reduction: $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$

Oxidation: $\text{Pb} \rightarrow \text{Pb}^{2+} + 2e^-$

c) $\text{O}_2 + 2\text{Sn} \rightarrow \text{O}^{2-} + 2\text{Sn}^{2+}$

Reduction: $\text{O}_2 + 2e^- \rightarrow \text{O}^{2-}$

Oxidation: $\text{Sn} \rightarrow \text{Sn}^{2+} + 2e^-$

Activity 6.3

(i) $\text{Cr}_2\text{O}_7^{2-} + \text{Fe}^{2+} \rightarrow \text{Cr}^{3+} + \text{Fe}^{3+}$

Oxidation number of Cr atom in $\text{Cr}_2\text{O}_7^{2-}$

$$2x + 7(-2) = -2$$

$$2x = +12$$

$$x = +6$$

The calculation reveals that the Cr atom has been reduced from +6 to +3 in Cr^{3+} . On the other hand, the Fe atom has been oxidised from +2 to +3. The reducing agent is Fe^{2+} , while the oxidising agent is $\text{Cr}_2\text{O}_7^{2-}$

(ii) $\text{ClO}_3^- + \text{Re} \rightarrow \text{ReO}_4^- + \text{ClO}^-$

The oxidation number of Re atom in ReO_4^-

$$x + 4(-2) = -1$$

$$x = +7$$

This shows that the Re atom has been oxidised from the oxidation state of zero in to the oxidation number of +7 in ReO_4^- . Therefore, Re is a reducing agent. On the other hand, the oxidation number of the Cl atom in ClO_3^- :

$$x + 3(-2) = -1$$

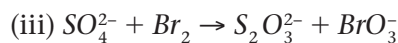
$$x = +5$$

While in ClO^- :

$$x + (-2) = -1$$

$$x = +1$$

The Cl atom has been reduced from the oxidation state of +5 in ClO_3^- to the oxidation state of +1 ClO^- . Therefore, ClO_3^- is an oxidising agent.



The oxidation number of S atom in SO_4^{2-} :

$$x + 4(-2) = -2$$

$$x = +6$$

While in $\text{S}_2\text{O}_3^{2-}$

$$2x + 3(-2) = -2$$

$$2x = +4$$

$$x = +2$$

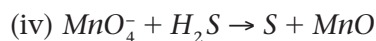
Therefore, S atom has been reduced from the oxidation number of +6 in SO_4^{2-} to +2 in $\text{S}_2\text{O}_3^{2-}$. Therefore, SO_4^{2-} is an oxidising agent.

The oxidation number of Br atom in Br_2 is zero. While in BrO_3^-

$$x + 3(-2) = -1$$

$$x = +5$$

This shows that the Br atom has been oxidised. Therefore, Br_2 is a reducing agent.



The oxidation number of Mn in MnO_4^- is:

$$x + 4(-2) = -1$$

$$x = +7$$

While in MnO

$$x + (-2) = 0$$

$$x = +2$$

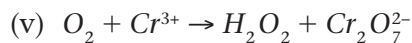
Therefore, Mn atom has been reduced from +7 to +2. Therefore, MnO_4^- is an oxidising agent.

On the other hand, the oxidation number of S in H_2S

$$2(+1) + x = 0$$

$$x = -2$$

Therefore, S atom has been oxidised from -2 to zero. H_2S is a reducing agent.



O atom in H_2O_2 has an oxidation number:

$$2(1) + 2x = 0$$

$$x = -1$$

While in O_2 it is zero. Therefore, O atom has been reduced from zero in O_2 to -1 in H_2O_2 . Therefore, O_2 is an oxidising agent.

The oxidation number of Cr in $\text{Cr}_2\text{O}_7^{2-}$

$$2x + 7(-2) = -2$$

$$2x = +12$$

$$x = +6$$

The oxidation number of Cr atom has increased from +3 in Cr^{3+} to +6 in $\text{Cr}_2\text{O}_7^{2-}$. Implying that Cr^{3+} has been oxidised Therefore, Cr^{3+} is a reducing agent.

Formal experiment

Questions

1. Justify the use of a safety precaution, other than wearing safety glasses, when carrying out this investigation.
2. Describe how the THREE products of this electrolysis could be identified.
3. Identify the anode and the cathode.
4. Write down the half-reactions taking place in each electrode.
5. Write down the overall redox reactions without spectator ions.
6. Write down the overall redox reactions with spectator ions.
7. Write down the name of spectator ion.
8. Write down TWO uses of the product identified in this experiment.

