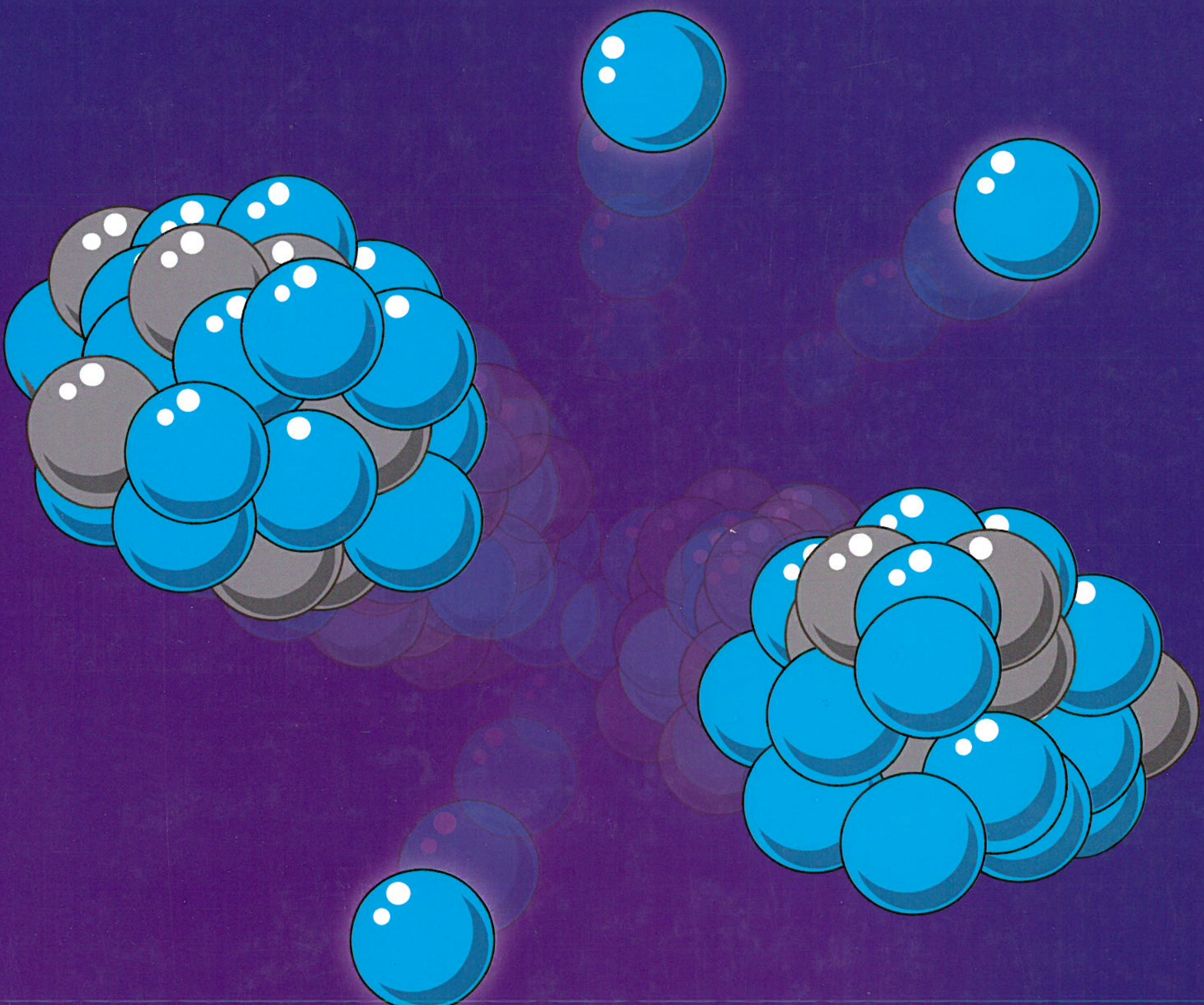
Exploring

PHYSICS

Stage 2



STAWA
SCIENCE TEACHERS' ASSOCIATION OF WESTERN AUSTRALIA

Exploring

PHYSICS

Stage 2

Editor:

George Przywolnik

Contributing authors:

Jeff Cahill

Carolyn Montgomery

Richard Rennie

Mike Starr

Tony Summers

With thanks to the editorial panels of previous STAWA Physics publications, on whose work much of this book is based:

Nic Sofoulis

Adrian Beck

Serge Gianatti

Gary Thomas

Shelley Yeo

John Hall

Geoff Lewis

STAWA

SCIENCE TEACHERS' ASSOCIATION OF WESTERN AUSTRALIA

STAWA
SCIENCE TEACHERS' ASSOCIATION OF WESTERN AUSTRALIA

Science Teachers' Association of Western Australia (Inc.)
PO Box 1099
Osborne Park WA 6916

First Edition, September 2008.
Revised October 2010.

Illustrations by George Przywolnik, John Clarke, Richard Rennie and David Keigwin
Design by David Keigwin
Set in Times New Roman and Helvetica

Printed in Australia by:

Daniels Printing Craftsmen
10 Walters Drive
Osborne Park
Western Australia 6017
Tel: (08) 9204 6800

ISBN 978 0 9803703 2 4
530.176

Exploring Physics Stage 2
Contents

Exploring Physics Stage 2
Contents

Nuclear Physics

Exploring Physics Stage 2
Contents

Heating and Cooling

Exploring Physics Stage 2

Contents

Electrical Fundamentals

How to Use This Book

Content organisers
Exploring Physics Stage 2 is organised around four main areas of content: Motion and Forces; Nuclear Physics; Heating and Cooling; and Electrical Fundamentals. Each content area is highlighted in a different colour to help you to find your way around the book.

Introductory contexts
There are two introductory context passages in each content area. Each context passage describes how the Physics ideas that follow can be seen in the world around you.

Comprehension exercises
A set of questions accompanies each context passage. These questions are keyed to the chapters that follow. You can use these questions to see how much of the Physics you already know; or to test yourself on the main ideas after you study them.

Explanations of major ideas
Each chapter begins with a short summary of key concepts, equations and techniques. Some of these are further explained through interactive tutorials on the accompanying CD-ROM.

Laboratory experiments
Each chapter includes one or more laboratory experiments designed to build your practical skills through application of the major ideas in a practical way, and to demonstrate your understanding by answering a number of questions. Many of these experiments can be adapted to use probes, data loggers and computers to gather and process data with a high degree of precision. The next section in this book gives a general guide to writing laboratory reports.

Sets of numerical and conceptual problems
Each chapter includes a number of problems that will test your understanding of the main ideas. The problems are a mix of numerical exercises which require you to calculate an answer, and conceptual problems which require you to write descriptions and explanations of physical phenomena, or to predict what will happen in a particular situation. Numerical answers are provided at the back of the book, with full solutions on the accompanying CD-ROM.

Investigations
Most chapters include one or more investigations. Usually, these are practical exercises or experiments in which you have to make some decisions about methods, equipment and the way you process the data. In general, you should write reports for your investigations in the same way that you write your laboratory reports.

How to Write Up Your Experiments and Investigations

Processing of results and questions

Written answers or calculations
- You should include answers to all questions.
- If calculations are required to generate new quantities from numerical results, you should include details of these calculations. If there are large numbers of similar calculations, then details of only one example of each type should be included.
- You should quote numerical results to the appropriate number of significant figures.
- You should estimate the uncertainty in any measurement you take, and use the uncertainties in your evaluation of your experiment.

Graphs
- You should draw graphs on graph paper using an appropriate scale.
- Graphs should not be smaller than half an A4 page.
- You should label axes with the appropriate scale, the quantity being plotted and the units used.
- You should draw a line of best fit for your points. The quantities plotted are measured values and therefore contain uncertainties (see below).

Conclusions
- The conclusion should relate to the aim or purpose of the experiment or investigation.
- Your conclusion should answer the question asked or implied in the aim.
- You do not have to write a separate conclusion if the conclusion is an answer to one of the questions asked at the end of the experiment or investigation.
- If the aim of the experiment is to verify a quantity having a known, generally accepted value (such as the acceleration due to gravity) you should make some comparison between your measured value and the established value.

Uncertainties of Measurement

The accuracy with which a quantity can be measured depends largely on the scale of the measuring instrument. The number of significant figures quoted in the recorded measurement is decided by the smallest scale division of the instrument.
For example:
When you measure a length with a metre rule where the smallest scale division is 1 mm, you should estimate your measurements to the nearest 0.1 mm (i.e. 'read between the lines' of the rule). The uncertainty should then show the lower and upper limits of confidence in your estimate. A reading for an experienced user might be 22.6 ± 0.05 mm. This would indicate that the measurer was confident that the reading was not as high as 22.7 mm or as low as 22.5 mm.
Consider a typical measurement of 22.6 ± 0.1 mm. This has an **estimated absolute uncertainty** of ± 0.1 mm.
When you add or subtract measurements, you can estimate the absolute uncertainty of the result by adding the absolute uncertainties of the measurements.

For example: 22.6 ± 0.1 mm – 14.2 ± 0.1 mm = 8.4 ± 0.2 mm

We can express uncertainty as a percentage. This can be useful when you evaluate an investigation, because the measurement having the largest percentage uncertainty tends to contribute most to inaccurate results. In a measurement the uncertainty can be expressed as a percentage by using the relationship:

$$\text{percentage uncertainty} = \frac{\text{absolute uncertainty}}{\text{measurement}} \text{x}100\%$$

In the above examples:

$$\text{percentage uncertainty in } 22.6 \pm 0.1 = \frac{0.1}{22.6} \text{x}100\% = \pm 0.4\%$$

and

$$\text{percentage uncertainty in } 14.2 \pm 0.1 = \frac{0.1}{14.2} \text{x}100\% = \pm 0.7\%$$

In this case, the smaller measurement has a greater percentage uncertainty than the larger measurement.
When you multiply or divide measurements, you can estimate the absolute uncertainty of the result by adding the percentage uncertainties of the measurements.
For example:
The area contained in a rectangle 22.6 ± 0.1 mm by 14.2 ± 0.1 mm is (22.6 x 14.2) mm^2 = 390.92 mm^2.
We have already calculate the percentage uncertainties above, so the uncertainty in the area must be ±(0.4 + 0.7)% = ± 1.1%.
The area is thus 390.92 mm^2 ± 1.1%.
1.1% of 390 is 4.3, so the absolute uncertainty in the area is ± 4 mm^2.
We should therefore report the area as 391 ± 4 mm^2.

One way to minimise uncertainties is to repeat a measurement several times and then calculate the average value. In this case, the uncertainty can be estimated by finding the standard deviation of the averaged measurements. Note that a standard deviation can only be reliably calculated from a large number of repeated measurements.

Significant figures

Significant figures represent an approximate way of indicating how confident you are of your measurements. The final digit carries an element of uncertainty. Thus, the number of significant figures is the number of certain digits, plus the first digit in which there is some uncertainty.

The following guidelines can help you work out the number of significant figures in a measurement or quoted number:

- All non-zero digits are significant.
- Zeros between non-zero digits are significant: e.g. 4003 has 4 s.f.
- Zeros to the right of a decimal point and following a non-zero digit are significant: e.g. 1.1003 has 5 s.f. and 0.01030 has 4 s.f.
- If only zeros occur to the left of a non-zero digit, those zeros are not significant: e.g. 0.002 has 1 s.f.
- Numbers such as 2000, where the decimal point is not included, are ambiguous: e.g. 2000 could have 1, 2, 3 or 4 s.f. In such numbers, the number of significant figures should be agreed beforehand.
- Scientific notation avoids ambiguity: e.g. 31 400 may have 3, 4 or 5 s.f. but 3.14 x 10^4 has 3 s.f.
- In calculations, the final result should contain no more significant figures than the data with the least number of significant figures.

The Science of Swimming

There are special reasons why some people swim faster than others. These reasons can be explained in terms of motion and forces.
Two pieces of information, combined together, allow a swimmer to work out how fast they can swim. For people swimming laps at a public pool, the pool length is distance travelled, while the lap time is the time taken. This information lets a swimmer calculate their average speed. If they include information about displacement as well, then they will also be able to determine their velocity.

A swimmer's acceleration from a stationary start depends on a number of factors. A swimmer applies a force to the water, using their hands and feet. This force firstly gets the swimmer moving (accelerates the swimmer), and then overcomes opposing forces (sustains the movement). Newton's second law allows us to work out how large these forces may be.

At all times, the Earth's gravity acts on the mass of the swimmer to create a downward force. Weight acts on all bodies, and is numerically equal to the product of the mass and the gravitational constant 'g'.

Water exerts an upward buoyancy force that can partly or completely overcome the effect of gravity.
This why swimmers can float, and why a heavy object feels lighter if you lift it under water.

We can represent all of the forces acting on a body, such as a swimmer, in a 'free body diagram'. A free body diagram helps us to work the resultant effect of a number of forces acting on a swimmer. For example, a free body diagram could indicate whether a swimmer would accelerate up, down, forward or backward!
As well as diagrams we have several convenient equations that express the relationships between distance, displacement, time, speed, acceleration, initial and final velocity.

You may notice that it is hard for a swimmer to get moving, but, once they get going, they can glide through the water for a considerable distance. The mass of a swimmer makes them resistant to changes in their motion.
This is what Newton's first law is all about.

Newton's third law tells us that for every applied force there must be an equal sized, and opposite direction force. When the swimmer's feet and hands exert a force on the water, the water provides this reaction force on the swimmer's hands and feet. Note that 'action' and 'reaction' forces never act on the same object. Thus, it is actually the water that pushes the swimmer forward. Why do you think that swim fins are not allowed in competitive swimming? Competitive swimmers always start a race by pushing on the wall of the pool with their feet. This allows them to accelerate faster than if they started by pushing on the water.

The Science of Swimming: Comprehension Questions

COMPREHENSION QUESTIONS

1. [see Chapter 1]
[a] Explain the difference between speed and velocity.
[b] A person swims 1.56 km in a straight line in 55.0 minutes. Calculate the swimmer's average speed, in metres per second.
[c] Calculate the distance, in metres, that this swimmer would travel in 1.5 hours.
[d] Calculate the time it would take for another swimmer to travel 285 m at a speed of 1.22 m s^{-1}.
[e] Estimate how far this swimmer could swim in an hour. Show all your working and list any assumptions you make.

2. [see Chapter 2]
[a] Calculate the average acceleration, in m s^{-2}, of a swimmer who took 1.50 seconds to reach a speed of 3.60 km h^{-1} starting from rest.
[b] Explain why this was an average acceleration.
[c] The acceleration of this swimmer was 0.35 m s^{-2} at the moment that they reached 3.60 km h^{-1}. If the swimmer maintained this acceleration for a further 1.5 seconds, calculate their final speed.

3. [see Chapter 2]
[a] A motor cyclist travelling at 60 km h^{-1} east accelerated to 100 km h^{-1} east at a rate of 2.5 m s^{-2} east. Calculate the time for which the acceleration lasted.
[b] The motor cyclist then accelerated from 100 km h^{-1} east at a rate of 1.74 m s^{-2} east for a period of 8.00 s. Calculate the distance travelled while accelerating from 100 km h^{-1}.
[c] Calculate the maximum speed reached by the motorcyclist.
[d] The motor cyclist then slowed down to a stop from this maximum speed in a distance of 125 m. Calculate the acceleration involved.

4. [see Chapter 2]
Use the data about the motor cyclist's journey in Question 3 above, plus any extra information that you may have to calculate, in order to draw the following graphs. In each case, show clearly what each axis represents.
[a] Draw a displacement vs time graph.
[b] Draw a velocity vs time graph.
[c] Draw an acceleration vs time graph.

5. [see Chapter 3]
Draw labelled free body diagrams for each of the following cases:
[a] A swimmer of mass 75.0 kg travels at a constant speed of 2.60 km h^{-1} along a straight lane. The total water resistance and friction force opposing the swimmer's motion is 80.0 N. The buoyancy force exerted by the water is 735 N.
[b] A high diver of mass 60.0 kg is falling toward the water at a speed of 15.0 km h^{-1}. Assume that air resistance and friction forces are negligible.
[c] An off-road vehicle of mass 2 tonnes contacts the ground at a speed of 50 km h^{-1} after bouncing into the air on a rough track. Assume that air resistance and friction forces are negligible.

6. [see Chapter 3]
[a] Why do swimmers need a force in order to accelerate?
[b] Why do swimmers need a force to maintain their motion?
[c] An off-road vehicle travels along a straight and level highway in two wheel drive (2WD) mode. The total air resistance and friction force acting on the vehicle is 1000 N. Calculate the horizontal force exerted by the road on each driving wheel when the vehicle travels at a constant speed.
[d] Estimate the horizontal force exerted by the road on each driving wheel when the vehicle travels at a constant speed in four wheel drive (4WD) mode. Show all your working and list any assumptions you make.
[e] Explain what advantage there might be in being able to use 4WD mode when crossing difficult terrain.

Chapter 1: Uniform Motion Explained

Notes

When an object moves and neither its speed nor its direction of movement changes, then we say it has 'uniform motion'.

Examples include:

- A horse gallops directly across the field at a speed of 12 m s^{-1}.
- An escalator carries its passengers up to the second floor at a constant speed.

There is an essential difference between speed and velocity. Speed is the rate of change of distance; both distance and speed are scalar quantities.

$$\textbf{Speed} = \frac{\textbf{distance travelled}}{\textbf{time taken}}$$

Where: speed is measured in metres per second (m s^{-1})
distance travelled is measured in metres (m)
time taken is measured in seconds (s)

Velocity is the rate of change of displacement, a vector quantity. Therefore, you must express velocity with a direction.

Mathematically,

$$\mathbf{v_{av}} = \frac{\mathbf{s}}{\mathbf{t}}$$

or, for an object whose velocity changes smoothly from an initial velocity u to a final velocity v:

$$\mathbf{v_{av}} = \frac{\mathbf{u+v}}{\mathbf{2}}$$

Where: $\mathbf{v_{av}}$ is the average velocity measured in metres per second (m s^{-1})
u is the initial velocity measured in m s^{-1}
v is the final velocity measured in m s^{-1}
s is the displacement measured in metres (m)
t is the time measured in seconds (s)

The relationship between v, s and t also works when the speed or velocity is constant:

$$\mathbf{v_c} = \frac{\mathbf{s}}{\mathbf{t}}$$

Experiment 1.1: Navigating Vectors

1

Aim

To experience scalars, distance travelled and speed; vectors, displacement and velocity.

Apparatus

(per group)

- Field compass
- Stopwatch

Pre-Lab

Your instructor will show you how to use the compass to take a bearing.
Plan a simple orienteering course in your school grounds. For example:

1. Start at A then walk 100 paces east
2. Then walk 50 paces north
3. Now walk 50 paces north west
4. Finally walk 75 paces south [Call this place B]

Lab notes

- Pace out the course you have planned. If necessary, modify the course to avoid obstacles or hazards. Time and record how long the journey from A to B took. Make sure that you record all your measurements as you take them.
- Measure and record the distance [in paces] from B back to your starting point at A.
- Measure and record the bearing from A to B.
- Repeat the exercise until all members of your group have walked the course and recorded their data.

Post-Lab Discussion

1. Back in the classroom: draw a scale diagram of your journey, using arrows to represent the displacement vectors. Make sure you record the scale clearly. Use this and your recorded measurements to answer the following questions.

2. When you worked out your displacement, how different was your scale diagram from the direct measurement? Which do you consider was the more accurate measurement? Explain.

3. For the journey calculate:
   [a] the distance between A and B;
   [b] the speed of the journey;
   [c] the displacement of B relative to A;
   [d] the velocity of your journey.

4. Magnetic north and geographical north are not in the same location. Is this a major source of error? Explain.

5. What are the main sources of uncertainty in this experiment? How could you minimise them if you did this experiment again?

Notes

Experiment 1.2: Rolling Along

Notes

Background

Uniform motion is a fairly common state for vehicles travelling along straight roads. The battery powered vehicles you will use in this lab are easier to measure, and safer to use, than real vehicles. The model or equation that you will generate from the lab data applies to full-sized vehicles just as much as it applies to toys. If you have access to computers, data logging equipment and the appropriate software, you may be able to adapt this lab to take a more high-tech approach.

Aim

To investigate uniform motion.

Apparatus (per group)

- a slow-moving, battery-powered toy vehicle
- masking tape
- metre ruler
- stop watch

Pre-Lab

- Run your vehicle along a stretch of floor and consider the possible relationship between the distance the vehicle moves and the time it takes to travel that distance.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) that you intend to control.
- Discuss with your lab partners what you will measure, and how you will obtain at least six pairs of measurements for each trial that you carry out.
- Prepare a table suitable for recording your measurements.

Lab notes

- Carry out several trials and record the data.
- Use the data you have recorded to make one or more line graphs of distance travelled, *vs* time. Draw a line of best fit by eye, rather than joining the dots.
- Determine the gradient (slope) of the line of best fit. Include the units of the gradient.

Post-Lab Discussion

1. Write the equation of the line of best fit.
2. Consider the intercept of the line of best fit with the distance axis. Is the intercept significant? Explain your reasoning.
3. Compare your gradient and equation with the values that other groups have obtained.
4. What have you found out about the speed of your vehicle?
5. Explain how you could use your results to predict
   [a] where the vehicle will be at a time between two of the measurements you made
   [b] where the vehicle would have been at a time 5 seconds after the last measurement you made.
6. Write a conclusion for your lab. You should refer to your original hypothesis, and to the dependent and independent variables.
   [a] Calculate the total distance they travelled between the starting position and the check point.
   [b] Calculate the pair's average speed for this journey.
   [c] Calculate the location of the check point, relative to their starting position. Give both the distance and the direction.
   [d] Hence, calculate the average velocity for the journey between the starting position and the check point.

Problem Solving and Calculations 1
Set 1: Uniform Motion

1.1 In a cricket match a bowler bowls a ball from one end of the pitch to the other, a distance of 20.1 m, in 0.750 s. Calculate the ball's average speed:

[a] in metres per second.

[b] in kilometres per hour.

Road Map

1.2 The distance between two towns is 165 km. If Jane can drive this distance in 1.50 hours:

[a] Calculate Jane's average speed for the journey.

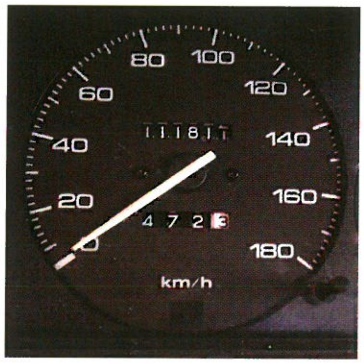
[b] When Jane calculated her average velocity for the trip, she found it was 20 km h^{-1} less than her average speed. Explain.

1.3 A passenger jet takes approximately 3.5 hours to fly from Perth to another city at a constant speed of 850 km h^{-1}. Assuming that there are no wind effects on its motion, calculate the distance the jet flies.

1.4 A triathlete pedalled her bicycle due east at a constant velocity. At 6:45 am she passed the 255 km peg. At 7:15 am she passed the 270 km peg.

[a] Calculate the triathlete's displacement.

[b] Hence, calculate her velocity.



Speedometer

1.5 Miriam and Molly are participating in a survival course. They hope that fully loaded with their packs, they can cover 1.0 km every 15 min. Estimate their displacement if they walk due west for 1.25 h before setting up camp.

1.6 An experimental rocket travels through space at a speed of 6.40×10^3 m s^{-1}. How long will the rocket take to travel to the Moon, a journey of 3.84×10^5 km?

1.7 A hot air balloon drifted 280 km south-east. If the balloon's average velocity was 8.2 m s^{-1} south-east, how long did the journey take?

1.8 Rebecca is one of her school's best sprinters and decides to work out exactly what her top speed is. How could Rebecca calculate her top speed?

Notes

1.9 After you receive a speeding ticket you decide to check the accuracy of your speedometer. Describe how you would do this.

Continued over

Problem Solving and Calculations Set 1: Uniform Motion

1.10 Two competitors in an orienteering competition knew that the next check point was some distance due north of their location. To avoid crossing some very difficult terrain, the competitors decided to get to the check point by jogging: north 800 m; then west for 600 m; then north for 1.0 km; then east for 600 m; and finally 200 m north. The competitors found that this journey took them 20 minutes.

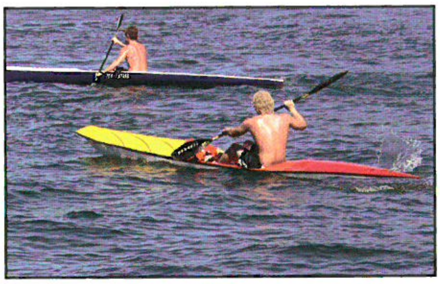
[a] Calculate the total distance they travelled between the starting position and the check point.

[b] Calculate their average speed for this journey.

[c] Calculate the location of the check point, relative to their starting position. Give both the distance and the direction.

[d] Hence, calculate the average velocity for the journey between the starting position and the check point.

1.11 Colin drove from one township to another at an average speed of 92 km h^{-1}. Before he started his journey he noted that the car's odometer reading was 26 455 km and on reaching his destination it displayed 26 708 km. The only time Colin stopped was to pull over to the side of the road to eat lunch. If the journey took exactly three hours, how long did Colin take for lunch?



Canoes

1.12 Marvin takes 20 minutes to paddle his canoe 800 m upstream.

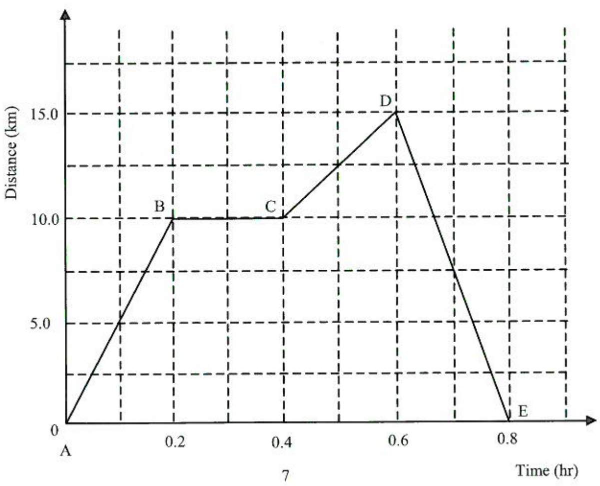
[a] Calculate Marvin's speed, relative to the bank.

If Marvin can paddle his canoe at 4.0 m s^{-1} in still water:

[b] Calculate the stream's speed, relative to the bank.

[c] How long will Marvin take to paddle 10 km upstream?

[d] How long will Marvin take to paddle 10 km downstream?



1.13 The graph (*left*) shows a motorcyclist's distance from her starting point, plotted against time. Use the graph to answer the questions that follow. Explain your choice in each case.

[a] Between which points did she travel at the greatest speed?

[b] Between which points was the motor bike stationary?

[c] At which point did the rider turn around to go back to her starting point?

[d] Calculate the total distance travelled by the motor cyclist.

[e] Calculate the motorcyclist's average speed for the journey.

[f] What extra information would you need to know in order to calculate the motorcyclist's average velocity for the journey?

1.14 A duck can paddle at 2.0 m s^{-1} in still water. If the duck takes 1.2×10^3 s to travel 0.60 km upstream, calculate:

[a] the stream's velocity;

[b] how long the duck will take to paddle 8.4 km downstream.

Chapter 2: Accelerated Motion Explained

2

Notes

When an object's velocity changes at a constant rate, then we say it has 'uniform acceleration'. Here are two examples of uniform acceleration:

- When the lights turned green, Peter accelerated his car from 0 to 12 m s^{-1} in 4.5 s.
- Christina started her bungee jump by leaping from the bridge and falling at a rate of 9.8 m s^{-2}.

Acceleration is a vector quantity, so it has direction. This means that if an object's direction of motion changes, there has been an acceleration. An example of this is:

- A car travelled around a smooth curve at a constant speed of 28 m s^{-1}.

You can calculate acceleration along a straight line with the following equations:

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

The same equation can be rearranged to give:

$$\mathbf{v} = \mathbf{u} + \mathbf{at}$$

where: **a** is the acceleration measured in metres per second per second (m s^{-2})
Δv is the change in velocity in m s^{-1},
v is the final velocity in m s^{-1},
u is the initial velocity in m s^{-1} and
t is the time in s.

Note that 'change in velocity' is equal to the final velocity minus the initial velocity. The idea of 'change in' a quantity will appear several times in this course. No matter what the quantity is, 'change in' always means 'final subtract initial'.

You can work out more about the uniformly accelerated motion of an object by using the following additional equations:

$$\mathbf{s} = \mathbf{ut} + \tfrac{1}{2}\mathbf{at}^2$$

and

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

where **s** is the displacement in metres (m).

Objects falling freely near the Earth's surface all fall with same initial acceleration, which is usually shown as 'g' in equations. The value of 'g' is about 9.8 m s^{-2}, anywhere on or close to the Earth's surface.

Thus, for freely falling objects that are not significantly affected by air resistance, we can write the equations of motion as:

$$\mathbf{v} = \mathbf{u} + \mathbf{gt}$$

$$\mathbf{h} = \mathbf{ut} + \tfrac{1}{2}\mathbf{gt}^2$$

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

where **h** is the vertical displacement in metres (m).

Experiment 2.1: Going Faster

Notes

Background

Any object whose speed changes must undergo acceleration. Examples are everywhere around us, from wriggling worms and wind-blown leaves to motorcycles and aircraft. A simple way to get a uniform acceleration in the lab is to put a low-friction toy vehicle or trolley on a slope. If you make the slope long and gentle, the times you have to measure will be relatively large, and your reaction time will not introduce significant errors. If you have access to computers, data logging equipment and the appropriate software, you may be able to adapt this lab to use photogates to measure the times with much greater precision than is obtainable with hand-held stopwatches.

Aim

To investigate accelerated motion.

Apparatus (per group)

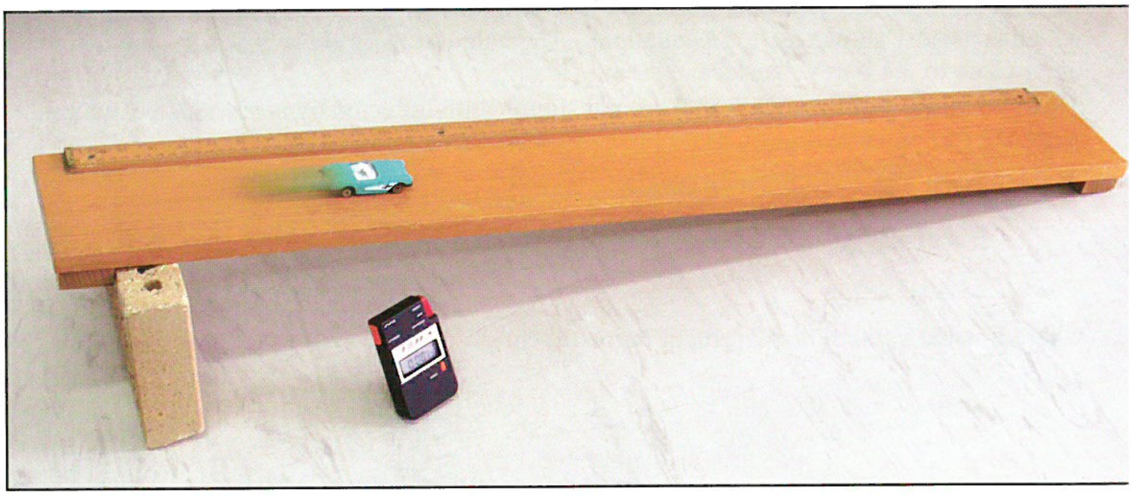
- a free-wheeling, low-friction toy vehicle, and a long flat ramp such as a wooden board

  or
- an air track, air track glider and blower
- metre ruler and stop watch

  or
- photogates or motion sensor and suitable software

Pre-Lab

- Set up the board or the air track so that one end is higher than the other.
- Run your vehicle down the board and consider the possible relationship between the distance the vehicle moves and the time it takes to travel that distance.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Discuss with your lab partners how you will measure the distance travelled at various times, and the angle of the slope.



Apparatus for Experiment 2.1

Continued ov

Experiment 2.1: Going Faster

- Prepare a table suitable for recording your measurements.
- Discuss with your lab partners how you can work out the speed or velocity of the vehicle at regular time intervals.

Notes

Lab notes

- Carry out several trials and record the data.
- Carry out the calculations to work out the speed or velocity of the vehicle at the selected times.
- Use the data you have recorded to make one or more line graphs of speed or velocity, *vs* time. Draw a line of best fit by eye, rather than joining the dots.
- Determine the gradient (slope) of the line of best fit. Include the units of the gradient.

Post-Lab Discussion

1. Write the equation of the line of best fit.

2. Consider the intercept of the line of best fit with the distance axis. Is the intercept significant? Explain your reasoning.

3. Compare your gradient and equation with the values that other groups have obtained.

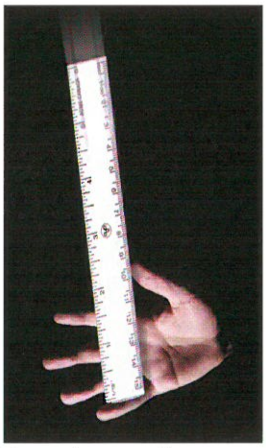
4. What have you found out about the acceleration of your vehicle?

5. The acceleration is a component of the acceleration due to gravity, and its magnitude (size) depends on the angle that the slope makes with the horizontal. Calculate the magnitude of the component of the gravity acceleration that is parallel to the slope. Compare this with the acceleration you worked out from your graph.

6. Explain how you could use your results to predict:
   [a] how fast the vehicle will be moving at a time between two of the measurements you made.
   [b] how fast vehicle would have been travelling at a time 2 seconds after the last measurement you made.

7. Write a conclusion for your lab. You should refer to your original hypothesis, and to the dependent and independent variables.

Experiment 2.2: Reaction Time



Dropping a ruler

Notes

Background

If you hear the noise from a starting pistol at the start of a race, it takes a short time, typically about 0.15 s, before your brain registers the signal and you leave the starting blocks. This time, which varies from person to person and situation to situation, is known as the 'reaction time'. When you operate a vehicle, whether it is a bicycle or an articulated road train, your reaction time becomes an important factor in reacting to hazards. Many external factors, including alcohol and other drugs, and even using a mobile phone, can seriously affect your reaction time and turn a potentially minor incident into a catastrophe.

A quick way to experience reaction time is to have a friend drop a ruler while you try to catch it. The distance the ruler falls before you can close your fingers around it can be used to work out your reaction time.

Aim

To investigate reaction time.

Apparatus (per group)

- metre ruler
- stop watch

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Work out how to use the equations of motion to calculate your reaction time.
- Plan the conditions under which each group member will measure the reaction times. For example, you may choose to make a measurement while you have a conversation with a third person.

Lab notes

- Use a metre rule, and measure the distance the ruler falls before being caught under a variety of conditions.
- Work out the range of reaction times that apply to you.
- Then help your friend by releasing the ruler for them to measure their reaction time.
- Carry out several trials and record the data.
- Carry out the calculations to work out the reaction times.

Post-Lab Discussion

1. Is there a pattern to the way the reaction times vary? Explain.

2. It is illegal to drive while using a mobile phone. Can you suggest a reason, based on your experimental results?

3. Imagine you are driving a car at the speed limit. Estimate how far your car would travel at full speed as you react to a sudden hazard in each of the following situations. Show your working in each case.
   [a] On a suburban street
   [b] On a freeway
   [c] On the open road in the country.

Problem Solving and Calculations Set 2: Accelerated Motion 2

2.1 A train starts from Mandurah with an acceleration of 0.8 m s^{-2} and reaches its maximum speed in 40 s. The train continues at this speed for 12 minutes, then slows down uniformly for 45 s before coming to rest at Murdoch Station.

[a] Draw a speed v time graph of the motion.

[b] Find the distance between Mandurah and Murdoch stations.

[c] Determine the train's maximum speed in km h^{-1}.

[d] Calculate the train's average speed in m s^{-1}.

Electric train

2.2 Describe how you can estimate the depth of a well with a stopwatch and a stone. Why is this only an estimation?

2.3 Calculate the average acceleration in each of the following:

[a] In a sprint race Carl can accelerate from rest to 11.13 m s^{-1} in 3.15 s.

[b] Caroline's sports-car accelerates from zero to 45 km h^{-1} in 2.65 seconds in first gear.

Sports car

2.4 A NASA rocket accelerates upward at 21.3 m s^{-2} for a period of 5.35 s.

[a] Calculate the change in velocity of the astronauts inside the rocket.

[b] What other information would you need to know in order to calculate their final velocity?

2.5 An aeroplane flies at a constant height and speed.

[a] Calculate the time it would take to fly 50 km at a constant 200 m s^{-1}.

[b] The aeroplane is now accelerated at 2 m s^{-2}. Calculate the time it would take to increase its speed to 250 m s^{-1}.

[c] The plane flies for another 50 km at the new speed of 250 m s^{-1}. Calculate the time taken for this part of its journey.

[d] Draw a labelled graph of the plane's motion as described above.

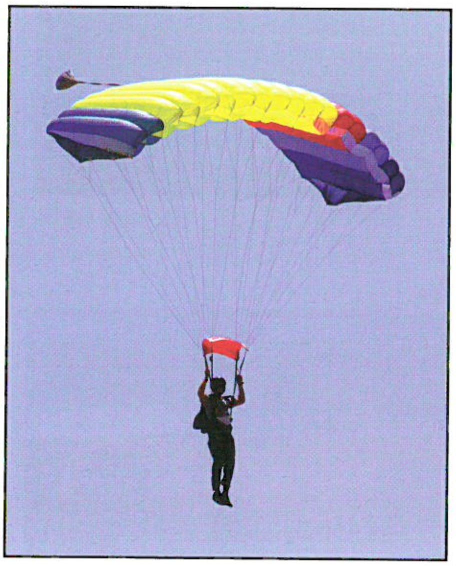
[e] Use the graph to work out the distance travelled during the acceleration phase. Explain your method.

2.6 Mei Lin can accelerate her bicycle from rest at the rate of 0.77 m s^{-2}. How far will she have travelled from her starting point by the time she achieves a speed of 7.0 m s^{-1}?

Continued over

Notes

Problem Solving and Calculations Set 2: Accelerated Motion


Parachutist

Notes

2.7 In her motorcycle log book, Suzi notes that her motorcycle can accelerate from 21.8 km h^{-1} to 28.6 km h^{-1} in 1.70 s.

[a] What is the magnitude of the acceleration of her motorcycle?

[b] If she maintained this acceleration, how much longer would it take her to reach 62.6 km h^{-1}?

2.8 Which of the following golf balls would have the greatest acceleration? Explain.

- A ball dropped out of a second floor window.
- A ball in mid-flight after being struck by a golf club.
- A ball that has been thrown down from a bridge towards the water below, measured after the thrower has let go.

2.9 As part of the pre-match entertainment at a football grand final, a skydiver parachuted towards the football oval at a constant downward velocity of 8.00 m s^{-1}. When he was 72.0 m above the ground he released a football directly above the centre of the playing field. Assuming that the ball's motion was not significantly affected by air resistance, calculate:

[a] the speed at which the football struck the ground;

[b] the time difference between the ball landing and the skydiver landing.

2.10 A motorist is driving his vehicle at 60 km h^{-1} when he encounters an emergency situation.

[a] Calculate his speed, in m s^{-1}.

Every driver has a 'reaction time' in which the driver recognises a hazard, decides what to do, and begins to react.

[b] The motorist in this case has a reaction time of 0.5 seconds. Calculate how far he travels between seeing a hazard and beginning to respond to the hazard.

[c] Calculate the acceleration (assumed constant) required to stop this vehicle in a time of 4.5 s once the brakes have been applied.

[d] Assuming constant acceleration, calculate the 'braking distance' that his vehicle travels after the brakes are applied.

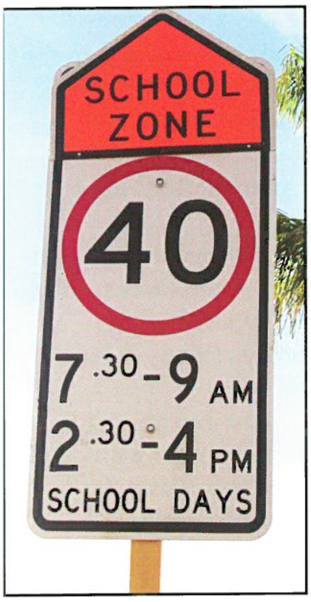
[e] Calculate the total stopping distance; that is, the distance travelled including both the reaction time and the braking time.

[f] Assuming that the driver's reaction time and the car's acceleration are independent of the car's speed, calculate the time it takes the car to stop, and the stopping distance, when the car is travelling at a speed of 55 km h^{-1}.

[g] Calculate the speed that the car, initially travelling at 60 km h^{-1}, will still have when the car travelling at 55 km h^{-1} has stopped.

Continued over

Problem Solving and Calculations Set 2: Accelerated Motion 2



Road sign

[h]An advertising campaign to promote public safety and better driving habits had the catch phrase 'drop five and save lives'. The message was that lowering speed, even by as little as 5 km h^{-1}, could make a big difference to the outcome of a crash or collision. Comment on this message, in the light of your work on earlier parts of this problem.

2.11 In Western Australia, the speed limit in built-up areas is 50 km h^{-1}. In areas around schools, the speed limit is even lower, at 40 km h^{-1}, during certain times in the morning and afternoon of school days.
Use your answers to the previous question to justify this lower speed limit.

2.12 When Robyn dropped a rock off a cliff, it struck the water below after 5 s with a speed of 50 m s^{-1}.
[a] Use the information given to estimate the acceleration of the rock.
[b] Estimate the rock's average velocity during its fall.
[c] What assumptions did you make about the rock's motion when you carried out these calculations?

Notes

2.13 Terry threw a baseball high above his head and then caught it again before it hit the ground. Its total flight time was 5.00 s. Ignoring air resistance:
[a] Calculate the speed at which Terry flung the ball into the air.
[b] Calculate the ball's speed just before it struck Terry's hands.
[c] Plot a graph of the ball's acceleration against time for its total flight time.

2.14 Cindy pedalled her bike for 10 s at a constant speed of 5.0 m s^{-1} and then decided to increase the speed. By pushing firmly on the pedals she accelerated her bike at a rate of 2.50 m s^{-2} for 4.0 s. Cindy then applied the brakes so that her bike decelerated at the rate of 6.0 m s^{-2} until it came to rest.
[a] Calculate Cindy's speed after 14.0 s.
[b] Plot a velocity-time graph for Cindy's bike.
[c] Use the graph to work out how far Cindy travelled before she stopped.

2.15 Vincent's car has a speed of 12.5 m s^{-1} at the moment when he steps on the accelerator. His car accelerates at 4.50 m s^{-2} for 7.00 s. He then applies the brakes, which decelerate his car at the rate of 11.0 m s^{-2} till it comes to rest. All this happens on a straight road.
[a] Plot a velocity-time graph for his car.
[b] Use the graph to deduce how far he has driven in this time.

2.16 A sailor rowed out from the shore in his dinghy at a constant acceleration of 0.11 m s^{-2} until he reached a speed of 1.7 m s^{-1}. He continued at this speed until he arrived at his yacht, anchored 30 m offshore. Calculate how long his trip took.

Investigations

Investigation 2.3: Measuring 'g' by the pendulum

You can measure 'g' using a pendulum. This investigation goes all the way back to the genius Galileo, who made a pendulum so frictionless that he could detect the Earth's rotation. There is a pendulum like Galileo's at the Gravity Discovery Centre near Gingin.

Plan, then investigate, how the time for one oscillation [the pendulum period] depends upon the pendulum length.

It is a good idea to time 10 swings, then calculate the average time for one swing from this information. This significantly reduces the error introduced by your reaction time.

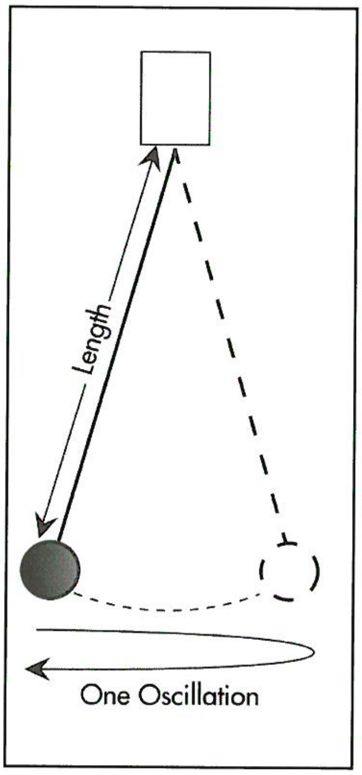
For this investigation, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.

Discuss with your lab partners what you will measure, and how you will obtain at least six pairs of measurements for each trial that you carry out. If you cooperate with other groups, you can between you get more data about other factors that may affect the period, such as the mass of the pendulum bob, or the amplitude (size of the swing).

Prepare a table suitable for recording your measurements.

Graph the period *vs* the length. If you do not obtain a straight line plot, try graphing other functions, such as (inverse of period) *vs* length, (period squared) *vs* length and so on, until you get a straight line plot. This is much easier to do if you use a graphing calculator, or computer program such as a spreadsheet or a graphing program. When you have found a straight line function involving the period and the length, write the equation for that function.

The pendulum period can be used to work out 'g', the acceleration due to gravity. Find out how this is done, and use your results to calculate 'g'. Comment on the accuracy (or otherwise) of your experimental data.



Pendulum setup

Investigation 2.4: Measuring 'g' by a free falling object

The acceleration due to gravity for a freely falling object at the Earth's surface is supposed to be about 9.8 m s^{-2}, no matter where it is measured. Use a suitable apparatus (such as a timing ball, a heavy weight attached to a ticker timer, or a picket fence and a pair of photogates) to measure 'g'. Repeat the measurement several times, trying to make each subsequent measurement more accurate than the ones before. Report on your success (or otherwise) and explain clearly what you measured, and how you worked out 'g' from your results.

Notes

Chapter 3: Force and Newton's Laws Explained

3

Notes

Newton's first law

- An object will remain in its state of motion unless acted upon by an unbalanced external force.

This explains why seat belts are life-saving devices in cars and why it can be dangerous to store parcels on the back shelf of a vehicle.

Newton's second law

- The acceleration of an object is directly proportional to the total force acting upon that object, and indirectly proportional to the mass of the object.

This law explains why it is more difficult to start an adult swinging on a playground swing than it is a small child. It also explains why you have to press the brakes on a bicycle hard to stop suddenly.

Mathematically, we can write Newton's second law as:

$$\mathbf{F_{net} = ma}$$

Where: $\mathbf{F_{net}}$ is the unbalanced, or total force acting on the object, measured in newtons (N)
m is the mass of the object (kg)
a is the acceleration of the object (m s^{-2})

Newton's third law

- Every time an object exerts a force on a second object, the second object exerts an equal sized but opposite direction force on the first object.

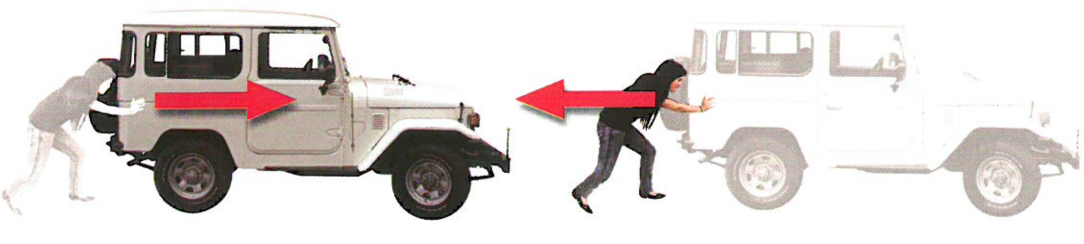
This is often shortened to:

- For every action, there is an equal and opposite reaction.

The third law explains, for example, why rockets work.

- Remember that the action force and the reaction force of Newton's third law act on different objects.

An object's motion depends only on the forces that act on it, not on the forces it exerts on other objects. For example, when you walk, you move because the Earth pushes you forward, not because you push back on the Earth.



Action - you push vehicle

Reaction - vehicle pushes you

Action and reaction always involves one force acting on two objects.

Continued over

Chapter 3: Force and Newton's Laws Explained

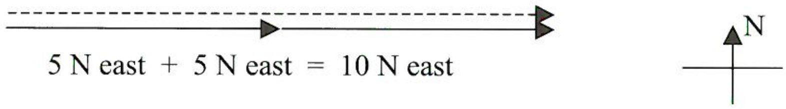
Notes

Forces are vector quantities

Because forces are vectors, you have to use the correct rules when adding or subtracting forces. The result of adding or subtracting vectors is a new vector whose size (magnitude) and/or direction may be different to the originals. It is relatively easy to add vectors acting in parallel directions. Adding or subtracting vectors at angles other than 0° or 180° requires the use of geometry.

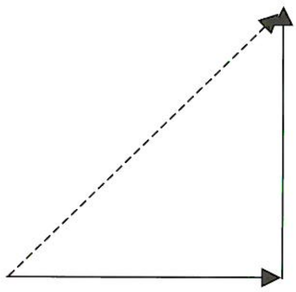
For example, adding two forces of 5 N each can give many different results, depending on the angle between the two forces:

Resultant force (dashed line)

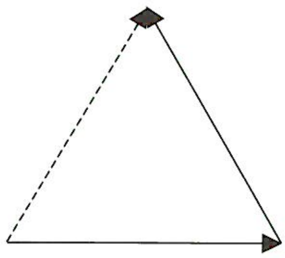


5 N east + 5 N east = 10 N east

5 N east + 5 N west = 0



5 N east + 5 N north = 7.07 N northeast



5 N east + 5 N north 30° west = 5 N north 30° east

Mass and Weight

The **mass** of an object is a measure of how much matter it contains.

The **weight** of an object is the force of gravitational attraction between that object and the nearest planet – in our case, the Earth.

If Donald says that he has a weight of 50 kg, he really should state that he has a mass of 50 kg. His weight is 490 N on Earth.

You can calculate weight using Newton's second law:

$$\mathbf{F_{wt} = mg}$$

Where: $\mathbf{F_{wt}}$ is the weight force, in N

m is the mass in kg

g is the acceleration due to gravity, 9.80 m s^{-2} at sea level on Earth, also known as the gravitational field strength of 9.80 N kg^{-1}

Experiment 3.1: Newton's Second Law

3

Background

Forces produce accelerations. The exact relationship between the size of the force and the size of the acceleration it produces is expressed in Newton's Second Law. The apparatus you will use in this lab is called a 'modified Attwood's machine'. The principle behind it is that the hanging weight exerts a force that accelerates both the cart and the weight, because these are linked. So you have to use the total mass of the cart and the weights when you calculate the acceleration from the mass and the force.

The apparatus used may vary between schools. Either an air track or a friction compensated slope and low friction trolley would work well. Photogates or motion sensors work well as timing mechanisms.

It works best if you can adjust the set-up to 'compensate' for friction. The simplest way to adjust for friction is to tilt the ramp or air track just a little bit, until a cart or glider put on it and gently pushed down the slope rolls or glides down at a constant speed. If you have access to computers, data logging equipment and the appropriate software, you may be able to adapt this lab to use photogates to measure the times with much greater precision than is obtainable with hand-held stop watches.

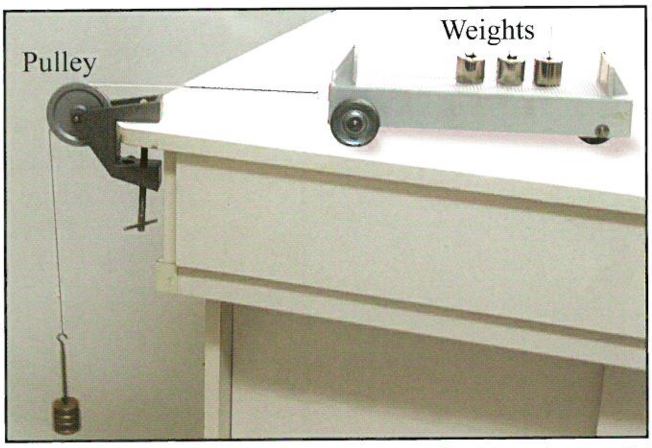
Notes

Aim

To investigate the relationship between net force, mass and acceleration.

Apparatus (per group)

- wheeled carts or air track glider
- wood ramps or air track
- pulleys with clamps
- access to a balance (for measuring masses of masses, carts etc.)
- photogates or motion sensor and suitable software



Apparatus for Experiment 3.1

Pre-Lab Discussion

- Allow a suspended mass to tow a cart (glider) across the track and observe its motion. Remember that a force is required to produce an acceleration. Identify the factors that might affect the acceleration of the cart. Before you proceed, check your list against the lists that other groups have made.
- After a group discussion, write down ideas on how to minimise the effect of friction. Again, check your ideas against those of other groups.
- Discuss how to measure the acceleration of the cart. Note that while you cannot measure it directly, there are at least two ways to determine the acceleration. Check your ideas against those of other groups.
- Identify the dependent and independent variables.
- Remember that the mass that is being accelerated is the total mass of the system (the cart and hanging mass are connected, so both must accelerate at the same rate).
- Design a table in which to record your experimental data, and any calculated values after you process it.

Continued over

Experiment 3.1: Newton's Second Law

Notes

Lab notes

- If possible, use small mass hangers (e.g. 5 g) and change by 10 to 20 g increments.
- To 'friction compensate' the slope, adjust the angle of incline so that the cart can move at a constant speed with a very small initial push.
- Remember to transfer masses from the cart to the hanger in order to keep the total mass constant when you vary the force.
- For each run, calculate the weight of the hanging mass in newtons.
- Keep the system's total mass constant, and change the accelerating force due to the hanging masses by transferring slotted masses between the glider or trolley and the hanger.
- Carry out several trials and record the data.
- Determine the acceleration (e.g. by using photo gates) and plot a graph of the acceleration produced *vs* the accelerating force. Draw a line of best fit by eye.

Post-Lab Discussion

1. Is there a pattern to the way the force and acceleration vary? Explain.

2. What is the significance of the gradient of the force *vs* acceleration graph?

3. What would you expect to happen if you kept the hanging mass constant (that is, kept the accelerating force constant) but changed the mass of the glider or trolley? If time permits, create a suitable hypothesis and test it.

Experiment 3.2: Friction

3

Background

Roller skates and roller blades are popular forms of local transport. Skaters and bladers can maintain speeds greater than those achieved by world champion sprinters. Skates and blades achieve this by minimising friction with the ground.

Aim

To investigate the friction that opposes the motion of a roller skater or roller blader.

Apparatus (per group)

- three pairs of roller skates or roller blades
- inclinometer
- stop watch or motion sensor
- access to bathroom scales
- tape measure
- access to a sloping roller-skating or roller-blading area

Pre-Lab Discussion

- Identify the dependent and independent variables.
- Discuss how you will minimise errors and uncertainties in this experiment.
- Design a table in which to record your experimental data, and any calculated values after you process it.

Lab notes

- Measure and record the length of the slope.
- Measure and record the angle that the slope makes with the horizontal.
- Measure and record the mass (including skates or blades) of each volunteer.
- For each run, calculate the weight of the hanging mass in newtons.
- Measure and record the time that each volunteer takes to roll the length of the slope, starting from rest.

Post-Lab Discussion

1. Using an equation of motion, calculate the average acceleration of each volunteer.
2. Using the angle of the slope, calculate the component, parallel to slope, of the acceleration due to gravity.
3. Hence, determine the average frictional force opposing the motion of each volunteer.
4. Is the average frictional force constant? Discuss what might make it vary.
5. What is the difference between kinetic and static friction? Which did you investigate in this lab?
6. Friction is directly proportional to the force that acts perpendicular to the area of contact. This is often called a 'normal' force. Should the average friction force increase or decrease as the angle of the slope gets steeper? Explain.
7. Roller skates and roller blades minimise friction, yet skaters and bladers are able to accelerate quickly from rest on flat, smooth surfaces such as roller rinks. Explain this apparent contradiction.