Review exercise

1. Oxidation is loss of electrons by substance in a reaction. It is accompanied by an increase in oxidation number. A substance undergoing oxidation is called a reducing agent.
2. Reduction is gain of electrons by a substance in a reaction; it is accompanied by a decrease in oxidation number. A substance undergoing reduction is called an oxidizing agent.

3. Redox or not:

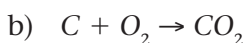


The oxidation number Na atom in NaCl

$$x + (-1) = 0$$

$$x = +1$$

There oxidation number of Na atom has increased from zero to +1. Therefore, this is a redox reaction.

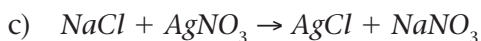


The oxidation number of C in CO_2

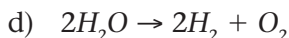
$$x + 2(-2) = 0$$

$$x = +4$$

Since there is a change in oxidation number, this is a redox reaction.



In this reaction all the species retained their oxidation states. This is therefore, not a redox reaction.

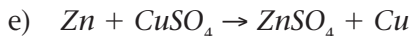


Oxidation number of H atom in H_2O

$$2x + (-2) = 0$$

$$x = +1$$

While H atom in H_2 has the oxidation number of zero. This change in oxidation number indicates that this is a redox reaction



The oxidation number of Cu atom in CuSO_4 is, (knowing that the charge of SO_4^{2-} is -2)

$$x + (-2) = 0$$

$$x = +2$$

The oxidation number of atom has changed from to 0. This is therefore, a redox reaction



Cl atom in Cl_2 has the oxidation number of zero. While in HCl

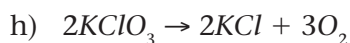
$$1 + x = 0$$

$$x = -1$$

Once again, a change in oxidation number implies that this is a redox reaction.



In this reaction there has only been a displacement of ions, but no change in oxidation number of any of the species. This is therefor, not a redox reaction.



The oxidation number of Cl atom in $2KClO_3$

$$1 + x + 3(-2) = 0$$

$$x - 5 = 0$$

$$x = +5$$

While in KCl

$$1 + x = 0$$

$$x = -1$$

Change on oxidation number of any of the species in a chemical reaction means that the reaction is a redox reaction.



None of the species has changed its oxidation state. This is therefore, not a redox reaction.

Marking guidelines for electrolysis of sodium chloride

1. Chlorine gas is produced in this reaction which is toxic.

The reaction must be carried out in the fume cupboard.

Answer could include: Explosive mixture of H_2 and Cl_2 and Electrical hazard

2.

Cl_2 gas	Cl_2 gas bubbling at anode Universal indicator added was bleached colourless from green near anode by Cl_2 Colourless I^- ions added were oxidised to brown I_2 molecules near anode by $Cl_2(g)$. Presence of I_2 confirmed by adding starch (blue/black colour) [any (2)]
H_2 gas	Bubbling at cathode and Gas collected pop test
OH^-	Universal indicator changed from green to purple near cathode indicating OH^- ion present

3. Anode is connected to the positive terminal of the battery. Cathode is connected to the negative terminal of the battery
4. Anode: $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$
Cathode: $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$
5. Overall reaction: $2Cl^- + 2H_2O \rightarrow Cl_2(g) + H_2(g) + 2OH^-$
6. $2NaCl(aq) + 2H_2O(l) \rightarrow Cl_2(g) + H_2(g) + 2NaOH(aq)$
7. Sodium ions

8. Chlorine gas	Chlorine is used for producing safe drinking water. Chlorinated compounds are used mostly for sanitation, pulp bleaching, disinfectants, and textile processing. Chlorine is also used for the manufacture of chlorates and it is important in organic chemistry, forming compounds such as chloroform, carbon tetrachloride, polyvinyl chloride, and synthetic rubber. Other uses of chlorine compounds include dyestuffs, petroleum products, medicines, antiseptics, insecticides, foodstuffs, solvents, paints and plastics. Any 2
Hydrogen gas	Hydrogen is widely used for the hydrogenation of vegetable and animal oils and fats. Hydrogen also finds uses in the metallurgy field because of its ability to reduce metal oxides and prevent oxidation of metals in heat treating certain metals and alloys. Hydrogen is extensively used in the synthesis of ammonia and in petroleum refining operations.
Sodium hydroxide	Sodium hydroxide is used in drain and oven cleaners, chemical manufacturing, oil refining, hydraulic fracturing, water treatment and metal processing. It is also commonly used in the manufacture of fabric, plastic wrap, paper and soap.