Notes

Problem Solving and Calculations Set 3: Force and Newton's Laws

3.1 Free body diagrams show all the forces that act on a single object (a 'free body'). Draw labelled free body diagrams to show the forces that act on:

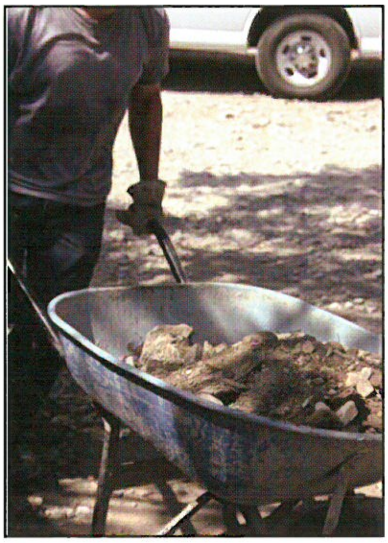
[a] a book resting on a desk;

[b] a person roller skating at a constant speed along a horizontal path;

[c] a rock climber sliding down a rope at a constant speed;

[d] an aeroplane accelerating along the runway before taking off;

[e] an aeroplane climbing and gaining speed after it takes off.



Wheelbarrow

3.2 A gardener pushes a wheelbarrow. According to Newton's Third Law, the barrow's reaction force on the gardener is the exact opposite of his force on the barrow. A bystander concludes the gardener and barrow will not move because they push equally against each other. Using a labelled free body diagram, explain to her why the gardener and barrow will move.

3.3 Use Newton's Law(s) and a free body diagram to explain why:

[a] It is difficult to walk on slippery surfaces such as wet bathroom floors.

[b] The rear drive wheels of an accelerating rally car throw up clumps of dirt.

[c] Joggers who run on grass tend to suffer fewer injuries than joggers who run on concrete or bitumen.

[d] You are more likely to have an accident on your bicycle if you are riding it on a gravel or wet pathway.

[e] It is dangerous to allow people (or dogs) to travel in the back of tray top trucks or open utilities.

3.4 Dr Spook is the first human to set foot on an unexplored planet. He radios back to the mother ship that his weight is 525 N on the surface of this planet. If Dr Spook's mass is 70.0 kg, what is the gravitational acceleration on the surface of this new world?

Notes

3.5 A 40.0 kg astronaut travels from Earth to Mars. The acceleration due to gravity on the Earth's surface is 9.80 m s^{-2} whereas on Mars it is 3.72 m s^{-2}.

[a] Compare the mass of the astronaut on Earth with her mass on Mars.

[b] Compare the weight of the astronaut on Earth with her weight on Mars.

[c] It takes a certain horizontal force to accelerate the astronaut at 2.0 m s^{-2} while she is on Earth. What horizontal force on Mars would accelerate her at the same rate?

[d] Would she be able to jump higher on Mars than she can on Earth? Explain.

3.6 You throw a 0.50 kg basketball vertically down onto a driveway. If the ball strikes the surface at 3.2 m s^{-1}, rebounds with a velocity of 1.9 m s^{-1} and is in contact with the driveway for 0.15 s, find:

[a] the change in velocity of the ball as its rebounds;

[b] the average acceleration of the ball as it rebounds; and hence

[c] the average force of the driveway on the ball.

Continued over

Problem Solving and Calculations Set 3: Force and Newton's Laws 3

Notes

3.7 A 13.0 kg crate of oranges falls off the back of a truck that is travelling at 6.50 m s^{-1} to market. If the crate slides along the road for 1.30 seconds before coming to rest, calculate the average frictional force the road surface applies to the crate.

3.8 Sean steps on the brake pedal for 2.5 s. This applies a retarding force of 2.10 x 10^3 N to slow his 750 kg car. Calculate his car's final velocity if its initial velocity is 16.5 m s^{-1} east.

3.9 A large truck and a small car collide head-on.
[a] Which vehicle experiences the greater force due to the collision? Explain.
[b] Which vehicle experiences the greater acceleration due to the collision? Explain.

3.10 Wilma examines the reaction forces that passengers in a lift experience by taking her bathroom scales into a lift within a tall building. Before the lift starts to move, Wilma stands on the scales. They show a reading of 50.0 kg. She remains on the scales as the lift travels between floors.
[a] Describe the motion of the lift if Wilma's scales show a reading of
i) 55.0 kg
ii) 50.0 kg
iii) 47.5 kg
[b] What reading will the scales show when the lift
i) starts to accelerate upwards at 1.60 m s^{-2}?
ii) moves at its cruising speed towards the top floor?
iii) accelerates at 1.30 m s^{-2} as it slows to stop at the top floor?
iv) starts to slow down at the rate of 1.60 m s^{-2} as it returns from the top floor to stop at the ground floor?

Weighing scales

3.11 Workers on a building site load a 15.0 kg platform with 160 kg of bricks. A winch hoists the bricks up the side of the building using a heavy duty cable attached to the platform. Calculate the size and direction of the force acting through the cable on the platform of bricks, if the winch:
[a] holds the bricks stationary 22.4 m above the ground.
[b] accelerates the bricks from the ground towards the first floor at a rate of 1.50 m s^{-2}.
[c] raises the bricks to the second floor at a steady speed of 7.50 m s^{-1}.
[d] lowers the bricks from the third floor towards the ground with an acceleration of 3.00 m s^{-2}.

Continued over

Problem Solving and Calculations Set 3: Force and Newton's Laws

3.12 Maria and Chris sit next to each other on chairs equipped with castor wheels.

[a] If both students have their feet off the ground and are roughly the same size, describe what happens if Maria suddenly pushed Chris away.

[b] How would the resulting motion differ if Maria had a much greater mass than Chris?

Baggage handlers cart

3.13 A baggage handler at the airport drives a cart, which applies a 965 N horizontal force to the trolleys it pulls out to the aeroplanes.
The cart is pulling two luggage trolleys, the first having a mass 525 kg and the second a mass of 385 kg. The frictional force is one-twelfth of the weight of the trolleys.

[a] Calculate the size of the frictional force.

[b] Calculate the net horizontal force acting on the trolleys.

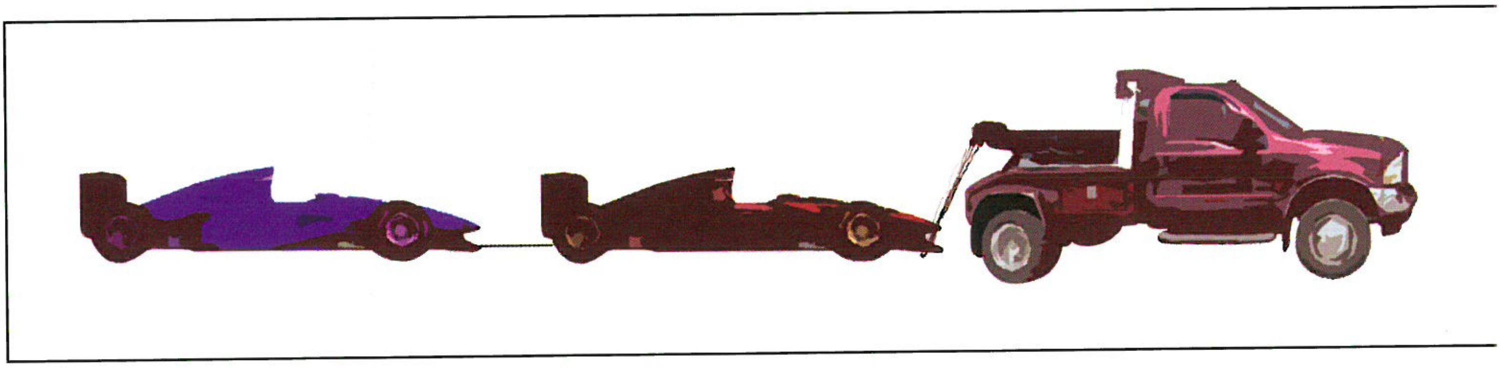
[c] Calculate the acceleration of the trolleys.

[d] What is the tension in the tow bar between the first and second trolleys?

[e] If the cart goes over a bump and disconnects from the second trolley, what is the new acceleration of the trolley that is still connected up?

3.14 Leo dropped a feather and a stone from a second storey window. He noted that the feather slowly fluttered to the ground while the stone plummeted. He then dropped a piece of limestone and a similar sized but heavier granite stone simultaneously from the window. Both rocks appeared to hit the ground at the same time. Explain Leo's observations.

3.15 At the Melbourne Grand Prix, two identical cars involved in the celebrity race broke down. Each car had a mass of 1.20×10^3 kg. A tow truck went out to the damaged vehicles and attached two tow ropes as the diagram shows. Calculate the tension in each of the two ropes as the truck started to tow the damaged vehicles back to the pits with an acceleration of 1.45 m s^{-2}.



Towing two cars

Investigation 3.3: Terminal velocity

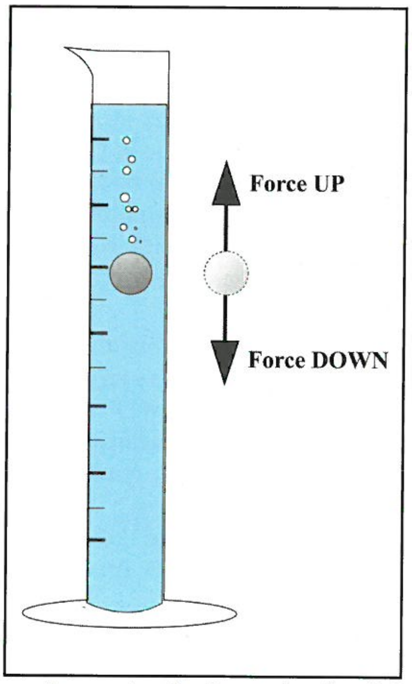
Any object moving through a fluid (e.g. air, water or honey) experiences a resistance force because of the viscosity of the fluid. Air is much less viscous than honey, so it is easier to move through air than honey.

When a ball bearing is dropped into a viscous fluid then there are two forces acting on the ball bearing:

1. The force of gravity – the ball bearing's weight
2. A friction-type force due to the liquid's viscosity

When the ball bearing reaches its terminal (maximum) velocity, these two forces must be equal in size but opposite in direction. This means the forces acting on the ball bearing are balanced and add up to zero.
This is the physics behind the parachute: the parachutist reaches the same final speed, no matter at what height they leave the support plane.

This terminal speed may depend upon the liquid, and on the diameter of the ball bearing. Design an investigation to determine the relationship between the terminal speed and the diameter of a ball bearing. Your design should include explanations of the hypothesis you will test, the evidence you will gather to test your hypothesis, the variables you will investigate and control and the ways that you will minimise uncertainties or errors in your results.



Apparatus for Investigation 3.3

Notes

Driving an Off-road Vehicle

Other laws of physics can be explained using the theme of driving a 4WD vehicle. For example, momentum is a term that is used in all sorts of contexts. You may have heard radio and TV personalities referring to the 'momentum of a winning team' as it surges to victory, or the 'momentum' of a new band as it becomes increasingly popular with its fans. The use of momentum in these instances has been borrowed from the scientific meaning of the word, which can be traced back to Newton's interpretation.

In scientific terms any object that is moving has a certain momentum. The momentum depends on its mass and velocity. 4WD vehicles, having greater mass than conventional sedans, usually have greater momentum when moving at the same velocity. This can be both an advantage and a disadvantage if the vehicle is ever involved in an accident. While the occupants may be better protected in such an incident, greater damage can be done to the other party.

You have probably heard of the expression 'conservation of the environment' which refers to restoring the original landscape when humans cut down trees or dig for minerals. Conservation of momentum means that the total momentum before a collision is equal to the total momentum after the collision. If a 4WD vehicle is travelling along a bush track with a certain momentum and it hits a stationary log, the total momentum before the collision is equal to the total momentum after the collision. The individual momenta of the log and the vehicle can be calculated before and after the collision and the conservation of momentum can be verified.

Conservation is also a concept that is applied to energy. As the 4WD vehicle travels along the track it has kinetic energy, which depends on its velocity and may be transformed into other energy types.

For example, if the driver is not careful the vehicle may travel too fast over a bump and become airborne. The vehicle now has transformed some of its kinetic energy into gravitational potential energy. Gravitational potential energy depends on the mass and height of the body above the surface. The total mechanical energy of an object such as a 4WD vehicle includes both its kinetic energy and its gravitational potential energy.

As the 4WD vehicle falls back to the track surface it loses its gravitational potential energy. This energy is mostly stored, as elastic potential energy, in the springs and shock absorbers as it hits the track again. When energy is transferred like this, we say that work is done. In a similar way, a hammer can do work by driving a nail into a piece of timber, just as the vehicle can do work on the springs. As a passenger you experience some jolting but most of the work is done on the suspension of the vehicle. The big idea here is that work is done when energy is transferred or transformed.

One reason for choosing to own a 4WD vehicle is power. Having power means different things to different people. Hopefully people choose a 4WD vehicle because of its powerful engine and not because they now have the 'power' to intimidate other road users! An engine's power is usually quoted in kilowatts and is measured by how many joules of energy it can output per second. 4WD vehicles with diesel engines are usually slower off the mark than similar-sized petrol-engined vehicles; but they are more powerful. Thus, they can pull heavier caravans and boat trailers because they can supply a greater quantity of energy per unit of time.

Driving an Off-road Vehicle: Comprehension Questions

1. [see Chapter 4]
   [a] Explain the difference between momentum and impulse.
   [b] Calculate the momentum of a 2.25 tonne off-road vehicle as it travels west along a bush track at 15 km h^{-1}.
   [c] Estimate the momentum of a 2.25 tonne off-road vehicle as it travels west along a freeway. Show all your working and list any assumptions you make.

2. [see Chapter 4]
   A 2.25 tonne off-road vehicle, travelling west along a bush track at 15 km h^{-1}, collides with a log. The vehicle and the log are travelling west at 10 km h^{-1} immediately after the collision.
   [a] Calculate the mass of the log.
   [b] Sketch a momentum *vs* time graph of the collision described in part [a] above, showing the momenta of the vehicle and the log both before and after the collision.

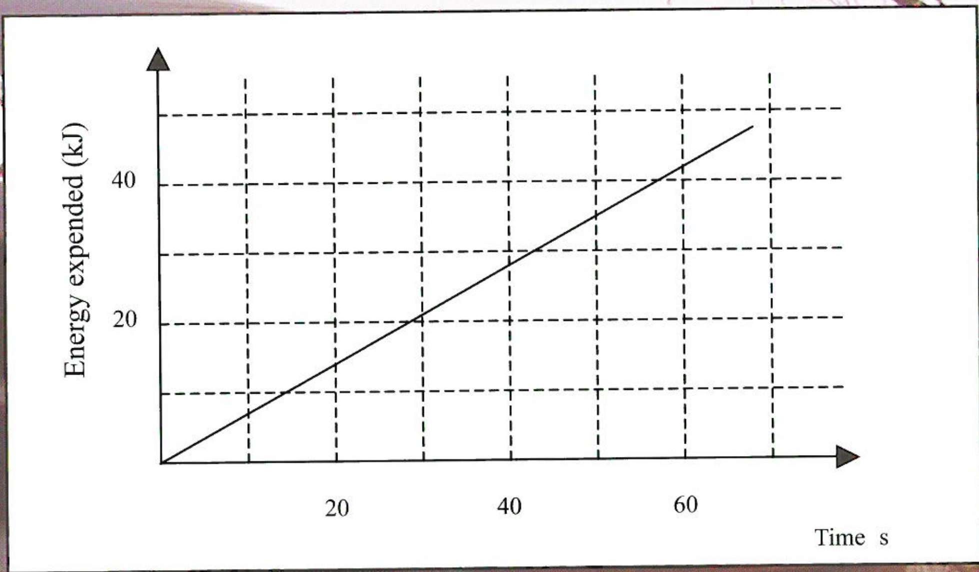
3. [see Chapter 5]
   [a] Explain the difference between kinetic energy and potential energy.
   [b] Calculate the kinetic energy of an off-road vehicle, mass 2.25 tonnes, travelling at a constant speed of 100 km h^{-1} along a straight and level highway.
   [c] Calculate the kinetic energy of an off-road vehicle of mass 2.25 tonnes travelling along a bush track at 15 km h^{-1}.
   [d] If such a vehicle hit a bump in a bush track, it could be launched into the air. Estimate the maximum height it could reach. Show all your working and list any assumptions you make.
   [d] Sketch (no further calculations required) a graph showing how the vehicle's kinetic energy and the potential energy vary with time during its flight after hitting a bump in the track.

4. [see Chapter 5]
   [a] Explain the relationship between work and energy.
   [b] Calculate the minimum work that must be done by a 2.25 tonne vehicle's engine to give it a velocity of 50 km h^{-1}, starting from rest.
   [c] Explain why this calculation gives a minimum value for the work done.

Continued over

Driving an Off-Road Vehicle: Comprehension Questions

5. [see Chapter 5]
[a] Explain the relationship between power and energy.
[b] Explain the relationship between work and power.
[c] Calculate the power of a vehicle motor that transfers 10^5 J to the vehicle in 10^3 s.
[d] A person expends energy at the rate of 435 W while pushing a vehicle across a parking lot at a constant speed. Calculate the total energy transferred from the pusher to his surroundings if he pushes the vehicle for 15 s.
[e] A vehicle's engine is rated at a maximum of 255 kW. Calculate the magnitude of the total air resistance and friction force that opposes this vehicle's motion at its top speed of 185 km h^{-1}.
[f] The graph below shows the energy, expended by a horse pulling a load, as a function of time. Use the graph to determine the power output of this horse.



Chapter 4: Momentum and Impulse Explained

4

Notes

Momentum

A table-tennis ball and a golf ball are roughly the same size. If a table-tennis ball hits you, you are unlikely to feel much pain. However, a golf ball travelling at the same speed can inflict serious injury. This happens because the golf ball has a greater momentum than the table-tennis ball. Momentum is a vector quantity. It is the product of the object's mass and velocity.

$$\mathbf{p} = \mathbf{m}\,\mathbf{v}$$

or

$$\Delta \mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = \mathbf{m}(\mathbf{v} - \mathbf{u}) = \mathbf{m}\Delta \mathbf{v}$$

where: **p** is the momentum measured in kilogram metres per second (kg m s^{-1})

$\mathbf{p}_i$ is the initial momentum in kg m s^{-1}

$\mathbf{p}_f$ is the final momentum in kg m s^{-1}

$\Delta\mathbf{p}$ is the change in momentum measured in kg m s^{-1}

m is the mass in kg

v is the final velocity in m s^{-1}

u is the initial velocity in m s^{-1}

$\Delta\mathbf{v}$ is the change in velocity in m s^{-1}

Force, impulse and rate of change

The rate of change of momentum of an object is directly proportional to the unbalanced force acting upon that object.

You can express this mathematically as:

$$\frac{\Delta \mathbf{p}}{\mathbf{t}} = \mathbf{F}_{net}$$

Thus $\mathbf{F}_{net}\mathbf{t} = \Delta \mathbf{p} = \mathbf{m}(\mathbf{v} - \mathbf{u})$

and $\mathbf{F}_{net} = \dfrac{\mathbf{m}(\mathbf{v}-\mathbf{u})}{\mathbf{t}} = \mathbf{m}\left(\dfrac{\mathbf{v}-\mathbf{u}}{\mathbf{t}}\right) = \mathbf{ma}$

where $\Delta\mathbf{p}$ is the change in momentum measured in kg m s^{-1}

t is the time measured in s

$\mathbf{F}_{net}$ is the overall or resultant force measured in newtons (N)

m is the mass measured in kg

v is the final velocity measured in m s^{-1}

u is the initial velocity measured in m s^{-1}

a is the acceleration measured in m s^{-2}

If an unbalanced force acts on an object for a time, the object accelerates; that is, the object's momentum changes. The larger the force, the greater the change in the object's momentum. Similarly, the longer the force acts on the object, the greater the change in momentum.

Continued over

Chapter 4: Momentum and Impulse

Notes

Impulse is the change of momentum caused by a force and is equal to the product of the force and time during which it acts. Impulse is a vector quantity. It is usually quoted in newton seconds (N s), which is the same unit as kilogram metres per second (kg m s^{-1}) used for momentum.

$$\textbf{Impulse} = \mathbf{F_{net}t} = \mathbf{m(v-u)} = \Delta\mathbf{p}$$

where: **impulse** is measured in newton seconds (N s) or kilogram metres per second (kg m s^{-1})
F is the force in newtons (N)
t is the time in s
m is the mass in kg
v is the final velocity in m s^{-1}
u is the initial velocity in m s^{-1}

Law of conservation of momentum

The law of conservation of momentum describes how 'the total momentum in any closed system will stay constant'.
You can express the conservation of momentum as:

$$\Sigma \mathbf{p_i} = \Sigma \mathbf{p_f}$$

For two objects colliding together, you can express this as:

$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

where: $\mathbf{m_1}$ is the mass of object 1 in kg
$\mathbf{m_2}$ is the mass of object 2 in kg
$\mathbf{u_1}$ is the initial velocity of object 1 in m s^{-1}
$\mathbf{u_2}$ is the initial velocity of object 2 in m s^{-1}
$\mathbf{v_1}$ is the final velocity of object 1 in m s^{-1}
$\mathbf{v_2}$ is the final velocity of object 2 in m s^{-1}

Experiment 4.1: Conservation of Momentum in an Explosion

Background

When one object breaks into pieces, we can expect the total momentum of the exploding system to remain constant. That means that is we can measure the mass and velocity of each object involved: the vector sum of their momenta before the explosion should equal the vector sum of their momenta after the explosion.

In this lab, the trolleys are initially stationary, and then move off in opposite directions, propelled by a released spring. Most lab trolleys have a spring built into one end that can be compressed, then released to push the trolleys apart. The way you should carry out the experiment depends upon the equipment you have. An air track is ideal, but pair of low friction trolleys also works well.

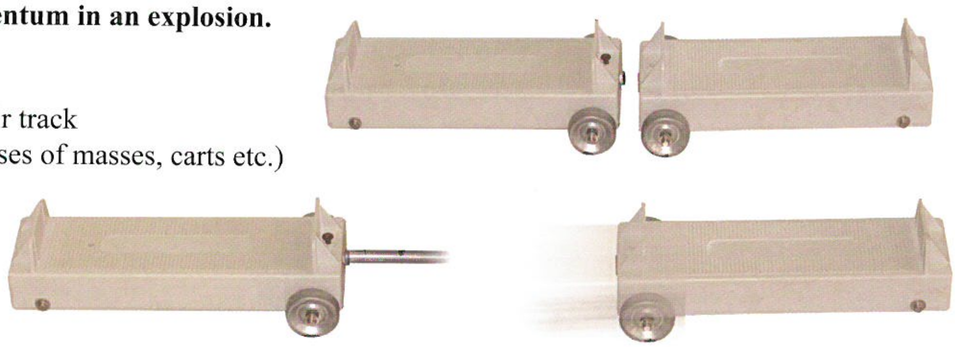
Aim

To investigate the conservation of momentum in an explosion.

Apparatus

(per group)

- wheeled carts or air track gliders and air track
- access to a balance (for measuring masses of masses, carts etc.)
- masses for loading the trolleys
- photogates or motion sensor
- suitable software



Apparatus for Experiment 4.1

Pre-Lab Discussion

- Discuss how to simulate an 'explosion' to separate the trolleys, and how to measure the velocities of the trolleys as they separate.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table in which you can record your experimental data.

Lab notes

- Set up the equipment, carry out several trials using various loads to change the masses of the trolleys and record the data.
- Carry out any calculations you need to test your hypothesis.

Post-Lab Discussion

1. Do your results confirm your hypothesis? Explain.
2. The occupants of a stationary car that it struck from behind by another vehicle may suffer 'whiplash' injuries. Why?
3. Does wearing a seat belt or having air bags in the front reduce the severity of whiplash? Why, or why not?

Notes

Experiment 4.2: Conservation of Momentum in a Collision

Notes

Background

When two objects collide, we can expect the total momentum of the colliding system to remain constant. This means we can measure the mass and velocity of each object involved: the vector sum of their momenta before they collide should equal the vector sum of their momenta after the collision.

The way you should go about this depends upon the equipment you have. An air track is ideal, but a friction compensated slope with low friction trolleys also works well.

Aim

To investigate the conservation of momentum in a simple collision.

Apparatus (per group)

- wheeled carts or air track gliders and air track
- access to a balance (for measuring masses of masses, carts, etc.)
- masses for loading the trolleys
- photogates or motion sensor
- suitable software

Pre-Lab Discussion

- Discuss how to measure the velocities of the trolleys. It is easier if the target trolley (trolley 2) is initially stationary, and if the two trolleys move off together after the collision, sticking to one another using Velcro or small magnets. More complex examples of momentum transfer are more difficult to measure using photogates.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table in which you can record your experimental data.

Lab notes

- Set up the equipment as shown in the diagram.
- Carry out several trials and record the data.
- Carry out any calculations you need to test your hypothesis

Post-Lab Discussion

1. Do your results support your hypothesis? Explain.

2. The occupants of a stationary car that is struck from behind by another vehicle may suffer 'whiplash' injuries. Why?

3. Does wearing a seat belt or having air bags in the front reduce the severity of whiplash? Why, or why not?

Problem Solving and Calculations Set 4: Momentum and Impulse 4

Notes

4.1 Nic has a mass of 64.0 kg and cycles north along Great Northern Highway at 9.50 m s^{-1}. Calculate Nic's momentum.

4.2 Michelle and Ricky park their car on a weighbridge. After getting out, they find its mass is 2.1 x 10^{3} kg. If Michelle and Ricky have masses of 55 kg and 45 kg respectively, calculate the momentum of the car and occupants as they drive into the city at a velocity of 36 km h^{-1} west.

4.3 Both a football and a football player have a momentum of 8.00 kg m s^{-1} south. Calculate the velocity of the:

[a] 75.0 kg player;

[b] 500 g football.

4.4 Calculate the impulse in each of the following cases:

[a] Tom's bat strikes a cricket ball and applies a 63.0 N force to the ball over a period of 0.10 s.

[b] Linda cues a 200 g billiard ball at right angles onto a cushion with a speed of 1.25 m s^{-1}. The ball rebounds from the cushion at the same speed.

[c] Luigi's 1.85 x 10^{4} kg semi-trailer has a 4.25 x 10^{3} kg load when he brings it to a halt from 80.0 km h^{-1}.

[d] You use your bicycle brakes to supply a retarding force of 150 N over a time period of 4.0 s to stop at an intersection from an initial velocity of 8.33 m s^{-1} west.

4.5 A gust of wind blowing for 13.0 s accelerates a model yacht, changing its momentum by 195 N s in the direction of the force. Calculate the magnitude of the force.

4.6 While driving a 250 kg go-cart, you step on the brake pedal for 2.5 s as you near a corner. This applies a retarding force of 810 N to slow down the cart. If the initial velocity of the cart is 16.5 m s^{-1}, calculate the cart's final velocity.

4.7 Max hid behind a bush. When Sam walked past, Max flung a water balloon at Sam with a velocity of 7.00 m s^{-1}. The 150 g water balloon struck a very surprised Sam in the middle of the back; a perfect shot! Calculate the change in the water balloon's momentum:

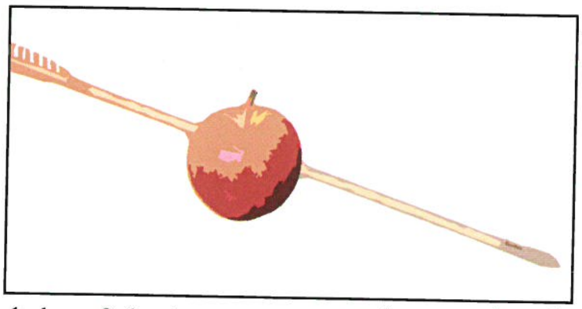
[a] as Max threw it;

[b] as it struck Sam.

4.8 Legend has it that a Swiss hero called William Tell shot an apple from his son's head using a crossbow. Consider a 100 g apple balanced on the head of young Tell. His father shoots an arrow of mass 120 g at a speed of 30 m s^{-1}. Calculate the speed at which the apple leaves the son's head if:

[a] the arrow is permanently embedded in the apple;

[b] the arrow passes through the apple and exits with a speed of 15 m s^{-1}.



Arrow and apple

4.9 Momentum, impulse and force play a large part in sport. Use your knowledge of physics to answer the following:

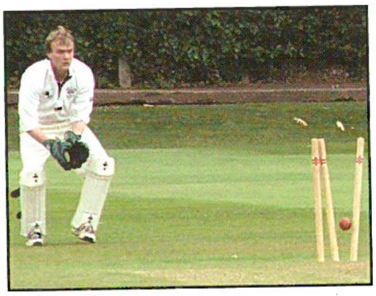
[a] In the game of netball, players often move quickly and then come to a sudden stop. How does the abrupt nature of the game relate to the knee injuries netball players frequently suffer?

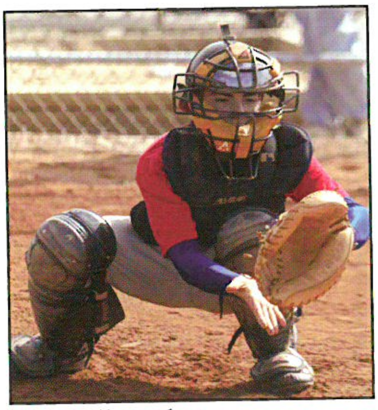
[b] A golfer swings a golf club at the ball. List two factors that govern the speed at which the golf ball leaves the face of the golf club. Explain how these factors influence the speed.

[c] Some dishonest hockey players hide strips of lead under tape near the bottom of their hockey sticks. Such illegally modified sticks can propel the ball faster than regulation sticks. Explain the physical reasons for this.

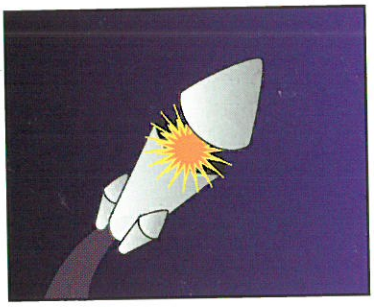
Continued over

Problem Solving and Calculations Set 4: Momentum and Impulse


Wicketkeeper


Baseball catcher


Safety hat


Separation

[d] Susie owned two identical tennis racquets and decided to experiment with the racquets by varying the tension in their strings. She had one strung loosely and the other strung tightly. She took both down to the tennis courts and played with each racquet in turn. Susie found that even though she used the same force when swinging both racquets at the ball, the more tightly strung racquet propelled the ball faster over the net than the other racquet. Why is it that using a tightly strung racquet provides the tennis ball with the greater change in momentum?

[e] When you watch a wicket keeper catch a cricket ball, you will notice that he allows his hands to trace the path of the ball as it reaches him. What is the advantage of doing this?

[f] Baseball catching is different, as the catcher moves toward the ball often with his hand extended in front of him. Explain the reason for the difference.

4.10 Modern cars have many design features to increase the safety for their occupants. In each case, use your knowledge of physics to explain how it increases the safety of a vehicle's occupants.

[a] Seat belts

[b] Collapsible steering wheels

[c] Crumple zones on the front and rear of cars

[d] Head rests on seats

[e] Air bags

4.11 During a collision between two cars, a passenger's head strikes the unpadded dashboard with an average force of 48 N for 2.0 ms. With a suitable air bag, the impact would have lasted a longer time of 80 ms.

[a] Calculate the average reaction force the air bag would exert on the passenger's head.

[b] Explain why the air bag is a safety feature.

4.12 Safety hats are worn on construction sites. The hat in the picture (*left*) has a 3.00 cm thick layer of foam rubber inside the helmet. Design regulations state that when a brick strikes the helmet from a height of 20.0 m it must not penetrate this protective layer. Assume the resistance that the foam offers is constant over time.

[a] What speed will the brick have after falling through a distance of 20.0 m?

[b] What is the acceleration caused by the foam if the brick is to stop in 3.00 cm?

[c] What force is exerted on the helmet if the brick has a mass of 1.50 kg?

[d] How long does it take for the brick to come to rest after striking the helmet?

[e] What impulse does the brick exert on the helmet?

[f] What is the change in momentum of the helmet?

4.13 Car manufacturers design seat belts to withstand a force many times greater than the weight of a person. Why is this so?

4.14 A spacecraft of mass 800 kg coasts through space at 500 m s^{-1}. An explosion separates the craft into two pieces, projecting the 240 kg tail section in the opposite direction with a speed of 120 m s^{-1}. Calculate the final velocity of the front section of the spacecraft.

Continued over

Problem Solving and Calculations Set 4: Momentum and Impulse 4

4.15 A soldier fired a 10.0 kg shell from a 5.00 x 10^3 kg cannon. The shell's velocity as it left the cannon was 75.0 m s^{-1}. Assuming that only the shell and the cannon are involved, calculate the:

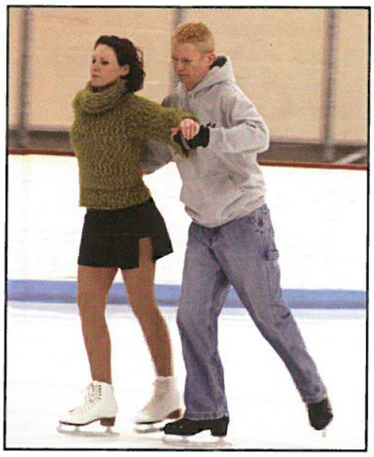
[a] mometum of the shell at the instant that it left the cannon;

[b] combined momentum of the cannon and shell before firing;

[c] combined momentum of the cannon and shell after firing;

[d] recoil velocity of the cannon.

4.16 A forensic scientist needs to find the impact speed of a bullet for a criminal investigation. She decides that the easiest way to achieve this is to measure the velocity of a block of wood that is on a low friction surface, like an air track, after she fires a bullet into it. Explain what she needs to measure, and how she could then work out the bullet's speed.

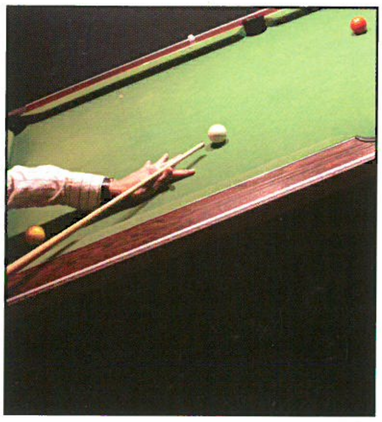


Skaters

4.17 Hamish and Mary experiment with heavy flat stones sliding across the ice rink. What speed will Hamish's stationary 0.50 kg stone gain after Mary's 4.0 kg stone strikes it at 2.5 m s^{-1}, and then continues forward with a speed of 1.4 m s^{-1} after the collision?

4.18 Natasha and Peter are skating arm in arm with a speed of 2.00 m s^{-1} towards the west end of a rink (*right*). Natasha's mass is 40.0 kg and Peter has a mass of 50.0 kg. Maria, of mass 45 kg, skates from behind at 5.00 m s^{-1} and grabs her two friends as she collides with them. At what speed do the three friends continue?

4.19 In a shunting yard a railway wagon of mass 4.20 x 10^3 kg rolls along a line at 2.0 m s^{-1} and collides with another wagon, mass 2.50 x 10^3 kg, moving 1.50 m s^{-1} in the same direction. The impact propels the smaller wagon away at 3.00 m s^{-1}. What is the velocity of the larger wagon after the collision?



Billiards

4.20 Sean tested the armour plating of a riot vehicle by firing a 0. 020 kg bullet at 500 m s^{-1} into its side at an angle of 45°. The armour plating deflected the bullet at a similar angle without any appreciable speed decrease. Calculate the magnitude of the change in the bullet's momentum.

4.21 Walter cues an 80.0 g ball towards Linda just as she cues a 60.0 g ball towards Walter. The larger ball's speed is 12.0 m s^{-1} and the smaller ball's 14.0 m s^{-1}. After the collision, Linda's ball has twice the speed of Walter's ball. Calculate the velocity of each ball after the collision if the balls move in:

[a] the same direction after the collision;

[b] opposite directions after the collision.

4.22 A railway locomotive pushed a stationary wagon to accelerate it to a speed of 4.00 m s^{-1}. The engine then applies an equivalent force over the same time on a second wagon to accelerate it from rest to a speed of 6.00 m s^{-1}. The second wagon rolls down the track, collides with the first, and the two lock together. The loco must now push the two stationary wagons to the other end of the shunting yard. What speed could the two railway carriages achieve if the loco applies the same impulse?

Chapter 5: Energy, Work and Power Explained


Bird in flight

Notes

Energy is one of the most important ideas in science. However, energy is an abstract concept, not a substance or an object. One result of this is that energy cannot be completely explained by a single phrase or sentence. Two ways to think about energy are:

- Energy (E) is a quantity that causes change to occur.
- Energy (E) is a measure of an object's ability to do work.

Kinetic and Potential Energy

When an object moves, it has kinetic energy (E_k).

For example, falling rain and a ballerina dancing across the stage both have kinetic energy.

The position or shape of an object determines its potential energy (E_p).

For example, a stretched elastic band has elastic potential energy. A lift at the eighth floor has gravitational potential energy.

Kinetic energy and gravitational potential energy are both scalar quantities. You can calculate them using:

$$\mathbf{E_k = \tfrac{1}{2}mv^2}$$

and:

$$\mathbf{E_p = mgh}$$

where: $\mathbf{E_k}$ is kinetic energy in joules (J)
$\mathbf{m}$ is mass in kilograms (kg)
$\mathbf{v}$ is speed in metres per second (m s^{-1})
$\mathbf{E_p}$ is gravitational potential energy in joules (J)
$\mathbf{g}$ is acceleration due to gravity, 9.80 m s^{-2} at sea level on Earth.
$\mathbf{h}$ is height in metres (m)

Work

Work (W) is a measure of the amount of energy transferred between the object doing the work and the object on which the work is done. When an object A exerts a force acts upon another object B, causing B to move in the direction of any component of the applied force, then A does work on B.

Work is a scalar quantity. You can calculate it as the product of the applied force and the distance through which the object moves in the same direction as the force:

$$\mathbf{W = Fs}$$

where: $\mathbf{W}$ is the work done, in joules (J)
$\mathbf{F}$ is the net force, in newtons (N)
$\mathbf{s}$ is the distance moved in the direction of the force, in metres (m)

Thus:

$$\mathbf{W = \Delta E}$$

For an object whose speed changes, this becomes:

$$\mathbf{W = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2}$$

For an object whose height changes, this becomes:

$$\mathbf{W = mgh_{final} - mgh_{initial}}$$

Continued over

Notes

For example: Stephanie does work on a suitcase when she lifts it off the ground; wind blowing from the north-east does work on a sail boat that speeds up in a westerly direction.

Power

Power (P) is the rate of doing work.

For example, consider identical twins who climb three flights of stairs. Peta decides to take her time and climb the stairs slowly, while Tenille runs up the stairs. Both Peta and Tenille do the same amount of work in climbing the stairs, but Tenille has expended energy more quickly and needed more power from her muscles.

By definition you calculate power from:

$$P = \frac{W}{t}$$

or you can express it as:

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

Where ΔE is any change in energy the object experiences. For example, you can calculate power from:

$$P = \frac{\Delta E_k}{t} = \frac{\frac{1}{2}mv^2 - \frac{1}{2}mu^2}{t}$$

$$P = \frac{\Delta E_p}{t} = \frac{mgh_f - mgh_i}{t}$$

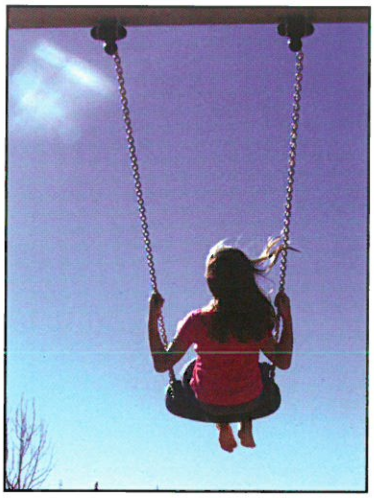
$$P = \frac{Fs}{t}$$

$$P = Fv_c$$

where **P** is the power in watts (W)
W is the work in joules (J)
t is the time in seconds (s)
ΔE is the change in energy in joules (J)
v_c is the constant velocity measured in metres per second (m s^{-1})

Conservation of Energy

Energy can be transferred or changed into another form. For example, a child on a swing gains potential energy as the swing climbs higher but at the same time loses kinetic energy as it slows. The child regains this kinetic energy on the downward swing but loses potential energy in doing so.


Swing

Other forms of energy include heat, light and sound. For example, consider a Girl Guide who drops her pocket knife onto a granite rock. As the knife falls from her hand its potential energy is converted into kinetic energy. On striking the rock, it produces a spark of light, makes a noise and bounces off.

Experiment 5.1: Roller Coaster

Notes

Background

Roller coasters use gravitational potential energy to provide all the energy needed to run the car from the start to the finish of the track.

In this lab, you will investigate the energy relationships along a short stretch of roller coaster track. If you have access to computers, data logging equipment and the appropriate software, you may be able to adapt this lab to use a motion sensor to measure the speed at the base of the track, or a pair of photogates to measure the time with much greater precision than is obtainable with hand-held stop watches.

Aim

To investigate the relationship between potential and kinetic energy.

Apparatus (per group)

- metre ruler
- stop watch
- low-friction toy car
- section of track
- retort stand and clamp
- access to a balance

Pre-Lab

- Work out how to use the equations of energy to calculate the gravitational potential energy of the car when it is at the top of the section of track.
- Work out how to use the equations of energy to predict the car's kinetic energy at the bottom of the track, and hence its speed at the bottom of the track.
- Work out how to use the equations of motion to predict the time the car will take to roll down the track.
- Plan your experiment using a range of initial heights for the start of the car's journey.
- Ensure you have planned to stop the car safely each time it runs down the ramp.
- For each height, use the equations to calculate (predict) the time that the car will take to reach the bottom of the track.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.

Lab notes

- Set up the track to match one of the heights you used in your pre-lab predictions.
- Carry out several trials and record the data.
- Repeat for the other heights you used in your predictions.
- Compare the predicted and actual times.

Continued over

Experiment 5.1: Roller Coaster

5

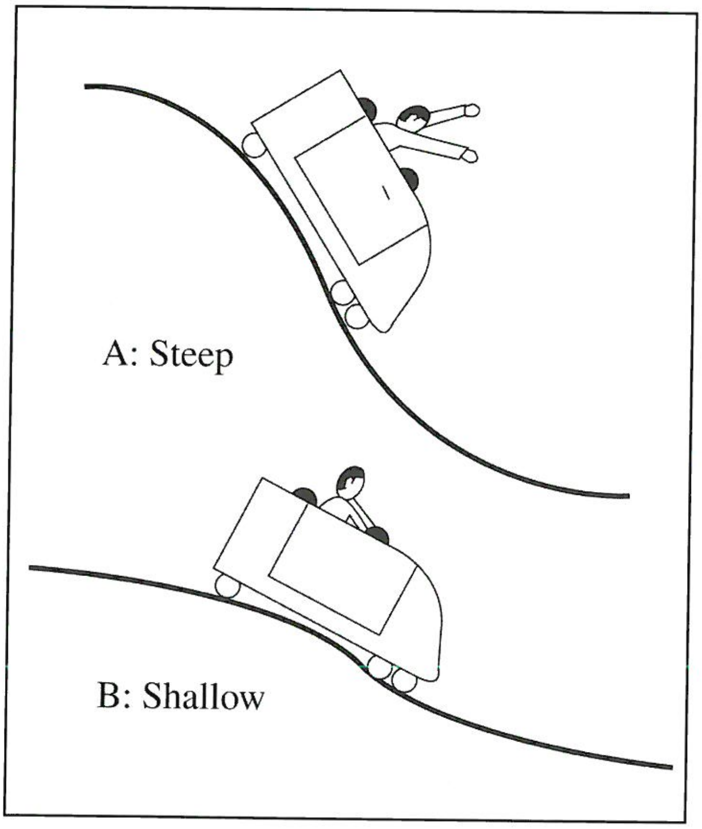
Post-Lab discussion

Notes

1. Did the results work out the way you predicted? Explain any patterns or differences.

2. In a full-sized roller coaster track, the car starts at a height 16 metres above the lowest point on the track. How does the angle (steepness) of the track affect the maximum speed of the car when it gets to the lowest point? For example, would you expect the car to be moving faster if the track looked like diagram A or diagram B? Explain your reasoning.

3. A ski jump works in a similar way to the roller coaster. A jumper pushes forwards at the top, accelerates down the ramp, then flies through the air and lands on the snow far below. Separate the journey into simpler stages, e.g.
   A: pushes forward at the top
   For each stage, identify:
   (a) whether work is done, and note by whom or what, on whom or what, and the result of any work being done; and
   (b) any change of energy that occurs during the journey.



Experiment 5.2: Vehicle Power

Notes

Background

The electric motor in a battery-powered toy vehicle converts much of the chemical potential energy stored in the batteries into kinetic energy of the vehicle.

Aim

To investigate the power output of a toy electric car.

Apparatus (per group)

- metre ruler or tape measure
- stop watch
- battery-powered toy car
- cotton thread
- set of masses and mass hanger
- masking tape

Pre-Lab

- Work out how to use the equations of energy to calculate the gravitational potential energy change of the masses when they are lifted from the floor to a measured height.
- Work out how to use the equations of power to calculate the car's power output.
- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Design a table suitable for recording all the measurements you will take.
- Discuss how you can minimise errors and uncertainties in the lab.

Lab Notes

- Put the electric vehicle on a bench and wrap some thread at least five times around one of the car's drive wheels.
- Attached the other end of the thread to a known mass and set it on the floor.
- Suspend the drive wheel so it is directly above the mass. Turn the drive wheel to take up any slack in the thread.
- Measure the height that the mass climbs before it reaches the drive wheel.
- Return the mass to the floor, switch on the car's engine and measure the time that the car takes to lift the mass through the measured height.

Post-Lab discussion

1. Calculate the effective power that the vehicle's motor produces.

2. The speed of the vehicle is limited by the power of its engine, and the friction that opposes the vehicle's motion. Design an experiment to measure the friction that opposes the vehicle's motion on a particular surface. If time allows, carry out your experiment and compare your result with those of other groups. Are they consistent with the statement abo the top speed in the first sentence of this question?

3. If you changed the experiment from question 2 by running your vehicle up a ramp inclined at 15° to the horizontal, would this affect the top speed you would expect? Expla

Problem Solving and Calculations Set 5: Energy, Work and Power

5

Notes

5.1 Calculate the kinetic energy of a 42.0 kg skateboard rider who has a speed of 3.70 m s^{-1}.

5.2 Calculate a 1.00 tonne wrecked car's potential energy gain when a crane lifts it off the ground and puts it on top of a 3.00 m high pile of scrap metal.

5.3 Ellen stands on top of a 45.0 m ocean cliff and throws a 0.500 kg stone with a horizontal velocity of 8.00 m s^{-1}.
[a] Calculate the kinetic energy of the stone as it left her hand.
The stone gains more kinetic energy as it falls.
[b] Calculate its kinetic energy just before it struck the water at the base of the cliff.

5.4 A small swimming pool pump has a power rating of 25 W.
[a] In theory, how much work could this pump do in one day?
[b] In practice, the work done will be significantly less. Why?

5.5 A 2.0 tonne furniture removal van is travelling at 18 m s^{-1} down a street. Calculate
[a] the van's kinetic energy;
[b] the retarding force that will stop the van in 48 m.

5.6 Calculate the amount of work done when:
[a] a contractor pushes a lawn mower 2.0 m across a lawn with a force of 8.0 N;
[b] a tennis player's racquet applies a 12 N force on a ball over a distance of 550 mm;
[c] a bricklayer lifts a 25 N brick a vertical distance of 1.8 m;
[d] miners raise 1 015 kg of coal from the bottom of a mine 310 m deep;
[e] a cleaner pushes a chest of drawers 10.0 m down a passage, with a constant speed, against a frictional force of 42.0 N.

5.7 A child throws a 0.200 kg stone down into a river from a 12.0 m high bridge. If the stone's initial speed is 10.0 m s^{-1}, what is the stone's kinetic energy as it hits the water? Neglect air resistance.


Rowing machine

5.8 A shop assistant:
[a] pushes a shopping trolley with a force of 12.0 N along an 18.0 m aisle. How much work is done?
[b] expends 100 J of energy lifting a box of cool drinks 0.800 m onto a shelf. Calculate the minimum force the assistant must have applied to lift the box.
[c] drives a powered trolley that produces a horizontal force of 30.0 N around the shop. The motor uses 1.20 kJ of chemical energy from its battery to do this. Calculate the distance that the trolley travelled around the shop.

5.9 Kathryn visited a fitness centre. She expended 100 J of energy each time that she pulled the oars of a rowing machine with an average force of 125 N. Through what distance did Kathryn pull the oars?

5.10 An ice skater accelerates to top speed by expending 3.00×10^3 J of energy. If she achieved this top speed after travelling 25.0 m, calculate the magnitude of the average force she generated.

Continued over

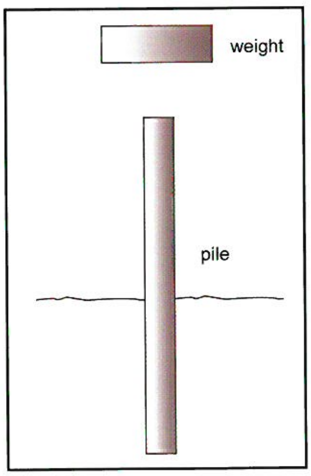
Problem Solving and Calculations Set 5: Energy, Work and Power

Notes

5.11 How much energy does a bore-pump need to raise 2.0 x 10^3 kg of water from the water table, 50.0 m below ground level?

5.12 Calculate the power that you develop when you:
[a] do 5.00 kJ of work by moving a desk across your room in 12.0 seconds;
[b] lift a 2.20 kg dumbbell from the ground to 2.30 m into the air above your head in 0.80 s;
[c] take 1.20 s to throw a 355 g softball at 20.0 m s^{-1} to first base;
[d] push a friend on skates using a horizontal force of 35.0 N for a distance of 15.0 m for 3.5 s.

5.13 Work, energy and power play a large part in sport. Use your knowledge of physics to answer the following:
[a] To build endurance, coaches will often train their athletes in the soft sand of the beach. Why would athletes use more energy during a one-hour training session on the beach than during a similar session on a grass field?
[b] A study of the world's best hurdlers reveals that they do not change the height of their centre of gravity as they leap over hurdles. In contrast, poor hurdlers lift their centre of gravity as they leap up and then drop their centre of gravity as they land on the other side of a hurdle. Explain why it is an advantage to keep the centre of gravity at a constant height when an athlete leaps over hurdles.
[c] Why does it require less energy to roller skate than to walk the same distance?
[d] Why does a sprinter start in a crouched position?
[e] Why does walking up a hill involve more work than walking the same distance along the flat?
[f] Why are the best long jumpers also very fast sprinters?
[g] Athletes have shown the Fosbury Flop technique for high-jumpers is better than the Scissor Kick technique. Why is this so?
[h] Why do high jumpers throw their arms into the air just before they leave the ground to clear the bar?



Pile driver

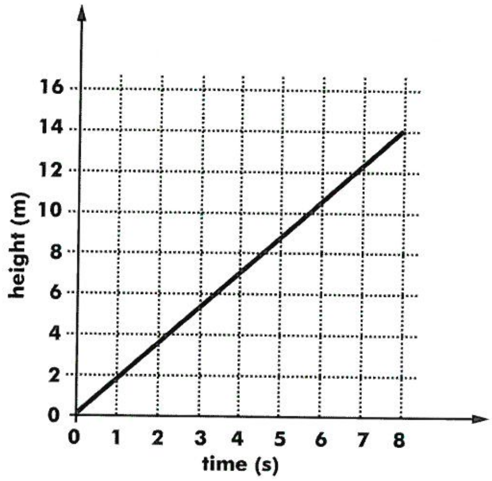
5.14 The diagram (*left*) shows a pile driver. The idea is that a large weight is repeatedly lifted and allowed to drop onto a steel or wooden 'pile', driving it further into the ground each time.
[a] Explain the physical principles involved in its operation.
[b] Explain, giving reasons, how the pile driver could be more effective.

5.15 A roller-coaster full of thrill seekers starts at the top of the ride. The 1.80 x 10^3 kg coaster then plummets 12.5 m down a steep incline. It then climbs out of the dip by travelling up a slope that takes it within 2.50 m of its original height above the ground.
[a] Calculate the minimum speed that the coaster needs when it is at the bottom of the slope.
[b] Explain why the coaster must have been travelling faster than this minimum speed.

Problem Solving and Calculations Set 5: Energy, Work and Power

5

5.16 Rob the builder used a motorised hoist to lift loads at a construction site.
[a] The graph (*right*) shows the time taken to lift a 256 kg load of bricks up the side of a building. What was the effective power of Rob's hoist?
[b] Calculate how fast this hoist could lift a 2750 kg load of bricks and sand.

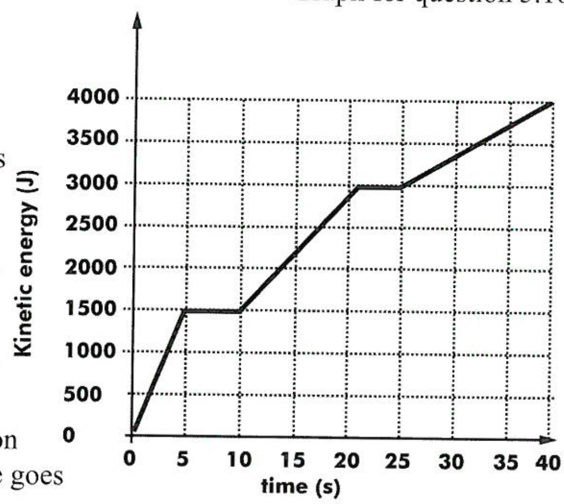


Graph for question 5.16

5.17 A technician is testing a new safety glass product. She fires a 3.60 kg frozen chicken with a speed of 130 m s^{-1} at a sheet of the glass. The chicken shatters the glass and emerges at 65.0 m s^{-1}. How much work did the chicken do to shatter the glass?

5.18 There is a 250 m difference in the altitude between the start and end of a ski slope. A 64.0 kg skier races down the slope.
[a] What theoretical kinetic energy could the skier gain?
[b] If friction converts 80.0% of the initial potential energy to heat, how much kinetic energy would the skier gain?
[c] What is the speed of the skier at the bottom of the slope?

5.19 Chris accelerated his three-speed bicycle along a flat, straight road. The graph (*right*) shows Chris' increase in kinetic energy over a 40 s period.
[a] Calculate how much power Chris is developing at the 2 s mark.
[b] Calculate how much power Chris is developing at the 15 s mark.
[c] Calculate how much power Chris is developing at the 35 s mark.
[d] Explain why there are some regions where there is no increase in kinetic energy.



Graph for question 5.19

5.20 A tidal power station works at 20.0% efficiency. Each day the station traps 2.50×10^{11} kg of water in its upper storage pool. When the tide goes out the operators empty the upper pool into a lower pool. The average difference on the height between the water levels in the two pools is 1.75 m. How much electrical energy does the power station produce daily?

5.21 A worker removes a 5.0 kg carton of soft drink from the top of a stack in a warehouse by sliding it down a ramp. The ramp has a 15° incline to the horizontal. At the bottom, 12 m down the ramp, the carton has a speed of 6.0 m s^{-1}.
[a] Calculate the gravitational potential energy of the carton at the top of the ramp.
[b] Calculate the carton's kinetic energy at the bottom of the ramp.
[c] How much work does the carton do to overcome ramp friction?
[d] Calculate the average frictional force the carton experiences.

5.22 Geoff rides his 213 kg motocross bike 25.3 m up a 30° slope at a constant speed. Calculate:
[a] the energy that the bike's motor expends if the frictional force opposing the bike's movement is one-tenth its weight;
[b] the power output of the bike if the constant speed is 12.0 m s^{-1}.

5.23 A wind blowing from the east applies a 20.0 N force to a model yacht. What work does this same wind do when it displaces the model yacht 54.0 m south-west?

Investigations

Investigation 5.3: Machine efficiency

The car, the bicycle, the human body and a power station are all examples of energy transfer systems. All have inefficiencies associated with the energy transfer process.

Choose one energy transfer system and make a poster or electronic presentation showing the energy transfers involved. At each step, provide evidence of the efficiency of the transfer, list the 'machine' involved and describe its purpose. Discuss ways in which the efficiency could be improved through the transfer process.

List all references you have used, especially for direct quotations and copied diagrams.

Apparatus for Investigation 5.4

Investigation 5.4: Spring energy

You will need two different springs; slotted masses or force sensors; metre ruler.

In general, as the force acting on an elastic system such as a spring increases, so does the energy stored in the system.

Your task is to determine the relationship between the applied force and the amount that a spring stretches. Take care when loading the spring: it is easy to overload and permanently deform a spring.

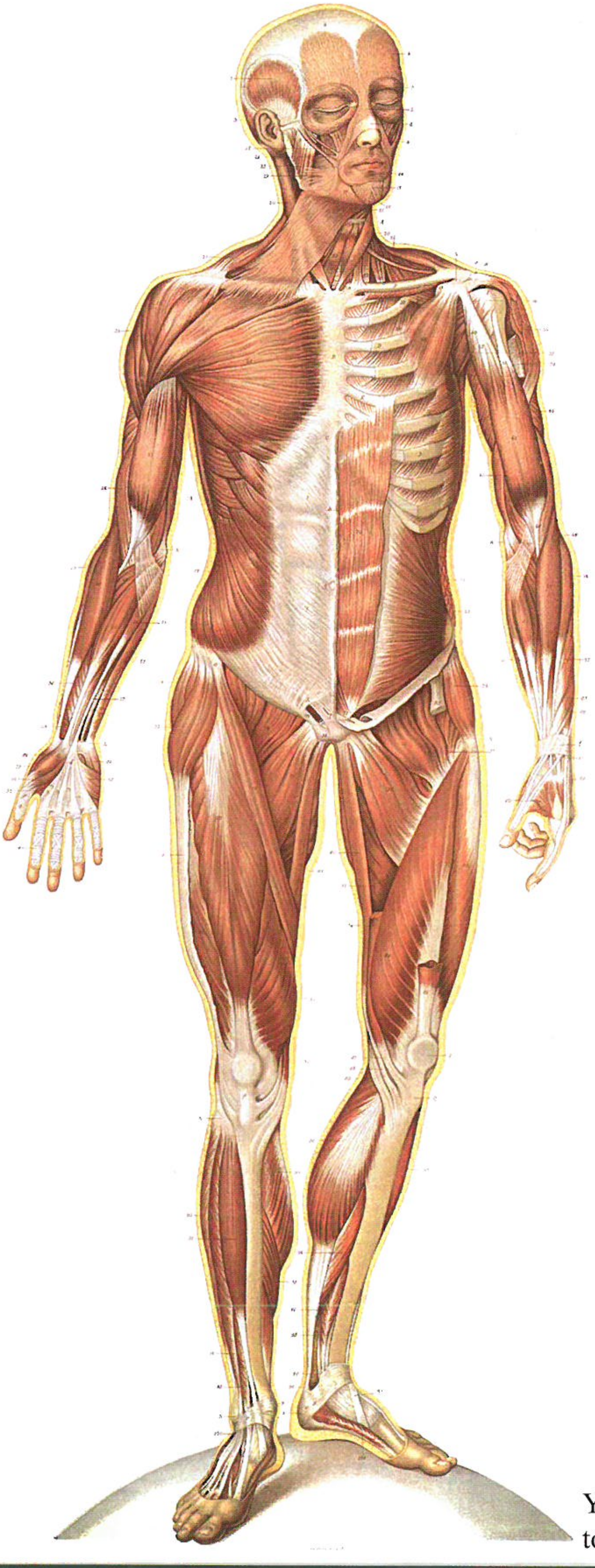
Hang the masses on the springs or use the force sensors to apply a force to the springs, and record the amount that each spring stretches. Note that a stiff spring may not begin stretching until the applied force reaches a particular (threshold) value. For each spring, graph the data by plotting the force on the y-axis and the spring stretch on the x-axis. Determine the equation for the graphs and explain what the gradient represents, and what the area under the curve represents.

Notes

Investigation 5.5: Personal power

Choose one set of muscles in your body and design a way to determine the useful power output of those muscles. Your design should include explanations of the hypothesis you will test the evidence that you will gather to test your hypothesis, the variables that you will investigate and control and the ways that you will minimise uncertainties and errors in your results.

Notes



You have many muscles to choose from

Radiation Treatments in Medicine

'Radioactive' refers to substances or materials. Radioactive substances such as uranium emit radiation. Radiation is what a radioactive nucleus emits when it decays. Radioactive atoms have unstable nuclei. For example, they may have too many neutrons or too many protons. In either case, these unstable nuclei break down (decay), ejecting (radiating) particles such as alpha or beta particles, or electromagnetic radiation, such as gamma rays. The radiated alpha or beta particles have kinetic energy. When these particles collide with atoms or molecules they transfer some of this energy.

Radiation workers (for example, in nuclear power stations or in radio therapy units) must monitor their radiation exposure. They wear small badges that contain special, radiation-sensitive film. Ionising radiation exposes this film. When developed, this film ranges from light (low radiation exposure) to dark (high radiation exposure). Workers can limit their exposure by wearing protective clothing and by keeping their distance from radioactive sources. Have you noticed that a radiographer leaves the room when exposing you to X-rays?

Radiotherapy is a therapeutic use of radiation. Firing high energy X-rays or gamma rays at cancer or tumour cells for a few minutes each day over a period of weeks should kill the cancer if it has been diagnosed in time. There are some unpleasant side effects, like skin damage, but this is a small price to pay for a cure.

Nuclear radiation is ionising–that is, it interacts with other materials to make ions (charged particles) by knocking electrons off atoms. It is the ionising property of radiation that makes it dangerous to living things. Atoms and molecules behave differently after they are ionised. For example, ionised molecules can react chemically with the complicated molecules in a living cell, killing the cell or changing the way it works.

Decaying radioactive nuclei are used in nuclear bombs and reactors, but many radioactive materials occur naturally. We live in a nuclear world. There is background radiation around us all the time.

Exposure to ionising radiation may produce effects ranging from no noticeable changes to injury or death. The exposure time, the body part being irradiated and the type of radiation used all play a part in the outcome. Because of this, we use different units depending on what we want to measure. One unit, the gray, measures the amount of energy absorbed from radiation. A different unit, the sievert, indicates how much damage this energy can do.

Lutetium-177 is a radioactive isotope (radioisotope). When a lutetium-177 nucleus decays it turns into stable hafnium-177. In this process, one of the neutrons in the lutetium nucleus turns into a proton. At the same time a high energy electron shoots out of the nucleus. This is a beta particle. Other radioisotopes may have decay modes that produce gamma radiation or alpha particles. Nuclear decay is random, so we cannot predict when a particular radioactive nucleus will decay. Despite this, the time taken for half of any amount of radioactive atoms to decay is constant. This is the meaning of the term 'half-life'. Lutetium-177 has a relatively short half life of 6.65 days.
Medical uses of radioisotopes such as lutetium-177 depend on three characteristics of radiation and radioactive materials. These are the half-life of the radioactive material, the penetrating power of the ionising radiation it emits, and the effect of this radiation on human tissue.

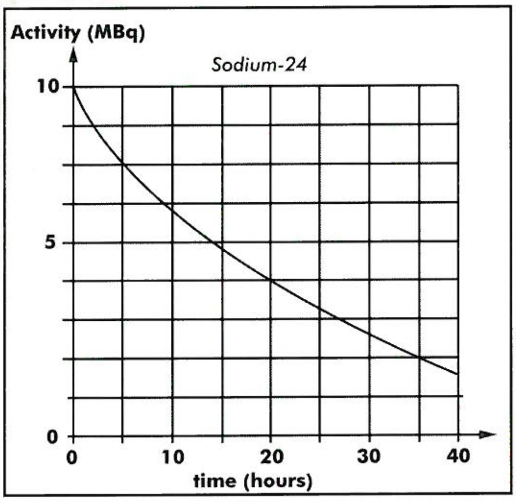
Radiation Treatments in Medicine Comprehension Questions

1. [see Chapter 6]
[a] Explain the difference between radioactive and radiation.
[b] What happens to a piece of radioactive material as time passes?
[c] What happens to a radiation particle, such as an alpha or a beta particle, as time passes?
[d] What property of radiation allows a Geiger-Muller tube to detect radiation?
[e] Why should external radiation sources have long half-lives while internal sources have short ones?
[f] Why should external radiation sources emit high-energy particles while internal sources emit low-energy ones?

2. [see Chapter 6]
Write balanced equations showing:
[a] the alpha decay of thorium-229 ($^{229}_{90}Th$)
[b] the beta decay of iodine-131 ($^{131}_{53}I$)
[c] the gamma decay of excited barium-137 ($^{137}_{56}Ba$)
[d] the positron (positive beta) decay of carbon-11 ($^{11}_{6}C$)
[e] the transmutation of berylium-9 ($^{9}_{4}Be$) into carbon-12 ($^{12}_{6}C$) through the absorption of an alpha particle.

3. [see Chapter 7]
[a] The half-life of beryllium-11 is 14 seconds. If the mass of beryllium-11 at time t = 0 is 12 g, determine the mass of beryllium-11 that remains at time t = 56 s.
[b] When scientists tested the newly-discovered isotope X they found that its activity decreased by 80% in a time of 4.65 hours. Calculate the half-life of isotope X.

4. [see Chapter 7]
The graph below shows a decay curve for the isotope sodium-24.



Use this graph to answer the questions that follow:
[a] Determine the activity at time t = 25 hours.
[b] Determine the time at which the activity will be 4.3 MBq.
[c] Determine the half-life of sodium-24.
[d] Would sodium-24 be more suited to being an external or an internal source if used for radiotherapy? What is the evidence for your answer?
[e] What other properties would help determine its suitability for radiotherapy?

Periodic Table of the Elements

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
1 **H** hydrogen								
3 **Li** lithium	4 **Be** beryllium							
11 **Na** sodium	12 **Mg** magnesium							
19 **K** potassium	20 **Ca** calcium	21 **Sc** scandium	22 **Ti** titanium	23 **V** vanadium	24 **Cr** chromium	25 **Mn** manganese	26 **Fe** iron	27 **Co** cobalt
37 **Rb** rubidium	38 **Sr** strontium	39 **Y** yttrium	40 **Zr** zirconium	41 **Nb** niobium	42 **Mo** molybdenum	43 **Tc** technetium	44 **Ru** ruthenium	45 **Rh** rhodium
55 **Cs** caesium	56 **Ba** barium	57 ***La** lanthanum	72 **Hf** hafnium	73 **Ta** tantalum	74 **W** tungsten	75 **Re** rhenium	76 **Os** osmium	77 **Ir** iridium
87 **Fr** francium	88 **Ra** radium	89 ****Ac** actinium	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium

Key	
24	← Atomic number
Cr	← Symbol
chromium	← Name

* Lanthanide Series	58 **Ce** cerium	59 **Pr** praseodymium	60 **Nd** neodymium	61 **Pm** promethium	62 **Sm** samarium	63 **Eu** europium
** Actinide Series	90 **Th** thorium	91 **Pa** palladium	92 **U** uranium	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium

Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
								2 **He** helium
			5 **B** boron	6 **C** carbon	7 **N** nitrogen	8 **O** oxygen	9 **F** fluorine	10 **Ne** neon
			13 **Aℓ** aluminium	14 **Si** silicon	15 **P** phosphorus	16 **S** sulfur	17 **Cℓ** chlorine	18 **Ar** argon
28 **Ni** nickel	29 **Cu** copper	30 **Zn** zinc	31 **Ga** gallium	32 **Ge** germanium	33 **As** arsenic	34 **Se** selenium	35 **Br** bromine	36 **Kr** krypton
46 **Pd** palladium	47 **Ag** silver	48 **Cd** cadmium	49 **In** indium	50 **Sn** tin	51 **Sb** antimony	52 **Te** tellurium	53 **I** iodine	54 **Xe** xenon
78 **Pt** platinum	79 **Au** gold	80 **Hg** mercury	81 **Tℓ** thallium	82 **Pb** lead	83 **Bi** bismuth	84 **Po** polonium	85 **At** astatine	86 **Rn** radon

64 **Gd** gadolinium	65 **Tb** terbium	66 **Dy** dysprosium	67 **Ho** holmium	68 **Er** erbium	69 **Tm** thulium	70 **Yb** ytterbium	71 **Lu** lutetium
96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lw** lawrencium

Chapter 6: Nuclei and Radiation Explained

Notes

Because of experimental evidence, scientists think the nucleus of an atom is an aggregate of two types of particles, protons and neutrons. Such nuclear particles are called nucleons. These two types of nucleons have almost the same mass. Protons have a positive electric charge whereas neutrons are electrically neutral.

The symbol for an atomic nucleus has the form:

$$^{A}_{Z}X$$

where: **Z** is the atomic number, which is the number of protons and therefore the charge on the nucleus.
A is the mass number, which is the number of nucleons (the number of heavy particles in the nucleus.)
X is the chemical symbol for the atom.

An example is:

$$^{7}_{3}\text{Li}$$

The element is lithium. The nucleus has three protons and four neutrons. We call it lithium-7. Another isotope of lithium, $^{6}_{13}\text{Li}$, has a different number of neutrons.
The following table shows the symbols and common names for a number of particles.

alpha particle $^{4}_{2}\text{He}$	beta particle $^{0}_{-1}\text{e}$	gamma ray $^{0}_{0}\gamma$	neutron $^{1}_{0}\text{n}$
α	ß	γ	n
positron $^{0}_{+1}\text{e}$	proton $^{1}_{1}\text{H}$	deuterium $^{2}_{1}\text{H}$	tritium $^{3}_{1}\text{H}$
ß+	p	D	T

In any nuclear reaction, whether it is radioactive decay or a transmutation reaction, you must apply the following two conservation laws:

1. **The mass number is conserved**. Hence, the sum of the mass numbers of the products must equal the sum of the mass numbers of the reactants.
2. **Charge is conserved**. Hence, the sum of the atomic numbers of the products must equal the sum of the atomic numbers of the reactants.

An example is: $^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + ^{1}_{1}\text{H}$

In this example, we see that:
mass is conserved because $(14 + 4) = (17 + 1)$
charge is conserved because $(7 + 2) = (8 + 1)$

Experiment 6.1: RadiationTracks in a Cloud Chamber

6

Background

Ionising radiation is so called because it can knock electrons off atoms in its path, and so create ions. The cloud chamber uses this property to make the paths or tracks of ionising radiation visible to the naked eye.

Apparatus for Experiment 6.1

Aim

To view and analyse particle tracks in a cloud chamber.

Apparatus (per group)

- Cloud chamber
- Dry ice
- Ethanol
- Lamp

Pre-Lab

- Find out how and why the 'clouds' form in a cloud chamber.
- Discuss the likely effect of putting a metal shield in front of the radioactive source.

Lab Notes

- Your teacher will set up a cloud chamber and adjust it until tracks are visible. It will be best in a slightly darkened room with the cloud chamber illuminated from the side with a narrow horizontal beam of light from a lamp.
- Examine the tracks without the metal shield in front of the source.
- Record your observations.
- Repeat the exercise with the metal shield in front of the source.
- Record your observations.

Post-Lab discussion

1. Sketch a diagram of the cloud chamber showing the position of the radioactive source, the super-cooled vapour and the shape of some tracks.

2. What difference does it make to put the metal shield in front of the source?

3. Describe and explain the difference between the tracks produced by alpha particles and beta particles.

4. Why are gamma tracks difficult to see? You may need to research the answer.

Notes

Experiment 6.2: Range of Alpha and Beta Particles in Air

Notes

Background

One of the safety principles that radiation industry workers observe is to maintain a safe distance between any radioactive source and themselves - the further the better. What is a reasonable minimum safe distance - 10 cm, 50 cm, 1 m or 10 m?

Aim

To determine how far alpha and beta particles penetrate through air.

Apparatus

- Geiger-Muller tube and counter
- Electronic timer or stopclock
- Retort stand and clamp
- Alpha source (americium-241) and beta source (strontium-90)
- Metre ruler
- Tongs and gloves

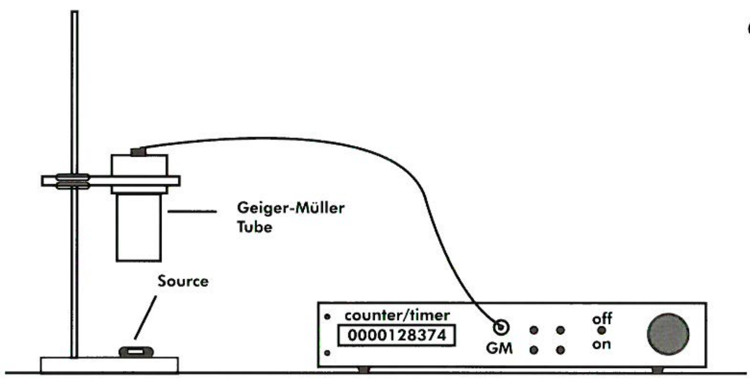
Pre-Lab

- Find out how to use the Geiger counter.
- Prepare two tables to record your data (one for the alpha source, one for the beta source).
- Warning: always use tongs when you handle radioactive sources.
- Warning: use heavy-duty rubber gloves when you work with alpha sources.

Lab Notes

- Set up the apparatus as shown, but without the source in place.
- Measure and record the background count over five minutes.
- Place the americium-241 source under the Geiger tube window and measure the counts per minute at intervals of 1 cm from the source to the Geiger tube window, over a distance of 12 cm. Record your observations.
- Repeat the exercise using the strontium-90 source, over a distance of 24 cm. Record your observations.

Continued over



Apparatus for Experiment 6.2

Experiment 6.2: Range of Alpha and Beta Particles in Air 6

Post-Lab discussion

Notes

1. Determine the average background count per minute.

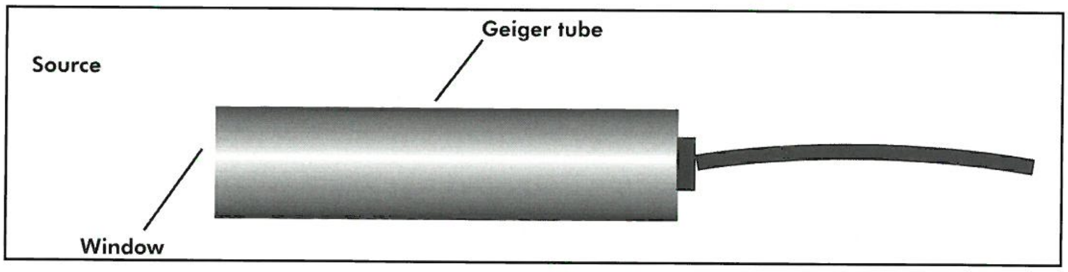
2. Obtain the true count rate (counts per minute) by subtracting the average background counts per minute from the total counts per minute.

3. Graph distance from the source *vs* true counts per minute for each source. If possible, graph both on the same axes.

4. Write a brief paragraph describing what you have found out from the results.

5. Use a reference book if necessary to find answers to the following:
   [a] What are alpha and beta particles?
   [b] What characteristics of these particles might affect the distance that they would travel through air?
   [c] Explain your results in terms of the characteristics of these two particles.

6. There is an error in the experimental procedure in that it is assumed that each particle is detected at the Geiger tube window. In actual fact, each particle could be detected anywhere throughout the length of the Geiger tube. The position would probably be different for each particle. Explain how this would affect your results and hence your conclusion.



7. The following table shows a number of more common beta-emitting radioactive sources and the energies of the emitted beta particles.

Source	Energy of beta particle (MeV)
Phosphorus -32	1.71
Strontium-90	0.54
Tritium	0.02

[a] Compare the three sources in terms of the expected range in air of their beta particles.
[b] Design a small safety warning label to be displayed either on a radioactive source container or on a bench top where people will use alpha and beta sources, making use of what you have learned in the experiment.

Experiment 6.3: Penetration Power of Radiation

Notes

Background

Both alpha and beta are ionising radiations, but they have very different abilities to pass through shielding substances. Their abilities to penetrate materials are related to their abilities to ionise molecules within those materials.
In order to know how to protect ourselves from hazardous radiation, it is necessary to have some idea about the ability of different radiations to penetrate matter. Three materials will be tested: paper, aluminium and lead.

Aim

To measure the relative measuring abilities of alpha and beta radiations.

Apparatus

- Stopclock, stopwatch or electronic timer
- Geiger tube and counter
- Radioactive sources: Americium-241 (alpha); Strontium-90 (beta); Cobalt-60 (gamma)
- Sheets of paper, aluminium and lead
- Two retort stands, boss heads and clamps
- Tongs and gloves
- Metre rule

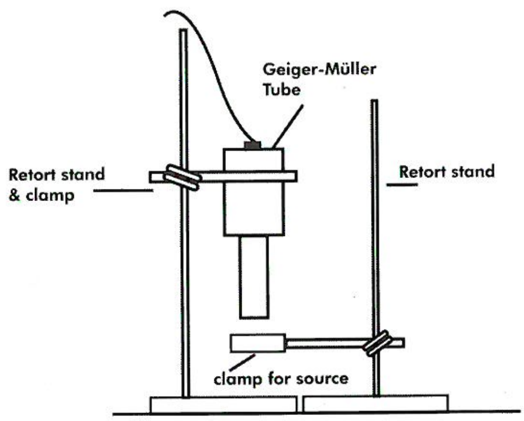
Pre-Lab

- Find out how to use the Geiger counter.
- Prepare three tables to record your data (one each for the alpha, beta and gamma sources).
- Warning: always use tongs when you handle radioactive sources.
- Warning: use heavy duty rubber gloves when you work with alpha sources.

Lab Notes

- Set up the apparatus as shown (*below*) but without the source and test sample.
- Measure the background count over 5 minutes to determine the average background count per minute.
- Put the first radioactive source in place and ensure that the Geiger tube is 1 cm above it.
- Measure the count rate in counts per minute.
- Place a sheet of paper between the source and Geiger tube and record the count rate in counts per minute.
- Without moving anything but the paper, repeat the procedure for aluminium and lead.
- Repeat these steps for the other two radioactive sources.

Continued over



Apparatus for Experiment 6.3

Experiment 6.3: Penetration Power of Radiation

6

Post-Lab discussion

1. Determine the true count per minute by subtracting the average background count per minute from each of the recorded counts per minute.
2. Compare each of the materials tested (paper, aluminium and lead) for their ability to block each type of radiation.
3. What difference does it make to put the metal shield in front of the source?
4. Draw up a small table that summarises the characteristics (mass, charge and speed) of alpha, beta and gamma radiation.
5. Account for the different penetrating abilities of each type of radiation in terms of their characteristics.
6. Americium-241 also emits gamma radiation. How has this affected your results?
7. How far through human tissue does each type of radiation penetrate?
8. People working with radiation sources often wear or use different types of shielding materials for protection. Find out about these materials.
9. Some watches use water doped with tritium (which is a beta-emitter) to make the hands glow in the dark. Comment on the safety implications of this practice.
10. The beta and gamma sources which you used were completely sealed in plastic but the alpha source was not sealed. Why not? Is it safe to have an unsealed radioactive source?

Further investigation

Gamma rays are the most penetrating of all. Because of the way gamma rays interact with matter, it is not possible to say that a particular thickness of material is enough to absorb all rays. Instead, it is more meaningful to talk about the half-thickness (or half-value thickness) of a material. Half-thickness is similar in idea to half-life; it is the thickness that is enough to absorb half of all the gamma rays that fall on it. A single gamma ray has a 50% chance of being absorbed by a nucleus within one half-thickness of a shielding material.
Plan and carry out an investigation to determine the half-thickness of lead using the gamma rays from your cobalt-60 source.

Notes

Experiment 6.4: Deflecting Alpha and Beta Radiation

Notes

Background

Part of your study in Stage 3 will deal with the reasons why the following effect occurs. If a stream of charged particles travels at right angles to a magnetic field, the particles will follow a curved path. Positively-charged particles will curve in the opposite direction to negatively-charged particles. Particles with no charge will not change direction: that is, they will continue in a straight line.

Aim

To separate and identify alpha, beta and gamma rays.

Apparatus (per group)

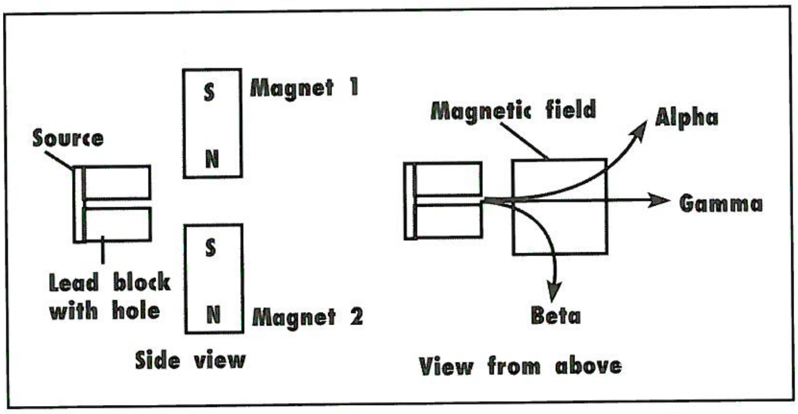
- a source of mixed radiation, such as alpha and gamma (americium-241) or any of the beta and gamma sources mentioned in the previous activity;
- two strong magnets;
- a lead block with a hole drilled through it;
- a Geiger tube and counter.

Pre-Lab

- Find out what electric charge (if any) is associated with alpha, beta and gamma rays.
- Discuss with your lab partners how you will detect the particles.
- Prepare a table suitable for recording your measurements.

Lab Notes

- Set up the apparatus as shown in the diagram (*below*). See if you can separate and detect the different types of radiation. Remember to handle the radioactive sources with tongs and protective gloves.
- Carry out several trials and record your observations.



Post-Lab discussion

1. Geiger counters do not detect gamma very efficiently, and alpha particles tend to be absorbed relatively quickly, even by air. Did you notice any such problems? How could you make your experimental set-up more effective?
2. Write a conclusion for your experiment. Your conclusion should include a summary of the results, a description of the steps you took to minimise error and the steps you took to maximise safety, a brief statement about what you would change if you were to repeat the experiment, and a suggestion for further research based on your findings.

Problem Solving and Calculations Set 6: Nuclei and Radiation

6

Notes

6.1 The symbols for four different nuclei follow. Determine the number of protons and neutrons in each nucleus and name the element the symbol represents.

a $^{17}_{8}O$

b $^{40}_{19}K$

c $^{234}_{92}U$

d $^{241}_{95}Am$

6.2 Complete the nuclear equations, replacing the § with its correct symbol.

a $^{23}_{11}Na + ^{4}_{2}He \rightarrow ^{26}_{12}Mg + \S$

b $^{239}_{93}Np \rightarrow ^{0}_{-1}e + \S$

c $^{22}_{11}Na \rightarrow ^{22}_{10}Ne + \S$

d $\S \rightarrow ^{131}_{53}I + ^{0}_{0}\gamma$

e $^{7}_{3}Li + ^{1}_{1}H \rightarrow 2\S$

6.3 Scientists have difficulty detecting neutrons because they have no charge. They often use boron-10 to detect them. When a neutron hits a boron-10 nucleus, the boron absorbs the neutron and emits an alpha particle. Scientists find it easy to then detect the alpha particle.
[a] Write the nuclear equation for the reaction between boron-10 and a neutron.
[b] Name an element formed in the reaction.

6.4 Write the nuclear equation for the alpha decay of uranium-234.

6.5 Radioactive potassium-42 ($^{42}_{19}K$) is used for biological investigations as it tends to accumulate in muscle tissue. Potassium-42 is a beta emitter. Write an equation to represent this decay of potassium-42, showing the atomic number and mass number of the daughter product. Use a periodic table or chart of nuclides to identify the product formed in the reaction.

6.6 In nuclear fallout, the fission reactions can produce large numbers of radioactive by-products. These products are themselves radioactive with varying half-lives. One such product, barium-141 ($^{141}_{56}Ba$), decays to form caesium-141 ($^{141}_{55}Cs$). What else is produced in this decay?

6.7 Iodine-131 ($^{131}_{53}I$) is a radioisotope used to treat iodine disorders. It decays by beta emission. Write down the nuclear equation of this decay, showing the atomic number and mass number of the daughter product. Use a periodic table or chart of nuclides to identify the product formed in the reaction.

Continued over

Problem Solving and Calculations Set 6: Nuclei and Radiation

Notes

6.8 Hospitals prefer short-lived radioisotopes for medical diagnostic purposes. These are generally manufactured on site with a radioactive 'cow'. A radioactive substance with a relatively long half-life (known as the 'mother nuclide') disintegrates and produces a decay product called the 'daughter product'. This daughter product has a short half-life and is drained from the generator and then used for medical purposes. This is called 'milking the radioactive cow'. One common type produces technetium-99m ($^{99}_{42}$Mo) from molybdenum-99 ($^{99m}_{43}$Tc). Write down the decay equation for this.

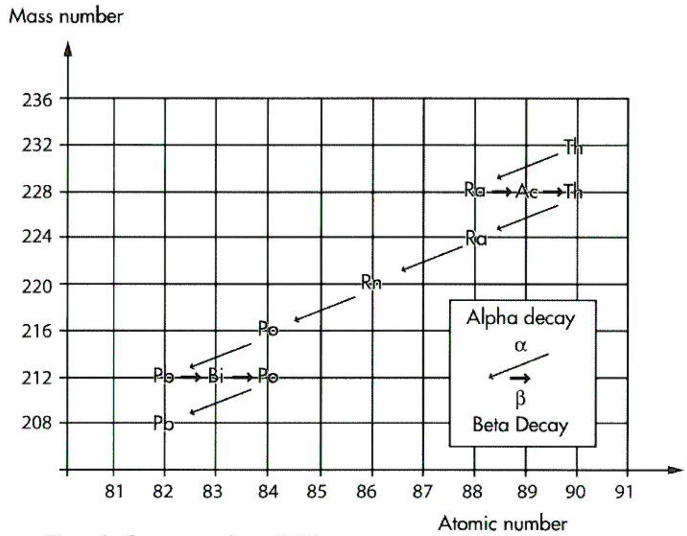
6.9 Radon-222 ($^{222}_{86}$Rn) is a naturally occurring radioisotope which exists as a gas. It decays by alpha emission. Write down the nuclear equation for the decay of radon-222. Use a periodic table or chart of nuclides to identify the product formed in the reaction.

6.10 One reaction that interests nuclear fusion researchers involves the fusion of deuterium and tritium to form alpha particles.
[a] Write the nuclear equation for this reaction.
[b] Name any other particle the reaction produces.

6.11 When cosmic rays hit nitrogen-14 nuclei in the upper atmosphere, they convert the nitrogen into a radioisotope of carbon, carbon-14. If each reaction ejects a proton, what type of cosmic radiation causes it?

6.12 Plutonium-239, a major waste product of nuclear reactors, decays by alpha emission. Its daughter also alpha decays, leaving a residual nucleus that beta decays. Write the nuclear decay equation associated with each decay.

6.13 Radon gas produces a significant proportion of environmental radiation. The graph shows part of the natural thorium-232 radioactive decay series as far as radon-220. Write nuclear equations for the first five decay reactions shown in the graph.



Graph for question 6.13

Continued over

Problem Solving and Calculations Set 6: Nuclei and Radiation

6

Notes

6.14 One of the possible fission routes when a neutron collides with a uranium-235 nucleus produces barium-141and krypton-92 and one other product. Write a nuclear equation of this possible route to identify what other product is formed.

6.15 In a nuclear fission reaction, uranium-235 ($^{235}_{92}U$) plus a neutron yields antimony-134 ($^{134}_{51}Sb$) and yttrium-95 ($^{95}_{39}Y$), three neutrons and another particle.
[a] Write an equation for this nuclear reaction.
[b] What other particle is produced?

6.16 Nuclear reactors that use excess neutrons generated by fission of uranium-235 to create fissionable plutonium-239 are called breeder reactors. A typical breeder type reaction involves a fission reaction in which uranium-238 absorbs a neutron. The product of this reaction then beta decays, and the product then beta decays again. Write balanced nuclear equations for these three reactions.

6.17 On the alpha bombardment of the isotope boron-11, nitrogen-14 is formed and another particle is produced. Identify that particle and write an equation for the reaction.

Investigations

Notes

Investigation 6.5: Alpha and beta

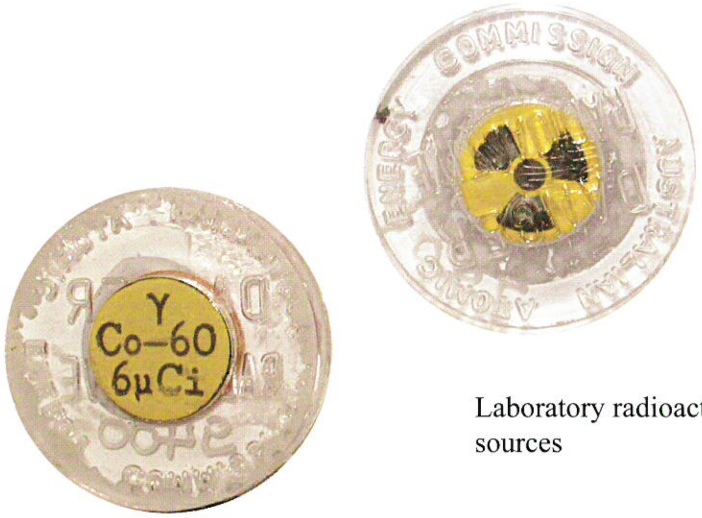
Background

Most radioactive sources produce two types of radiation, i.e. alpha and gamma rays or beta and gamma rays. The relative proportion of each varies between different radioisotopes but is constant for a particular type of nucleus. If your school has any of the following sources you can determine the relative proportions of the two emissions.

caesium-137
iodine- 131
cobalt-60 (the beta particles from this nuclide have a fairly low energy)

The task

Discuss with your partner or group how to best
determine the ratio for the source that you have.
Design your investigation, obtain the equipment you need and then complete, and report on, your
investigation.



Laboratory radioactive sources

Investigation 6.6: PET problem

Background

Your best friend messages you that she is to have a PET scan. She is very worried that she might be affected by radiation but admits that she doesn't know enough about the procedure to know whether or not it is safe.

The task

Do the necessary research and prepare a brief written document to assist your friend to understand the diagnostic procedure which she is about to undergo. Indicate as fairly as possible the risks and benefits of the scan.

Chapter 7: Half Life Explained

7

Notes

Activity

A radioactive sample emits radiation every time a nucleus decays. Scientists call the number of decays that happen every second in an amount of radioactive material its 'activity'. The SI unit for activity is the becquerel (Bq).
1 Bq = 1 decay per second

Half-life

The half-life of a radioactive isotope is the time in which half of the sample's nuclei decay. There is a good reason for calculating the time it takes for the decay of half the nuclei in a sample. If we waited for all the radioactive nuclei in the sample to decay, it would take almost forever. The total decay time is independent of the rate of decay.
The following graph shows the decay behaviour of any sample. The curve is exponential. This shows that activity never becomes zero.

Number of half-lives	0	1	2	3	4	5	...n
Number of nuclei left	N	$\frac{N}{2}$	$\frac{N}{4}$	$\frac{N}{8}$	$\frac{N}{16}$	$\frac{N}{32}$	... $\frac{N}{2^n}$

Therefore, to get a measure of how quickly an isotope decays, we refer to the time it takes for half the sample to decay instead of the time the sample needs to decay totally.
Activity is proportional to the number of nuclei not yet decayed.

Experiment 7.1: Simulated Radioactive Decay (Method 1)

Notes

Background

This investigation is a simulation of radioactive decay. Radioactive decay is a random event. You will have noticed this by watching or listening to the uneven count rate on a Geiger counter when it is detecting low intensity radiation. If, however, a large number of atoms are disintegrating, the average number of disintegrations per second can be predicted with reasonable accuracy.

The half-life of a radioactive substance is the time taken for its decay rate or activity to decrease by one half. This is also the time taken for the number of undecayed nuclei to decrease by one half.

Aim

To simulate half life using a non-radioactive decay process.

Apparatus (per group)

- 1 packet of M & Ms®
- 1 clean paper cup
- 1 sheet of clean paper
- 1 or more consumers (for discarded M & Ms)

Number of throws	Number of disintegrations	Number of nuclei remaining
0	0	
1		

Pre-Lab

- In this simulation you will use M & Ms to represent radioactive nuclei. A 'decayed' M & M is one which falls with the 'M' facing up. Discuss how you will safely dispose of the wastes from your experiment.
- Set up a table suitable for recording the data from your simulation. An example is shown (*above*).

Lab Notes

- Begin by tipping the M & Ms onto the sheet of paper on the bench-top. Count them and then transfer them to the paper cup. Enter this information in your data table a time t = 0.
- Again tip the M & Ms onto the sheet of paper. This is your first 'throw'.
- Count and remove the 'decayed' nuclei (the M & Ms with the M facing up). Put the remaining 'undecayed' M & Ms back in the paper cup. Enter the data in your table at time t = 1.
- Repeat these steps until all of your sample has decayed.
- Dispose of the 'decayed' M & Ms thoughtfully!
- All groups will pool their data at the end so that you can include a much larger number of starting nuclei (M & Ms) in the final analysis.
- Transfer your data to a table of the whole class's results.

Post-Lab Discussion

1. In this simulation, time is represented by the tipping of the M & Ms onto the paper. Plot a graph of the number of nuclei remaining against 'time-units'.
2. Plot a graph of the class results.

Further Investigation

- How would the results differ if you used a large number of dice instead of M & Ms?

Experiment 7.1: Simulated Radioactive Decay (Method 2)

7

Background

Notes

This investigation is a simulation of radioactive decay. Radioactive decay is a random event. You will have noticed this by watching or listening to the uneven count rate on a Geiger counter when it is detecting low-intensity radiation. If, however, a large number of atoms are disintegrating, the average number of disintegrations per second can be predicted with reasonable accuracy. For a particular radioactive nucleus you cannot predict whether it will decay in the next second or not. Similarly, when tossing two coins in 'two-up', you cannot predict whether you will throw two heads in the next toss or not. You can, however, predict the likely number of two-head tosses in a large number of tosses. There is a degree of order in a large number of apparently random events.

In the experiment, you will decide whether or not a 'radioactive nucleus' decays by the toss of two coins. All students in the class will do the same and the results will be pooled. It may be useful to have one or two students as class recorders to collect all data.

Aim

To simulate half life using a non-radioactive decay process.

Apparatus

(per group)

- 2 coins
- A small box with a lid
- 5 - 7 counters ('radioactive nuclei')

Pre-Lab

- Set up a table suitable for recording the data from your simulation.

Lab Notes

- Start by recording in your data table the total number of 'radioactive nuclei' in the whole class.
- Line up your 'radioactive nuclei' on the bench in front of you.
- For round 1, shake the coins in the box, remove the lid and look at them. If two heads have turned up, the first of your 'radioactive nuclei' has decayed. Remove it and put it in a central 'decay bin'. Repeat this for each of your 'radioactive nuclei'.
- After each round, you will be asked for the number of nuclei that decayed. Add this number to the class total for the round.
- Repeat the process for round 2, tossing the coins for each of your remaining nuclei.
- Keep going until the class has only a few nuclei remaining.

Post-Lab Discussion

1. Draw a graph with 'number of nuclei remaining' on the vertical axis and time, in the form of 'round number', on the horizontal axis. Draw a line of best fit, by eye.
2. How long did it take for the number of nuclei remaining to drop to one half of the original number? How long did it take for the number to drop to one half again? The two answers should be similar. Are they?
3. What time elapses before the number of 'radioactive nuclei' is halved from the number present at
   [a] t = 1 round, and
   [b] t = 2 rounds?
4. The points on your graph probably do not conform exactly to a smooth curve. What difference or differences would you expect if you had used
   [a] fewer 'radioactive nuclei'?
   [b] a much larger number of 'radioactive nuclei'?
5. Write out a formal definition of 'radioactive half-life' and explain the similarities between this activity and the real process of radioactive decay.

Problem Solving and Calculations Set 7: Half Life

Notes

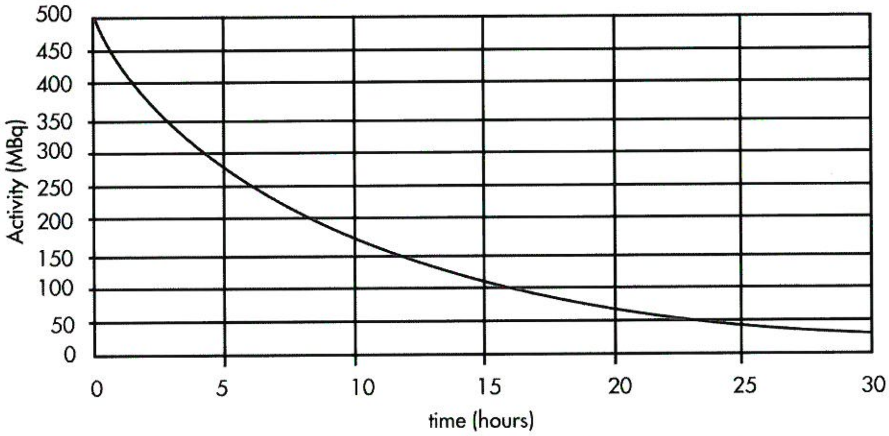
7.1 A radioactive counter shows that the rate of emission of beta particles from a radioactive source decreased to half the initial rate in 22 hours.

[a] What is the half-life of the element?

[b] What fraction of the original number of radioactive atoms is still unchanged in that time?

[c] What fraction of the original number of atoms will have disintegrated in 44 hours?

7.2 Technetium-99m is the most common radioisotope that doctors use in nuclear medicine. The following graph shows the activity of a normal 500 MBq dose of technetium-99m over 30 hours.



Decay graph of a 500 MBq sample of technetium-99m

[a] What is the half-life of technetium-99m?

[b] How long would it take before the activity of the dose drops to about 2 MBq?

7.3 One product of nuclear power plants is the isotope cæsium-137, which has a half-life of 30 years. How many years will it take for the activity of a sample of Cs-137 to reduce to $\frac{1}{16}$ of its original value?

7.4 The radioactive isotope phosphorus-32 ($^{32}_{15}P$) has a half-life of 14.3 days and decays to a stable product. Sam, a nuclear technician, prepared a sample of this isotope with an initial activity of 2.4 MBq. What was the activity of the sample 42.9 days later?

7.5 The initial count rate for a particular sample of a radioisotope is 2048 counts per minute. This drops to 128 counts per minute after 150 minutes.

[a] Calculate the half-life of this isotope.

[b] Explain, in relation to the atoms present, how this decrease has come about.

7.6 Urologists use radioactive iodine in their diagnosis of kidney problems. The isotope they use has a half-life of 12 hours, and the doctors need samples that have an activity of 8.0×10^5 Bq when they inject those samples into the patient. Calculate the activity of a sample of the isotope:

[a] when a nuclear technician prepares it 24 hours before use;

[b] 24 hours after the doctor injects it in a patient.

Problem Solving and Calculations Set 7: Half Life

7

Notes

7.7 A sample of processed waste from a nuclear reactor contains 1.0×10^{24} plutonium-239 atoms. The half-life of plutonium-239 is 2.41×10^4 years.
[a] How many plutonium-239 atoms will decay in the next 2.41×10^4 years?
[b] Write an equation for the alpha decay of Pu-239 to uranium-235.

7.8 The half life of a radioactive cobalt-60 source radiographers use for medical irradiation is 5.3 years.
[a] If the activity of a new source is 800 GBq, what is its activity after 26 years?
[b] If it is not safe to dispose of the source till the radioactivity is less than one thousandth of its original activity (i.e. 800 MBq), estimate to the nearest decade when this will be.

7.9 You are studying samples of two radioisotopes, each containing the same number of undecayed atoms. Sample X has a short half-life of 8 seconds, while sample Y has a long half-life of 1600 years. Which sample has the greater activity? Explain your answer.

7.10 The gold isotope, gold-198, that engineers use to track sewage, is a beta-emitter with a half-life of 2.7 days.
[a] If the original activity of a particular sample is 8 MBq, what is the approximate activity after 7 days?
[b] What is the equation for its decay?

7.11 Carbon-14 is a radioactive isotope of carbon present in the tissues of all living organisms. The ratio of carbon-12 to carbon-14 in living things is the same as the ratio in the Earth's atmosphere. Why is there less carbon-14 in old animal bone compared with the same mass of new bone?

7.12 An archæologist finds a fragment of a wooden artefact from the site of an ancient human settlement in Australia. He measures the ratio of carbon-14 to carbon-12 in the wood and finds only 12.5% of the current atmospheric ratio. How long ago did someone make the artefact? The half-life of carbon-14 is 5730 years.

7.13 Cassie and Stuart were given the task of finding the half-life of a new radioactive element that has been produced as a result of reactions occurring in a nuclear reactor. They used a Geiger counter to measure the number of decays per minute at different elapsed times, as shown in the table below.

Time Period (minutes)	0-1	5-6	10-11	15-16	20-21	25-26	30-31	35-36	40-41	45-46	50-51	55-56	60-61	65-66
Counts (decays per minute)	2520	1978	1842	1492	1228	1015	883	694	621	557	473	406	364	322

Continued over

Notes

[a] Draw a graph of rate of decay versus time and hence determine the approximate half-life of the sample.
[b] While carrying out the experiment, Cassie and Stuart observed that if they held a piece of aluminium foil between the Geiger counter and the source, the count rate dropped dramatically. What type of radiation was emitted from the source? Give reasons for you answer.

7.14 Magnesium-24 ($^{24}_{12}$Mg) is a stable nuclide. It can be transformed into sodium-24 ($^{24}_{11}$Na) by neutron bombardment. Sodium-24 is radioactive, being a beta and gamma emitter with a half-life of 15 hours. It is used as a tracer in blood circulation studies. It decays back to magnesium-24.
[a] Write nuclear equations for the neutron bombardment of magnesium-24 and the subsequent decay of the sodium-24 back to magnesium-24.
[b] If 1.0 g of sodium-24 is injected into the blood of a patient, approximately how long will it take for 90% of this amount to decay?

7.15 Radon-222 is a chemically inert radioactive gas which decays by alpha emission to a solid radioactive daughter polonium-218, also an alpha emitter. The radon-222 has an approximate half-life of 4 days and the polonium has an approximate half-life of 3 minutes.
[a] A sealed sample of radon-222 has an activity of 3.80 kBq. Estimate the activity of the radon-222 in 20 days time.
[b] When you begin to access the potential for harm caused by an isotope, you must take into account the following questions:
• Is the isotope's half-life significant compared to your expected life span?
• Can your body eliminate the isotope if it is ingested or absorbed?
• How much energy is released by the isotope per unit volume of your tissue?
With these ideas in mind, which of the two isotopes (radon-222 and polonium-218) would you expect to be more harmful? Why?

7.16 A large amount of strontium-90 was released during the Chernobyl nuclear reactor accident in 1986. Strontium-90 enters the body through the food chain and accumulates in the bones. How long will it take for 95% of the Sr-90 released during the accident to decay? The half-life of Sr-90 is 28.9 years.

7.17 Naomi, a forensic scientist, takes a 50.0 g sample of carbon from the skull of a human skeleton. She finds that this sample has a carbon-14 decay rate of 200.0 decays per minute.
[a] Given that carbon from a living organism has a decay rate of 15.0 decays minute^{-1}g^{-1} and that carbon-14 has a half-life of 5730 years, estimate the age of the skeleton.
[b] Why is this an estimate rather than a measurement?

7.18 [a] Many artificially produced radioisotopes have short half-lives. Why are these isotopes **not** found in nature?
[b] Many naturally occurring radioisotopes have short half-lives. Why **are** these isotopes found in nature?

Investigations

Investigation 7.2: The dating game

Notes

Background

There are several methods of dating ancient artefacts and rocks that involve analysing the ratios of radioisotopes within the object to be dated.

The task

Choose one of the following dating methods:

- Carbon dating
- Potassium-argon dating
- Uranium-lead dating
- Rubidium-strontium dating

Do the necessary research and prepare a brief written document to explain how the dating technique works and what purposes it is most suited for.

Investigation 7.3: The right to know

Background

It is estimated that about one in three people in Australia will undergo some form of medical diagnostic procedure with a radioactive tracer. Unfortunately, many people know little about these procedures. Too often, assurances from experts that the procedures are perfectly safe do little to reduce the patients' anxiety.

The task

You have been given the job of preparing an information pamphlet for patients about to undergo such a diagnostic procedure. Choose any one of the following procedures as the focus of the pamphlet:

[a] The use of iodine-131 to assess thyroid malfunction.
[b] The use of technetium-99m to determine kidney structure and functionality.
[c] The use of chromium-51 to investigate protein loss from the gastro-intestinal system.
[d] The use of potassium-42 to trace blood flow.
[e] The use of xenon-133 to study lung function.
[f] The use of cobalt-57 in in-vitro diagnostic kits.
[g] The use of thallium-201 to gauge heart damage after a heart attack.

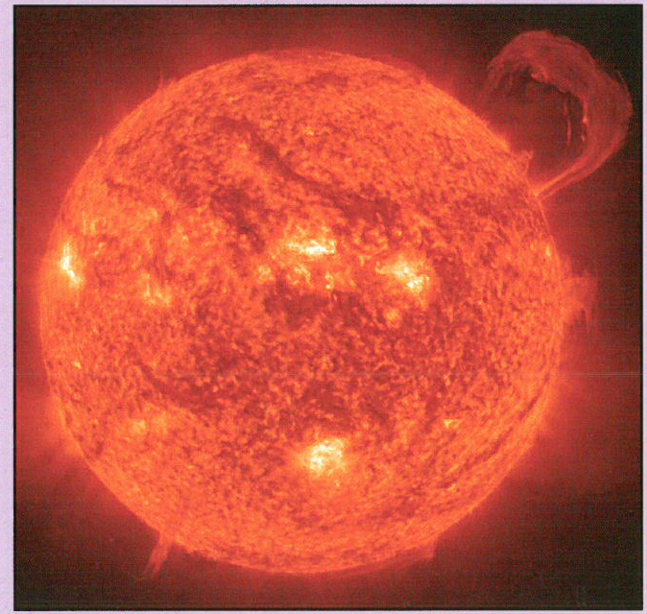
You will have to assume that the readers will not know anything about atomic structure or radioactivity. The pamphlet should explain the procedure simply but correctly. Both the advantages and risks of the procedure will need to be outlined clearly. You may use diagrams and photographs, or both, either as part of your explanation or to make the pamphlet more interesting.

Nuclear Energy

We use nuclear energy all the time. The Sun produces solar energy when small, light nuclei combine to produce larger nuclei and lots of energy. This process is called 'fusion'. Nuclear power plants use large, heavy nuclei. When these break apart, they produce smaller nuclei, radiation and energy. This process is called 'fission'.

We can get carbon-free energy from uranium in nuclear power stations, using the process of fission. In the fission process one slow-moving neutron enters a fissile nucleus such as uranium-235. The product quickly splits into two other nuclei and usually two or three fast-moving neutrons. What happens to the neutrons that are released? They can fly off, be captured by some other material, or slow down and be absorbed by another fissile nucleus, splitting it and sending more neutrons off. This may repeat over and over again, leading to a chain reaction.

When either fission or fusion occurs, there is a mass difference between the initial mass and the final mass of all the bits and pieces. Einstein's mass-energy equation shows us just how much energy is involved.



An unusual view of the Sun taken through a filter.

So, you may ask, what is the difference between a bomb and a power plant? The difference is control. If a nuclear power station is controlled properly, energy is released at a steady rate and electricity is generated without polluting the atmosphere. When things go wrong the effects can be catastrophic. At Chernobyl in 1986, an unauthorised experiment in a badly-designed reactor made the core so hot that it melted. The core meltdown destroyed the reactor and released tons of radioactive debris into the atmosphere.

A reactor core accident is different from a nuclear explosion: unlike nuclear reactors, nuclear weapons are designed to explode. The devastating effects of nuclear weapons were made evident at Hiroshima and Nagasaki in 1945.

Both core accidents and nuclear explosions may cause immediate casualties. Both may also have serious long-term effects on the health of survivors, and on the future use of the affected site.

Nuclear explosion

Nuclear Energy: Comprehension Questions

Notes

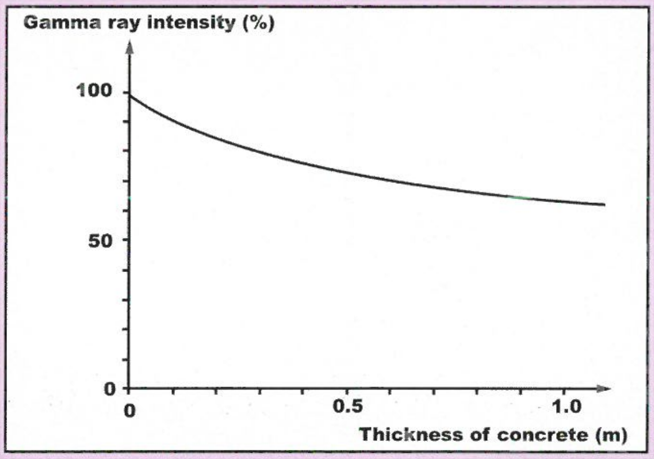
1. [see Chapter 8]
   [a] Explain the difference between energy and mass difference.
   [b] Explain the relationship between mass difference and binding energy.
   [c] Explain the difference between nuclear fission and nuclear fusion.

2. [see Chapter 8]
   Plutonium-238 was for a time used as an energy source for heart pacemakers. This meant that a piece of highly radioactive plutonium-238 had to be put into a patient's chest and left there for years.
   [a] Explain why pacemaker designers thought this would be a safe practice.
   [b] What does this practice imply about the half-life of plutonium-238?
   [c] The isotope plutonium-238 ($^{238}_{94}Pu$) has an atomic mass of 238.0496 u. Calculate its binding energy, and hence its binding energy per nucleon.
   [d] Plutonium-238 decays by alpha emission to uranium-234 (atomic mass 234.0409 u). Calculate the mass difference involved in this decay, and hence calculate the energy released by one such decay.

3. [see Chapter 8]
   One example of nuclear fusion is when a deuterium nucleus combines with a lithium-6 nucleus, producing only helium-4.
   [a] Write a balanced equation for this process.
   [b] The atomic mass of lithium-6 is 6.015 12 u. Calculate the mass difference and hence the energy released in this process.
   A neutron is absorbed by a uranium-235 nucleus and the resulting fission produces yttrium-88 ($^{88}_{39}Y$), cerium-146 ($^{146}_{58}Ce$), and some neutrons and beta particles.
   [c] Write a balanced equation for this process.
   [d] The atomic mass of yttrium-88 is 87.90950u and the atomic mass of cerium-146 is 145.91877u. Calculate the mass difference, and hence the energy released by this reaction.

4. [see Chapter 9]
   [a] List and explain three characteristics that determine whether a particular isotope is suitable for radiotherapy.
   [b] Why does radiotherapy have side effects?

5. [see Chapter 9]
   [a] Explain the relationship between the sievert and the gray.
   [b] The radiation dose absorbed by a worker in a nuclear facility does not tell the whole story about their exposure. Explain.
   [c] The graph (right) shows the extent to which concrete absorbs gamma rays.
   The containment shell of a nuclear reactor typically consists of a thick layer of steel surrounded by several metres of concrete. Explain why the designers feel this is necessary.



Chapter 8: Binding Energy Explained

Notes

Atomic nuclei

Scientists think atomic nuclei are composed of the basic nuclear building blocks, protons and neutrons. Electrical forces would normally make the positive protons repel each other. Fortunately, nuclear binding forces are stronger and hold these nucleons together against the electrostatic forces. Without this strong nuclear force matter as we know it could not exist.

To illustrate the forces acting in nuclei, consider the helium nucleus. It consists of two protons and two neutrons. If you add the mass of two protons to the mass of two neutrons, you would expect that you would have the same as the helium nucleus. Experimental measurement will show you that this is not so! The helium nucleus has a smaller mass.

If you could force together two neutrons and two protons you would find that the reaction produces an enormous quantity of energy. This energy comes from the 'missing' mass during fusion of the nucleons. Scientists call the 'missing mass' the mass defect. They call the energy it converts to the binding energy of the nucleus.

Binding energy is mathematically related to the mass defect by Einstein's famous equation:

$$\mathbf{E = mc^2}$$

where: **E** is the energy in J

m is the mass in kg

c is the speed of light = 3.00×10^8 m s^{-1}

The binding energy per nucleon is a measure of the stability of a nucleus. You calculate it by dividing the total binding energy of a nucleus by the number of nucleons in the nucleus.

Nuclear reactions

In the same way that chemical reactions can absorb or release energy, nuclear reactions can absorb or release energy. If a nuclear reaction releases energy, it will have come from some mass which has been 'lost' during the reaction. You calculate the mass difference in a nuclear reaction as follows:

mass difference = mass of products - mass of reactants

If reacting or product particles have significant energies then you must apply the principle of conservation of mass and energy.

total mass + energy of reactants = total mass + energy of products

Continued over

Chapter 8: Binding Energy Explained 8

Data

You can express masses in either kilograms or unified mass units, sometimes called atomic mass units, u. The definition of a **unified mass unit** is:

$$1\ \text{u} = \frac{1}{12} \text{ x mass of a carbon-12 atom}$$

$$= 1.660\ 54 \times 10^{-27}\ \text{kg}$$

Other data:

1 eV = 1.60×10^{-19} J

1 MeV = 1.60×10^{-13} J

Energy equivalent of 1 u= 931 MeV

Mass of proton = 1.67262×10^{-27} kg = 1.00727 u

Mass of neutron = 1.67493×10^{-27} kg = 1.00867 u

Mass of electron = 9.11×10^{-31} kg = 5.49×10^{-4} u

Note: The atomic masses in the table below include the masses of the electrons. In this book we will simplify the calculations by working only with the protons and neutrons. The answers provided have been calculated without including electron masses.

Notes

Atomic masses

Isotope	Atomic mass (u)
Hydrogen-1	1.00783
Hydrogen-2	2.01355
Hydrogen-3	3.01605
Helium-3	3.01603
Helium-4	4.00260
Lithium-7	7.01601
Carbon-12	12 exactly
Carbon-14	14.00324
Nitrogen-14	14.00307
Oxygen-17	16.99913
Strontium-90	89.90774

Isotope	Atomic mass (u)
Krypton-92	91.92616
Iodine-131	130.90613
Barium-141	140.91441
Xenon-142	141.92971
Gold-198	197.96824
Mercury-198	197.96677
Thorium-234	234.04360
Uranium-235	235.04393
Uranium-238	238.05079
Plutonium-239	239.05216

Experiment 8.1: Simulating a Chain Reaction (Method 1)

Notes

Background

A chain reaction occurs when one reaction provides the energy or a stimulus required for the next reaction. Neutron-induced nuclear fission reactions are chain reactions. In this type of reaction, a fissile nucleus such as plutonium-239 undergoes fission after it absorbs a neutron. The fission reaction produces neutrons, which can be absorbed by other fissile nuclei and cause them to fission. Keeping such a chain reaction occurring at a steady rate is a major challenge for designers and operators of nuclear power plants.

Aim

To simulate and observe a chain reaction.

Pre-Lab

Find out about the method by which nuclear chain reactions occur. Major ideas include:

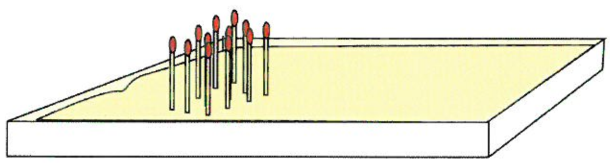
- Do all nuclei undergo fission reactions?
- What starts or initiates a fission reaction?
- What are the products like?
- What passes from one nucleus to the next – that is, what makes the 'chain'?
- What happens if the chain reaction goes too slowly?
- What happens if the chain reaction goes too quickly?

Apparatus

- a small sand tray, about the size and shape of a lamington tin, containing slightly damp sand about centimetre deep;
- several boxes of matches;
- digital camera

Lab Notes

- Poke the matches into the sand head end up and spaced no more than half a centimetre apart. This tends to work better if you tilt the tray so that one end is higher than the other.



- Light a corner match (at the bottom, if the tray is tilted) and then stand back a little.
- Make a photographic record of your chain reaction if you have access to a camera.

Post-Lab Discussion

1. Describe what happened in your simulated chain reaction.

2. Explain how this simulated a nuclear chain reaction. Include some discussion of how your simulation and a nuclear reaction are alike, and how they are different.

3. Suggest how you could control the speed of the chain reaction so that it produced energy at a constant rate.

Experiment 8.1: Simulating a Chain Reaction (Method 2)

8

Notes

Aim

To simulate and observe a chain reaction.

Pre-Lab

Find out about the method by which nuclear chain reactions occur. Major ideas include:

- Do all nuclei undergo fission reactions?
- What starts or initiates a fission reaction?
- What are the products like?
- What passes from one nucleus to the next – that is, what makes the 'chain'?
- What happens if the chain reaction goes too slowly?
- What happens if the chain reaction goes too quickly?

Apparatus

- a large number of spring-type mouse traps (as many as you can get)
- a large, flat container, such as a large bakery tray or cardboard box;
- digital camera

Lab Notes

- Carefully set all the mouse traps and place them close to one another (even overlapping if you have a steady hand) over the bottom of the tray. If you should accidentally set one trap off or drop it on the others, pull your hand away quickly!
- To begin the reaction, drop a small object onto one of the mouse traps at the edge of the tray.
- Make a photographic record of your chain reaction if you have access to a camera – you have to be quick!

Post-Lab Discussion

1. Describe what happened in your simulated chain reaction.

2. Explain how this simulated a nuclear chain reaction. Include some discussion of how your simulation and a nuclear reaction are alike, and how they are different.

3. Suggest how you could control the speed of the chain reaction so that it produced energy at a constant rate.

Problem Solving and Calculations Set 8: Binding Energy

Notes

8.1 Estimate the difference in mass between the nuclei of nitrogen-14 and nitrogen-13. Show your reasoning and discuss any assumptions that you have to make.

8.2 Under certain circumstances, a gamma ray photon may suddenly change into an electron and a positron.
[a] Write a nuclear equation to represent this change.
[b] Calculate the minimum energy of the photon.

8.3 Calculate the binding energy per nucleon for an atom of uranium-235.

8.4 The binding energy per nucleon values for two nuclei are:

Nucleus A: 6.9 MeV nucleon^{-1} Nucleus B: 8.8 MeV nucleon^{-1}

Which of these is the more stable nucleus? Explain.

8.5 Calculate the total binding energy, and the binding energy per nucleon, of:
[a] a lithium-7 nucleus, $^{7}_{3}\mathrm{Li}$.
[b] an iodine-131 nucleus, $^{131}_{53}\mathrm{I}$.

8.6 Of the two hydrogen isotopes, deuterium and tritium, which has the higher binding energy per nucleon? Show your reasoning.
deuterium = $^{2}_{1}\mathrm{H}$ tritium = $^{3}_{1}\mathrm{H}$

8.7 A small proportion of all the carbon in living organisms is the radioactive isotope carbon-14. Calculate the binding energy per nucleon of both the carbon-12 ($^{12}_{6}\mathrm{C}$) and carbon-14 ($^{14}_{6}\mathrm{C}$) nuclei and hence state which is more stable.

8.8 One of the simplest fusion reactions is:

$^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + {}^{0}_{+1}\mathrm{e} + \text{energy}$

[a] What is the name of the particle?
[b] Calculate how much mass a single instance of this fusion reaction converts to energy.
[c] Calculate how much energy a single instance of this fusion reaction releases.

8.9 Another fusion reaction is called the 'D-T' reaction because it involves deuterium and tritium nuclei fusing:

$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$

[a] Calculate how much mass a single D-T fusion reaction converts to energy.
[b] Calculate how much energy a single D-T fusion reaction releases.

8.10 Uranium-238 undergoes a series of radioactive decays, the first of which is:

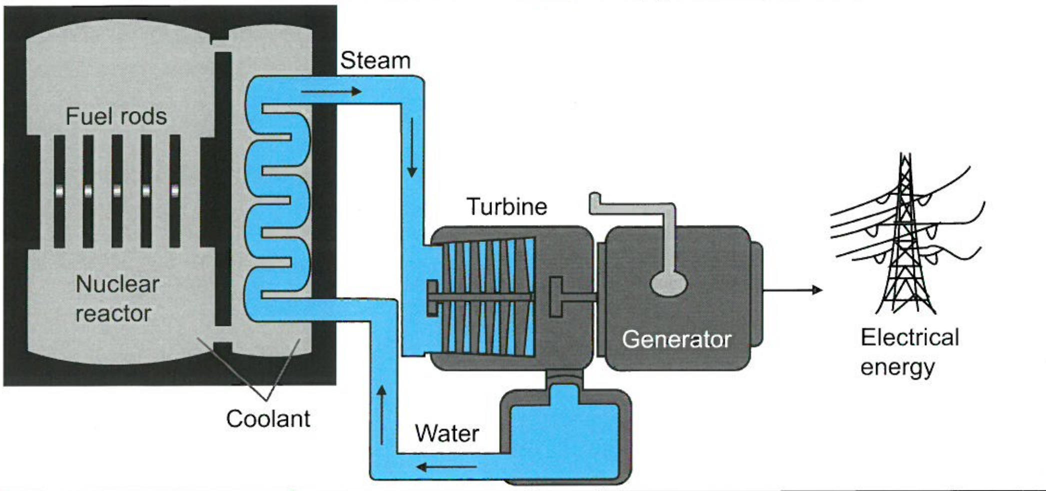
$^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{234}_{90}\mathrm{Th}$

Calculate how much energy one such uranium-238 decay releases.

8.11 In a fission reactor, a nucleus of uranium-235 may capture one neutron. The products of this fission are xenon-142 ($^{142}_{54}\mathrm{Xe}$), strontium-90 ($^{90}_{38}\mathrm{Sr}$) and neutrons.
[a] Write the nuclear equation for this fission. Indicate the number of neutrons that are released in this reaction.

Continued over

Notes



[b] How much energy is released when one uranium nucleus undergoes this fission?
[c] Such fission reactions form the basis of both the nuclear reactor and the nuclear bomb. What is the essential difference between a reactor and a bomb?

8.12 The coolant for a nuclear reactor is used to take the thermal energy from the nuclear fission process. Generally this excess thermal energy is used to generate steam and then turn turbines for electrical generation. If there is a loss of coolant, there is sufficient thermal energy generated in the reactor to cause a meltdown even after the fission process has stopped.
[a] Where does this thermal energy come from?
[b] Why can't this thermal energy be used to generate electricity?

8.13 After absorbing a neutron, a uranium-235 nucleus can fission to produce barium-141 ($^{141}_{56}\text{Ba}$) and krypton-92 ($^{92}_{36}\text{Kr}$).
[a] Write the equation for this reaction.
[b] Calculate the energy that would be released from this fission of a uranium-235 atom.
[c] Calculate the mass in kilograms of a single uranium-235 atom.
[d] Hence, calculate the number of uranium-235 atoms in 1.00 kg of pure uranium-235.
[e] Estimate the energy that would be released from the complete fission of 1.00 kg of uranium-235 atoms. What assumption do you have to make to calculate your answer?
[f] A nuclear power station produces 9.76×10^{13} J of electrical energy per day. Estimate the mass (in kilograms) of U-235 required to produce this energy.

8.14 Hydrogen ($^{1}_{1}\text{H}$) and deuterium ($^{2}_{1}\text{H}$) fuse to give helium-3 ($^{3}_{2}\text{He}$).
[a] Write a balanced nuclear equation showing this fusion reaction.
[b] How much energy does a single such fusion release?
[c] How many deuterium atoms are there in 1.00 kg of deuterium?
[d] How much energy does the fusion of 1.00 kg of deuterium release?

Continued over

Problem Solving and Calculations Set 8: Binding Energy

Notes

8.15 When alpha particles ($^{4}_{2}He$), having kinetic energy 3.0000 MeV bombard nitrogen-14 ($^{14}_{7}N$) nuclei, oxygen-17 ($^{17}_{8}O$) forms and the reaction releases a proton. Calculate the kinetic energy shared by the reaction products.

8.16 When atmospheric nitrogen-14 collides with a neutron, one of the possible results is that carbon-14 is produced plus a nucleon is released.

[a] Write a nuclear equation to represent this reaction.

[b] Calculate the change in mass (in kilograms) that occurs in this reaction.

[c] Assuming that all of the energy resulting from the nuclear reaction is transferred to the nucleon, calculate the energy transferred to the nucleon.

[d] If all of this energy released is transformed to the kinetic energy of the nucleon, with what speed will the nucleon leave the nucleus?

Investigations 8

Investigation 8.2: The nuclear debate (i)

Background

Should Australia build nuclear reactors for generating electricity?
Currently, Australia has a number of different types of power, or electricity-producing, stations. They are:

- Conventional coal, oil or gas-fired power plants.
- Hydro-electric power stations.
- Small-scale solar generating plants.

The task

Compare each of the above types of power station, including a nuclear power station, under the following headings:

- Cost per kWh (unit) of electricity produced.
- Generating capacity.
- Future supplies and projected costs of raw materials.
- Safety of personnel such as in mining, transport, plant workers
- Environmental damage and repair.
- Other issues or concerns.

Present your findings in chart or poster form.

Investigation 8.3: The nuclear debate (ii)

The task

You are required to compile a class briefing on the development of the nuclear bomb.

- A description of the appropriate nuclear reactions.
- An explanation of how the nuclear reactions are made to take place.
- A discussion of how a nuclear reaction can cause an explosion.
- A bibliography.

One of the following issues should be addressed in some detail within your briefing. You must ensure that the issue fits into the context you have chosen.

- Safe disposal of nuclear waste.
- The idea of a 'nuclear winter'.
- The history of the development of the atom bomb.
- Mass-energy conversion in nuclear fission reactions (i.e. $E = mc^2$)
- The short- and long-term effects of a nuclear explosion on property and living things.

Note: You may negotiate to make your briefing a short story or play. It should be fiction, but must include all relevant factual information.

Notes

Chapter 9: Radiation and the Environment Explained

Absorbed dose
Radiation damage to living body cells depends on two factors:
[1] the **energy** the cells absorb from the radiation.
[2] the **time** over which the cells absorb the radiation energy.
Scientists call the energy cells absorb from radiation the **absorbed dose.**
They measure this in joules absorbed per kilogram of tissue.

$$\textbf{Absorbed dose} = \frac{\textbf{energy absorbed}}{\textbf{mass of affected body part}}$$

The SI unit for absorbed dose is the gray, Gy.
1 Gy = 1 joule per kilogram ($J\ kg^{-1}$)

Table of weighting factors

Radiation type	Approximate quality factor
gamma rays	1
beta particles	1
slow neutrons	3
fast neutrons	10
alpha particles	20

Dose Equivalent
Absorbed dose is a useful concept when you compare the effects of different amounts of radiation of the same type. However, when you consider the effect on living tissue of a mixture of types of radiation, such as alpha and beta, or compare different types of radiation, absorbed dose is not a useful concept.

Symptoms of early radiation sickness syndrome

Dose Equivalent, Sv	Body damage
0.25	Reduction in lymphocyte (white blood cell) count
1	Possible nausea, vomiting
4	Nausea, diarrhoea, drop in blood cell count. About 50% of exposed group die within weeks from failure of blood-forming organs
5	Loss of hair, 50% die
6	Damage to stomach and intestine walls with loss of fluids: immediate radiation sickness; bloody diarrhoea: extreme thirst, purpura; death within 3 weeks
10	Severe damage to central nervous system; death within days

The problem is that equal amounts of different types of radiation affect living cells differently. Absorbed dose does not consider the different amounts of harm caused by equal numbers of grays from different types of radiation. To take this into account, scientists multiply the absorbed dose by a weighting factor called the quality factor (QF). This factor is much bigger for alpha radiation than for beta or gamma radiation, reflecting the greater amount of damage done to living tissues by the larger alpha particles.
Scientists call the result the 'dose equivalent', and measure it in units called sievert, Sv, where:
Dose equivalent = Absorbed Dose × Quality Factor
1 sievert (Sv) = 1 joule per kilogram ($1\ J\ kg^{-1}$) × QF

Lethal Dose
LD is the symbol for lethal dose, meaning a dose that results in death. LD-50 represents a mean lethal dose which is the dose that would kill 50% of the exposed people. Scientists sometimes extend this symbol further to LD-50/25 which represents the dose which would kill 50% of exposed people in 25 days.

Experiment 9.1: Radiation and Distance

9

Background

While using photographic film and sources similar to radium and uranium, Henri Becquerel discovered radiation in 1896. He also noticed that when the radioactive source was very close to the photographic plate, there was a much brighter affected area than when it was moved away at some distance.

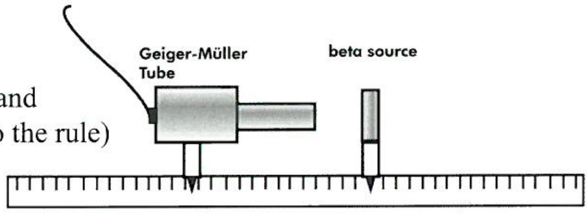
Radiation travels in every direction in straight lines from the centre of the source. A well-known example is light rays from the Sun. As the radiation moves farther from the source, it becomes less intense. With this information, we are going to investigate this effect to determine any mathematical relationship between distance and radiation. In this experiment the distances are 8 cm, 16 cm, 24 cm, and 32 cm from the source.

Aim

To explore and calculate the relationship (if any) between the distance from a radioactive source and the intensity of beta radiation.

Apparatus

- Geiger counter
- Optical bench or metre rule
- Strontium-90 (beta source) and a stand (to hold the source at right angles to the rule)
- stop watch
- graph paper



Lab Notes

- Set up the equipment similar to the diagram above.
- Set the digital Geiger counter to one minute intervals. Record background activity.
- Place the counter on the slider, 8 cm from the beta source.
- Record counts per minute (c min^{-1}) in a table like the table (below) for each trial, and calculate the average count rate.
- Move the Geiger counter and slider to 16 cm from the source. Repeat your measurement.
- Move the Geiger counter to 24 cm and repeat your measurement.
- Move the Geiger counter to 32 cm and again repeat your measurement. Indicate the standard error of the experiment.

Distance (cm)	Data Point r	r^2	Trial 1 (Corrected counts per minute)	Trial 2 (Corrected counts per minute)	Trial 3 (Corrected counts per minute)	Mean (Corrected counts per minute)	$(\frac{1}{r^2})$
8	1	1					
16	2	4					
24	3	9					
32	4	16					

Continued over

Notes

Experiment 9.1: Radiation and Distance

Notes

Processing of Results

1. Graph the corrected activity readings as counts per minute (in c min^{-1}) *vs* distance.
2. Graph the corrected activity readings (in c min^{-1}) *vs* $\frac{1}{r^2}$.

Questions

1. What was the background count for this experiment?

2. What would be the likely sources of this background activity?

3. Would the background activity be the same taken at sea level as taken on top of a mountain? Explain.

4. What happens to the intensity of beta activity when the distance between the Geiger counter and source is four times as great as the initial distance? Three times as great?

5. According to the inverse square law, when the distance is doubled from 8 cm to 16 cm, the reading should decrease to ¼ its initial reading. Do your data calculations agree with the inverse square? If they do not agree, suggest a reason.

6. Why was a beta source used for this experiment and not an alpha or a gamma source? What results would you have expected if you had used either of these two sources?

7. Explain how distance and radioactive materials are potential hazards to you.

8. Interpolate the number of counts for the beta source at a distance of 12 cm.

9. Evaluate how background activities may influence your data.

Problem Solving and Calculations Set 9: Radiation and the Environment 9

Notes

9.1 Alpha particles are less penetrating than beta particles, which in turn are less penetrating than gamma rays.
[a] Explain the different penetrating abilities of these types of radiation and give reasons for the differences.
[b] It is dangerous to have an alpha-emitting substance in contact with your skin. It is more dangerous if you swallow or breathe it. Explain why.

9.2 People who use radioactive materials every day must minimise their exposure to radiation.
[a] Explain how a radiographer uses the principles of shielding and distance to safely treat her patients when she uses a cobalt-60 radioactive source.
[b] During radiation treatment or when having an X-ray, the patient's ovaries or testes are normally covered with a lead blanket. Why do they use lead for this?
[c] Why are the reproductive organs, in particular, kept covered?

9.3 Radiation treatment of cancer in an internal organ such as the kidney or intestine may involve directing a beam of gamma rays from a cobalt-60 source. The beam is rotated steadily around the patient but always directed inward towards the affected organ.
[a] Why are gamma rays used rather than alpha or beta particles?
[b] Is it true that radiation treatment such as this kills only cancer cells and not normal cells?
[c] Why is the source rotated around the patient's body?
[d] Will this radiation treatment cause the patient's cells to become radioactive? Explain.

9.4 Workers in the Western Australian mineral sands industry are continually monitored for radiation exposure. In particular, they are monitored for external exposure to gamma rays and internal exposure to alpha particles from ingested dust.
[a] Why is internal exposure to alpha particle radiation of major importance?
[b] What precautions could be undertaken in the workplace to minimise workers' exposure to radioactive particles in dust?

9.5 Are fast neutrons or slow neutrons more damaging to humans? Explain why.

9.6 Jamie is a radiologist with the local hospital. While working on one particular machine, she was accidentally exposed to 36 mGy of an alpha source.
[a] What was Jamie's effective dose in this incident?
[b] If the source was beta or gamma, would the dose be more or less harmful? Explain your answer.

9.7 Explain exactly what the following expressions mean:
[a] LD-50/50 = 4.5 Sv
[b] LD-100/20 = 9.5 Sv

Continued over

Problem Solving and Calculations Set 9: Radiation and the Environment

Notes

9.8 Reg, a miner who is employed at a radioactive mine, has a body of mass 78.5 kg. He received a total dose of 16.2 J of radioactive energy in the form of alpha particles.
[a] What is the radiation dose in Gy?
[b] What is the dose equivalent in Sv?
[c] Is this enough to cause Reg serious damage? If so, describe the likely damage.
[d] If the dose was a concentrated radiation beam that only hit approx 0.6 kg of his lungs, how would that alter your answers to [a], [b] and [c] above?

9.9 Naturally-occurring radioactive substances in the human body such as potassium 40 provide your body with a dose equivalent of about 1.4 mSv y^{-1} (millisieverts per year). Calculate how much energy this internal radioactivity releases in an average 50 kg child in one year. Assume the quality factor is 1.

9.10 One of the long-term effects of nuclear explosions is radioactive fallout.
[a] What is radioactive fallout?
[b] Why is this a long-term effect?

9.11 A significant proportion of background radiation is due to radon gas and its 'daughter' products.
[a] Where does the radon come from?
[b] Where are radon concentrations likely to be highest?

9.12 In a radiation accident a worker absorbs 28.7 J of radioactive energy from gamma rays. If she has a body mass of 64.2 kg:
[a] What is her absorbed dose?
[b] What is the dose equivalent?
[c] Is this dose enough to cause serious immediate damage?
[d] If she had instead absorbed the energy from alpha radiation, how different would her situation be?

9.13 Engineers use the radioisotope gold-198 ($^{198}_{79}Au$), a beta emitter, to track sewage.
[a] Gold-198 decays to mercury-198 ($^{198}_{80}Hg$). Write the equation for this decay.
[b] Determine the amount of energy released by one decay of gold-198.
[c] Describe briefly how they can track sewage using gold.

9.14 As a result of nuclear bomb testing, strontium-90 has entered the environment. Strontium is chemically similar to calcium and, if ingested, may end up as a long-term component of bone. A resident of an affected area is found to have absorbed strontium-90 with an activity of 100 MBq. The half-life of strontium-90 is almost 30 years so the decline in activity may be ignored if the radiation dose is relatively large.

Continued over

Notes

[a] The energy released in each decay is 2.0×10^{-13} J. How many joules of energy will be released from his bones each second?
[b] The patient has a mass of 60 kg. Calculate his daily (that is, each 24 hours) absorbed dose in grays (Gy).
[c] The radiation is a mixture of beta and gamma types and has a quality factor of 1.0. What will be his daily dose equivalent in mSv?
[d] If a dose of 5 sieverts is likely to be fatal in 50% of the population, what would you estimate the life expectancy of the patient to be?

9.15 Flight crew, made up of pilots and cabin crew, of several major airlines wear film badges to monitor their exposure to radiation.
[a] What is the source of the radiation to which they are exposed?
[b] Why are aircrew in particular monitored and not workers in other transport industries?
[c] Explain how a film badge works.
[d] Why are film badges generally unsuitable for detecting alpha particle radiation?
[e] How does a film badge discriminate between beta and gamma radiations?

9.16 Your thyroid gland, at the base of your neck, produces hormones that govern the reaction rate of many of your body's chemical reactions. These hormones contain the element iodine which is present in small quantities in a normal diet. A significant proportion of the radioactive fallout from the Chernobyl accident was the radioisotope iodine-131, a beta emitter. People living in the contaminated area were subsequently given potassium iodide tablets to take every day to try to prevent the iodine-131 from seriously affecting them. How could the potassium iodide tablets provide protection?

9.17 Miners working in a large uranium mine experience the following background radiation per year:

gamma rays	7.5 mGy
beta particles	6.0 mGy
fast neutrons	0.3 mGy
slow neutrons	1.5 mGy
alpha particles	0.15 mGy

The mining company regulations state these miners may only receive a maximum of 8.0 mSv of background radiation per year.
[a] How many days per year should the company allow any one team of miners to work in the mine so nobody receives more than the maximum dose?
[b]What assumptions have you had to make to answer [a]?

Investigations

Investigation 9.2: Environmental radiation

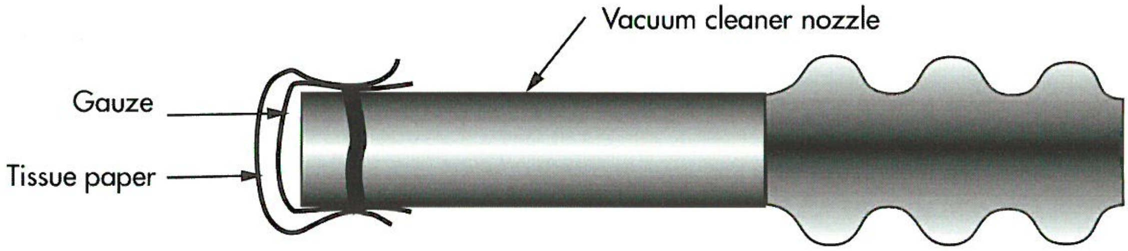
Naturally occurring and human-induced radiation in the environment are topics of concern for many people. The presence and effects of radon in homes, schools and other buildings is an example of this concern.

Before beginning this investigation into radon, look up one or two reference books and find out where environmental radon comes from and where it is most likely to be found in greatest concentrations.

There are several ways to collect some of the daughter products of radon. The first method will probably be easier in a school situation.

(a) Method 1

The purpose of this investigation is to try to detect radiation in dust deposited in buildings or present in the air. To do this, samples of dust need to be collected. A vacuum cleaner, fitted with an appropriate filter, might be left in the atmosphere for a period of time. The filter pad could be checked by placing it near the detector of a Geiger counter. As well, samples, collected from surfaces which are currently receiving dust should be checked. Choose a place in a school building where you think radon levels will be high. Attach some wire gauze and tissue paper to the nozzle of a vacuum cleaner as in the diagram below. Leave the vacuum cleaner to run for 15-30 minutes. Radioactive daughter products may collect on the tissue paper.



While you are waiting for the dust to collect, you should set up the Geiger counter to determine the background radiation count.

You should sample dust from a number of environments, including places that are well ventilated as well as some where the air changes slowly. Test samples collected by running the vacuum cleaner in the open air as well as from under buildings if possible. Remember, if you want to compare one test area with another, you will need to collect dust for equal periods of time.

(b) Method 2

Arrange for two enthusiastic sporting types to play non-stop squash or racquetball for about 15 minutes; enough time for the ball to become quite warm. The warm ball will be electrostatically charged and in moving backwards and forwards across the room, will pick up radioactive particles from the air.

The task

Whichever method you choose, begin recording the radiation counts as soon as possible after collecting the radioactive particles. Record your results in a suitable table, and answer the questions below.

1. Considering the origin of the dust, do you think that dust that settles today will have a different composition from that which settled yesterday?

2. Are there any significant differences in the number of counts collected from different locations? Is this what you expected? Explain your results.

3. The flow chart below shows a decay series that starts with the radioisotope thorium-232 and ends with the stable (non-radioactive) lead-208.

$${}^{232}_{90}\text{Th} \xrightarrow{\alpha} {}^{228}_{88}\text{Ra} \xrightarrow{\beta} {}^{228}_{89}\text{Ac} \xrightarrow{?} {}^{228}\text{Th} \xrightarrow{?} {}^{224}\text{Ra} \xrightarrow{?} {}^{220}\text{Rn} \xrightarrow{?} {}^{216}\text{Po} \xrightarrow{?} {}^{212}\text{Pb} \xrightarrow{?} {}^{212}\text{Bi} \xrightarrow{?} {}^{212}\text{Po} \xrightarrow{?} {}^{208}\text{Pb}$$

Continued over

Investigations

9

The table below shows the half-life for each decay reaction. Complete the table, indicating the new atomic number of each daughter product, and the decay mode for each decay reaction.

Isotope	Symbol	Atomic Number	Decay Mode	Half Life
Thorium-232	${}^{232}_{90}Th$	90	α	1.40 x 10^{10} years
Radium-228	${}^{228}_{88}Ra$	88	β	5.75 years
Actinium-228	${}^{228}_{89}Ac$	89		6.15 hours
Thorium-228	${}^{228}Th$			1.91 years
Radium-224	${}^{224}Ra$			3.63 days
Radon-220	${}^{220}Rn$			55.6 seconds
Polonium-216	${}^{216}Po$			0.145 seconds
Lead-212	${}^{212}Pb$			10.6 hours
Bismuth-212	${}^{212}Bi$			60.6 minutes
Polonium-212	${}^{212}Po$			2.99 x 10^{-9} s
Lead-208	${}^{208}Pb$		stable	stable

Note that radon-220 is a gas under normal conditions, while the other isotopes in the table, and their compounds, are solids at room temperature and pressure.

4. Which particles (α or β) are more dangerous if they are generated outside your body?
5. Which particles (α or β) are more dangerous if they are generated inside your body?
6. In terms of the radioactivity they produce, which of the isotopes in the table above would be most dangerous to inhale so they get into your lungs? Explain your reasoning.
7. Some rocks, such as granite, contain thorium. Radon-220 has a short half life, but the air above such rocks always contains some radon-220. Suggest why this is so.
8. Does this experiment collect any radon (in the tissue, or on the squash ball)? Explain.
9. Explain why radon concentrations are often greater in houses that are poorly ventilated.
10. People who live in warm climates are likely to be exposed to lower concentrations of radon than those who live in colder regions. Suggest a reason for this.
11. Assuming that your vacuum cleaner or squash ball is able to collect dust from a cubic metre of air per minute, estimate the activity of the air (in becquerels) in your environment from the number of radioactive events in your dust samples.

Investigations

Investigation 9.3: What's radioactive?

Notes

A number of common materials are slightly, or in some cases quite strongly, radioactive. Collect as many of the following as you can and test them for their radioactivity. Your teacher may be able to provide you with more items.

- old watch (or clock) with a luminous dial
- mineral sands (preferably separated into different components)
- granite
- gas lamp mantle
- solid potassium chloride
- solid uranyl nitrate [This is both poisonous and radioactive - handle with care!]

You will need to control (e.g. keep constant) the following factors in order to fairly compare the different materials:

- background radiation;
- distance from Geiger tube;
- how long each measurement takes.

Investigation 9.4: Smoke detectors

Background

Some types of smoke detectors contain the radioisotope americium-241 which is an alpha-emitter with a half-life of 432 years. The emitted alpha particles ionise the air and any smoke particles will stick to the ionised air particles, triggering the alarm.

The task

[a] What are the advantages of using a radioactive source with a long half-life?

[b] How long will it take for the activity of a sample of americium-241 to decrease to 1.00×10^{-3} of its original activity?

[c] Write a balanced nuclear equation for the alpha emission.

[d] Why did the designers choose an alpha emitter instead of a beta or gamma emitter for this particular application?

[e] Should you wear gloves when you handle the smoke detector: for example, when installing it or when changing the batteries? Why, or why not?

[f] Over a period of years, what is the risk that the radioactive emissions in the smoke detector will cause other objects, such as part of the ceiling, to become radioactive? Explain your response.

[g] How safe are these devices? Does the risk due to radioactivity outweigh the benefits? Present your findings in electronic, chart or poster form.

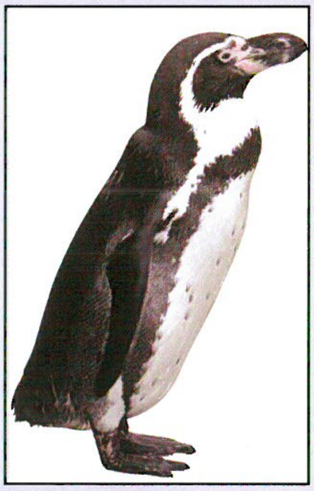
Notes

Heating and Cooling
Feathers, Fur and Protective Clothing

Living things, especially animals, have very sophisticated ways to measure and control the temperature inside their bodies. The chemical reactions that keep animals alive only work properly in a narrow range of temperatures. If an animal's body gets too cold or too hot, these reactions go wrong, or stop altogether. Animals must keep their body temperatures at or near the optimum, even when their surroundings are hotter or colder.

Normal human body temperature is about 37 °C. Thermal energy naturally transfers from where the temperature is higher to where the temperature is lower. People in very cold places, such as the Antarctic, have body temperatures considerably higher than the temperature of their surroundings, even in the summer. They must take special precautions to avoid losing energy as heat.

Antarctic animals have built-in protection, or adaptations, to cope with the severe conditions. Penguins have round, stocky bodies; short, stubby limbs; a layer of fat under the skin; and densely overlapping feathers to protect them from the cold. Although individually small, penguins are social creatures and gather in large groups. This behaviour reduces heat loss, by lessening wind chill and increasing the ratio of body mass to exposed body surface. Most heat loss takes place through the skin, and small animals tend to lose heat faster than large animals in similar surroundings. Penguin chicks, for example, have a thick coat of fluffy feathers. They would lose heat too quickly from their small bodies if they had shorter, flatter adult feathers.



Penguin

Whales rely on a thick layer of blubber, or fat, and large body size to conserve heat. Even the fish have special enzymes and antifreeze agents to protect them in winter.

Humans lack such natural adaptations against severe cold. A human in Antarctica can only survive for an extended period if they modify their behaviour. An Antarctic researcher, out of doors in winter, has to wear several layers of thick clothing, designed to trap layers of still air between the skin and the outside. This arrangement, rather like the penguins' feathers and the whales' blubber, reduces heat loss. Tents used in the Antarctic have double walls, trapping an air layer between them to reduce heat loss. Like many penguins, seals and whales, most Antarctic researchers are migratory. They leave the area in the winter, returning in the summer months.

Antarctic summer temperatures average around 0 °C, while in winter Antarctica is the coldest place on Earth. Strong prevailing winds sweep bitterly cold air from the interior of the continent to the coast. These winds may reach speeds of over two hundred kilometres per hour. Exposure to such wind increases the effects of the low temperature. This increased effect is called a 'chill factor'. In addition, because of the intense cold, the air above Antarctica is as dry as in any desert.

People in very hot places, such as the deserts of inland Australia, have the reverse problem. The temperature of their surroundings is much higher than human body temperature. In these conditions, they must take special precautions to avoid excessive heat gain.

The fringe of an Australian desert

Feathers, Fur and Protective Clothing Comprehension Questions

Notes

1. [see Chapter 10]
   [a] Explain the difference between thermal energy and heat.
   [b] Explain the difference between thermal energy and temperature.
   [c] 54 °C is not twice as hot as 27 °C - it is 9% hotter. Explain.

2. [see Chapter 10]
   If you drop a ball, where does its energy go? Design an experiment to check your hypothesis.

3. [see Chapter 11]
   Discuss the ways in which the following reduce heat loss:
   [a] A thick coat of fluffy feathers;
   [b] A thick layer of blubber;
   [c] Large body size.

4. [see Chapter 11]
   [a] What is wind chill, and why does it happen?
   [b] Suggest three different ways in which desert dwellers can reduce heat gain from their surroundings.

Kangaroo in the desert

Chapter 10: Heat, Temperature and Thermal Energy Explained

Notes

Energy comes in several basic forms, including kinetic and potential energy.
We measure energy in units called 'joules'.

Kinetic energy is the energy an object has because of its motion.
For example, a moving motor vehicle has kinetic energy. Any kind of movement gives an object kinetic energy.

Potential energy is the energy an object has stored up as a result of its position. We also refer to energy stored in a molecule or in an atomic nucleus as potential energy.
For example, a motor vehicle at the top of a hill has gravitational potential energy.

The **thermal energy** of an object is the total of the kinetic and potential energies of all of the particles in that object.
The particles in a substance all move (by vibration, rotation or by travelling from place to place) so they all have kinetic energy. They also attract or repel neighbouring particles. This gives all atoms and molecules potential energy as well.
We can transfer thermal energy from one object to another. Many people refer to thermal energy transfer as a 'flow' of heat.

Heat is thermal energy being transferred between objects because of a difference in their temperatures.

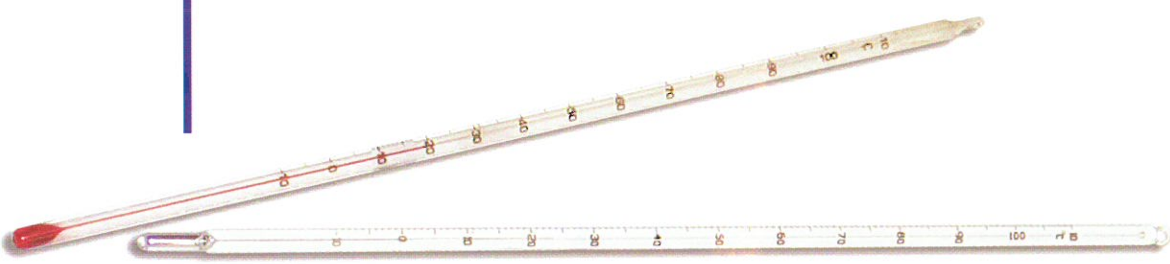
Temperature measures how hot or cold an object is. We measure temperatures in degrees Celsius or in kelvin.

The temperature of an object depends on the average of the kinetic energies of its particles (atoms, molecules) but not on their potential energies.

Two objects are in **thermal equilibrium** when their temperatures are equal, and heat transfer between the objects stops.

The Kinetic Theory of Matter
Scientists believe that all matter consists of particles (atoms and molecules) that move randomly and continually. In solids, these particles vibrate about fixed locations in the solid. In gases and liquids, the particles actually travel around, as well as rotating and vibrating. All atoms and molecules having temperatures above absolute zero have kinetic energy.

Continued over



Thermometers

Chapter 10: Heat, Temperature and Thermal Energy Explained 10

The basic assumptions of the **Kinetic Theory of Matter** are:
(i) All matter consists of tiny particles, such as atoms, molecules or ions.
(ii) Electrical forces, both attractive and repulsive, exist between these particles.
(iii) All these particles move randomly and hence they all possess kinetic energy.
(iv) Collisions between particles involve no loss of kinetic energy, except when they lead to chemical reactions: that is, the particle collisions are said to be perfectly elastic.

Notes

Conservation of Energy
The Law of Conservation of Energy states that the total energy of a closed system stays constant.
In a closed system, neither energy nor material can enter or leave the system. It is isolated from its surroundings.
Whenever energy is converted from one form to another, it is conserved. Conservation means that the total amount of energy does not change. Note that the amount of kinetic energy or potential energy may change; it is the total that is constant.

Degradation of Energy
Whenever energy changes from one form to another, some energy may transform into a useful form, while the rest of the energy will always change to a form that we cannot readily use. This physical law means that all energy gradually degrades, often into (low grade) thermal energy.
For example, a motor vehicle at the top of a hill has gravitational potential energy. If you release the brake and allow the vehicle to roll downhill, its potential energy decreases and at the same time its kinetic energy increases. At the bottom of the hill, you engage the brake once more, and the vehicle comes to a stop. It now has neither potential nor kinetic energy, because its energy has become thermal energy, mostly in the brakes.
Efficiency
Engineers usually try to make energy transformations as efficient as possible so the maximum amount of energy converts into a useful form. The efficiency of any energy transformation relates to the proportion of useable energy that results from a transformation.
We can express efficiency as a percentage:

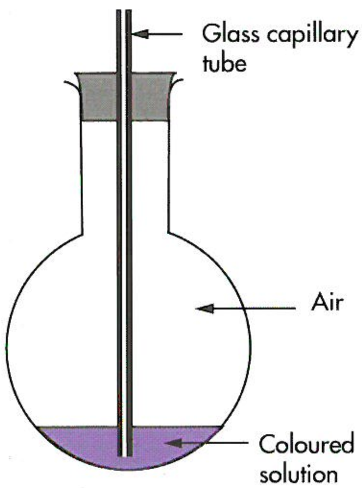
$$\textbf{Efficiency} = \frac{\textbf{Useful Energy}}{\textbf{Input Energy}} \times 100\%$$

Heat-sensitive pad

Experiment 10.1: Gas Thermometer

Background

Many types of thermometer exist. All of them use some property of a substance that changes with temperature to measure what the temperature is. All of them have to be calibrated – that is, the scale readings have to be matched to some standard values. Most laboratory thermometers use a liquid (such as alcohol or mercury) in a glass tube. The standard temperature values or 'fixed points' for liquid-in-glass thermometers are usually 0 °C and 100 °C.



Apparatus for Experiment 10.1

Aim

To construct and calibrate a gas thermometer.

Apparatus (per group)

- marking pen
- flask
- single hole stopper
- water with food colouring
- glass capillary tube to fit the hole in the stopper

Pre-Lab

- Your instructor will show you how to safely push the capillary tube into the stopper.
- In your group, discuss and agree on the fixed points you will use to calibrate your thermometer.
- Plan how you will attach your calibrated scale to the thermometer.

Lab Notes

- Assemble the thermometer as shown in the diagram.
- Calibrate the device and attach the scale.
- Use your thermometer over a period of three or four days and compare the results with a standard liquid-in-glass thermometer.

Post-Lab Discussion

1. What causes the liquid in the capillary tube to move up and down?
2. What are some limitations of this type of thermometer?
3. Find out about three other types of thermometer (i.e. not liquid-in-glass or gas) and briefly report on how they work and why they are useful.

Notes

Experiment 10.2: The Power of a Bunsen Burner

Bunsen burner

Background

The rate at which a heat source supplies energy is its power. Gas burners such as the Bunsen burner are convenient heat sources in the laboratory.

Aim

To estimate the power output of a Bunsen burner.

Apparatus (per group)

- 1 L Pyrex® beaker
- Bunsen burner
- tripod and gauze mat
- stop watch
- thermometer
- access to a balance

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Discuss with your lab partners how you will accurately measure the mass of the water that you will heat in the beaker.
- Discuss with your lab partners how you will determine the power of the Bunsen once you know how much energy it supplied.
- Prepare a table suitable for recording your measurements.

Lab Notes

- Add about 700-800 mL of water to the beaker, determine the mass and initial temperature of the water you added and record the values.
- Put the beaker on the tripod and gauze mat, and heat it for 5 minutes using the hottest Bunsen flame.
- Stir the water, and measure and record the final temperature.

Post-Lab Discussion

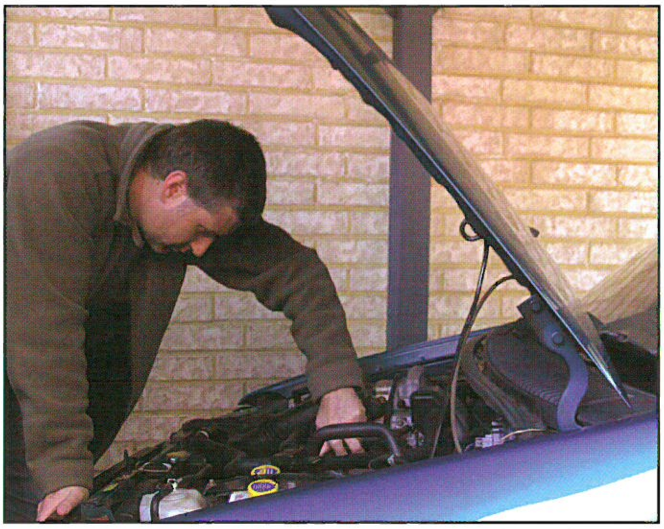
1. Calculate the energy supplied to the water using the relationship
   Energy supplied = (mass of water) x (4180) x (temperature change of water)
   (If you have not yet learned about the specific heat capacity of water being 4180 J kg^{-1} $^{o}C^{-1}$, don't worry – this will be covered soon.)
2. Calculate the power of the Bunsen burner.
3. Explain why your calculated value is an estimate. Is it likely to be lower or higher than the real value? Why?
4. Why were you instructed to measure the temperature change of the water over a 5 minute period rather than, say, 15 minutes?
5. Why were you instructed to stir the water before measuring its temperature?
6. How could you estimate the power of an electric hotplate?
7. Write a conclusion for your lab. You should refer to your original hypothesis, and to the dependent and independent variables.

Notes

Problem Solving and Calculations Set 10: Heat, Temperature and Thermal Energy

10.1 What form of energy is the main source of the thermal energy in each of the following?
[a] a hot footpath;
[b] an electric iron;
[c] an overheated wheel bearing.

10.2 Maria, a technician, needs to find out the efficiency of a new design of car engine. She runs the engine on an amount of fuel that she knows contains 985 kJ of chemical energy. She measures the useful mechanical energy output of the engine to be only 215 kJ. Calculate the engine's efficiency.



Overheated engine

10.3 Compared with cool days, motoring organisations get many more calls to their breakdown teams for assistance with overheated engines on hot days. Explain why this is so.

10.4 Mohammed measures that his racquet gives a squash ball 45.0 J of kinetic energy when he hits it with a particular shot. He also measures that it only has 18.0 J of kinetic energy after one bounce off the court wall.
[a] What percentage of its mechanical energy does the ball lose when it bounces off the wall?
[b] Describe an experiment that might allow you to verify your answer.
[c] What happens to most of this 'lost' energy?

10.5 When you apply the brakes of a car its kinetic energy decreases.
[a] To what form of energy is most of this kinetic energy converted?
[b] Where does the resulting energy go?

Notes

10.6 On a hot day your friend suggests that you should leave the freezer door open to help cool the room the freezer is in. Explain what would this do to the temperature of the room.

10.7 Engineers describe high-quality reverse cycle air conditioners as 'heat pumps'. When you compare the electrical energy entering a reverse cycle air conditioner with its heat output, you will find that it has an apparent efficiency greater than 100%. This seems to break the laws of energy conservation. Explain what is happening.

10.8 People often refer to thermal energy as 'low-grade' energy.
[a] Explain why.
[b] How is low-grade energy different from high-grade energy?
[c] Give some examples of high-grade energy.

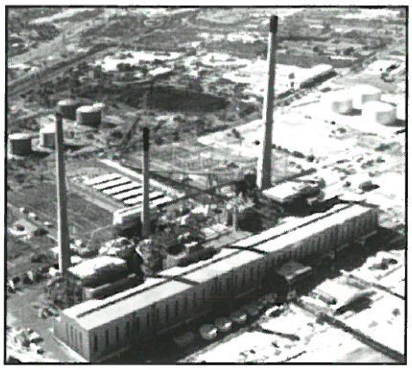
Problem Solving and Calculations Set 10: Heat, Temperature and Thermal Energy

10

10.9 When a power station converts chemical or nuclear energy to electrical energy it converts about 50% of the energy to low-grade thermal energy.
[a] Suggest how people could use this energy before the power station operators allow it to enter the environment.
[b] Why is this low-grade thermal energy less useful in the warm Australian climate?

10.10 Engineers design heat engines, which convert thermal energy to mechanical energy.
[a] Why do they deliberately design heat engines to operate at high temperatures?
[b] Why do such engines operate more efficiently in cold weather?

10.11 A modern power station, or, more correctly, an energy station, converts heat into electrical energy at an efficiency of 50.0%. If the station produces electrical energy at a rate of 1.00×10^3 MW from burning coal, calculate the mass of coal it burns each day. The coal it uses produces 25.0 MJ of heat per kg when it burns completely. Remember that $1.00 \text{ W} = 1.00 \text{ J s}^{-1}$.



Kwinana power station, or, more correctly, energy station. This station has used oil, coal and natural gas as fuel in its lifetime.

Notes

Experiment 11.1: Convection Currents

Notes

Background

Water is not a good conductor, but heat travels through it quickly by another process called 'convection'.

Aim

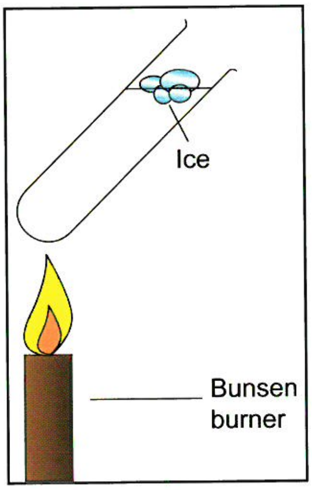
To investigate heat transfer efficiency in water.

Apparatus (per group)

- two similar Pyrex® boiling tubes
- ice broken into pieces small enough to fit in the boiling tubes
- small weight such as a lead fishing sinker or a large ball bearing
- test tube tongs

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Discuss with your lab partners how you will heat the boiling tubes safely. Think about the safety of the people nearby as well as those in your group. Consider also how to heat the tubes without damaging the test tube tongs.



Lab Notes

- Set up the apparatus as shown in the diagram (*upper left*) and heat the boiling tube. Record your observations.

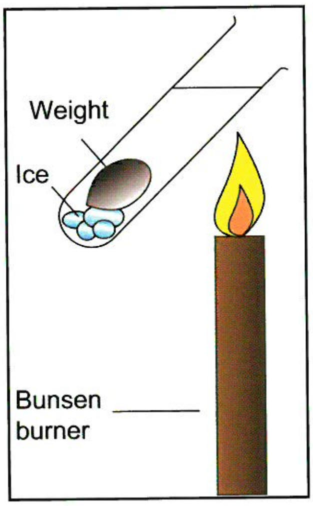
- Set up the apparatus as shown in the diagram (*below left*). The small weight must be able to hold the ice at the bottom of the boiling tube. Heat the boiling tube as shown.
  Record your observations.

Post-Lab Discussion

1. Describe and explain what happened when you heated the boiling tube at the bottom, with the ice at the top.

2. Describe and explain what happened when you heated the boiling tube at the top, with the ice at the bottom.

3. Write a conclusion for your lab. You should refer to your original hypothesis, and to the dependent and independent variables.

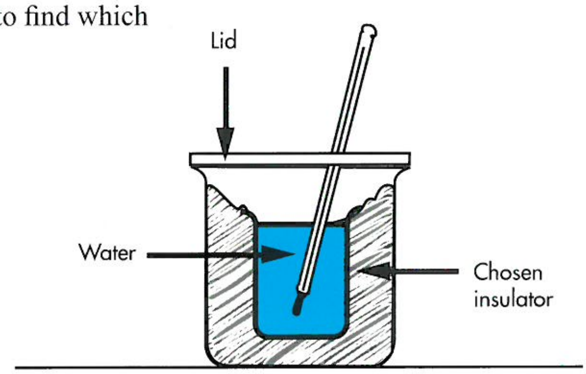


Experiment 11.2: Insulators

11

Background

Many materials are classified as 'insulators' but surprisingly few are used to insulate temperature-controlled environments. You can compare three samples to find which materials make the best insulators, and why.



Apparatus for Experiment 11.2

Aim

To plot cooling curves for an insulated container of liquid.

Apparatus (per group)

- large take-away container or can with a tight-fitting lid
- 100 mL measuring cylinder
- thermometer
- rubber stopper
- small beaker
- access to insulating material [such as crumpled paper, shredded paper, polystyrene nuggets, crumpled aluminium foil, cotton wool, sawdust]
- access to hot water
- stop watch

Notes

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table suitable for recording the data from your experiment.
- Plan which of the insulators your group will test, and how you will do it.

Lab Notes

- Set up the experiment as shown, with one of the insulators below and around the inner beaker. Isolate the inner beaker by standing it on a rubber stopper as shown.
- Measure 100 mL of hot water and pour it into the inner beaker. As soon as the thermometer reading reaches a peak, start timing. Record the first temperature reading at time 0.
- Stir the water, measure and record its temperature each minute for 15 minutes.

Post-Lab Discussion

1. Plot graphs of the temperature *vs* time. These are called 'cooling curves'.

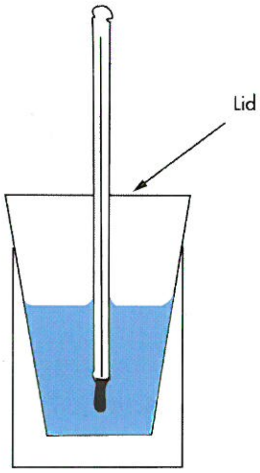
2. Use the graphs to determine how long the water took to cool from 75 °C to 65 °C with each insulator in place and repeat for temperature range 50 °C to 40 °C.

3. List the materials you tested in order from the best insulator to the worst.

4. Explain why the best insulator was so effective.

5. Why were you instructed to stir before measuring the temperature?

Experiment 11.3: Why Do Coffee Cups Have Lids?



Background

If you have bought take-away coffee you will know that the cups always have tight-fitting lids. This is partly to prevent hot liquid splashing out and injuring the consumer.

Aim

To investigate whether there is a physical reason for supplying lids with take-away beverage containers.

Apparatus (per group)

- plastic takeaway cup with a tight-fitting lid
- thermometer
- small beaker
- access to hot water
- stop watch

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table suitable for recording the data from your experiment.
- Make a mark inside the take-away cup, about three-quarters of the way up from the bottom.

Notes

Lab Notes

- Stand the take-away cup in the beaker as shown in the diagram. This is to reduce the risk of knocking the cup over as you stir and measure the contents.
- Using your mark as a reference, three-quarters fill the cup with hot water. Measure and record the temperature of the water in the cup, and start timing straight away.
- Stir, then measure the temperature of the water at thirty-second intervals for a total of ten minutes, recording the temperatures and times as you proceed.
- Repeat the experiment, using the same amount of water but this time fixing the lid on the take-away cup immediately after adding the hot water.

Post-Lab Discussion

1. Draw graphs of the experimental data.

2. Explain which graph shows the liquid cooling at the faster rate.

3. Explain the differences between the cooling rates.

Problem Solving and Calculations Set 11: Heat Transfer 11

11.1 Builders often insulate parts of homes with material that consists of a thin shiny sheet of reinforced aluminium foil. How does this material reduce heat transfer?

11.2 Swimmers often notice that when they start to swim in a still body of water after a hot, sunny day the surface water is warm but the deeper water is cold. Explain why this happens.

11.3 Explain why supermarket freezers still manage to keep the contents frozen despite often having no lids.

11.4 Why does a concrete floor feel colder than a carpeted floor at the same temperature?

11.5 Why does a metal fork feel colder than a plastic fork despite both being taken out of the same cutlery drawer?

11.6 Explain clearly:
[a] how an electric bar heater heats a room;
[b] why energy conservation advisers recommend that you should turn on ceiling fans on the slow setting when you use a room heater.

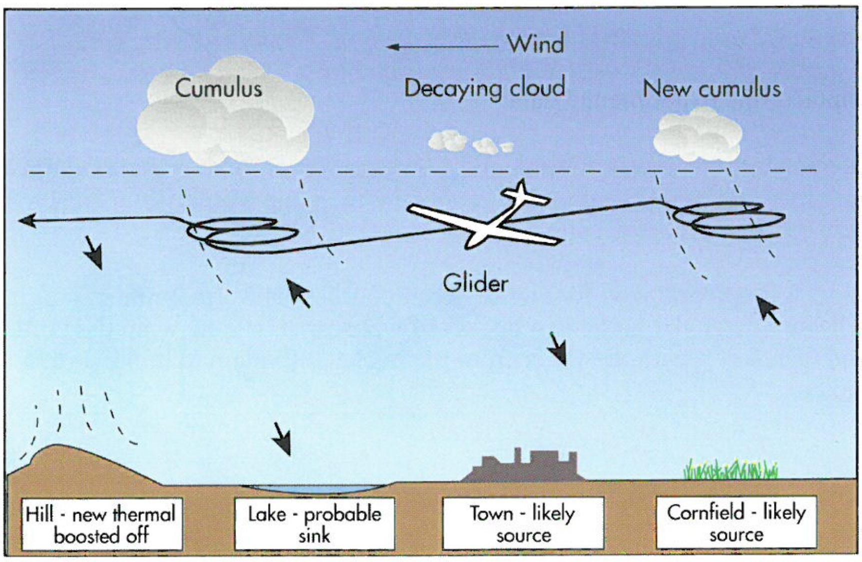
11.7 When you expose yourself to direct sunlight in summer you can become quite hot. If you wear white clothes the effect is not as severe as it is when you wear dark clothes. Explain the reasons for this difference.

11.8 One function of clothing is to reduce heat loss from your body on cold days. Explain how clothes do this.

11.9 Energy-conscious home owners often insulate their homes with thick pads of loosely packed glass fibres. Explain how these pads reduce heat transfer.

11.10 How do thick curtains help reduce heat loss from the windows of a house?

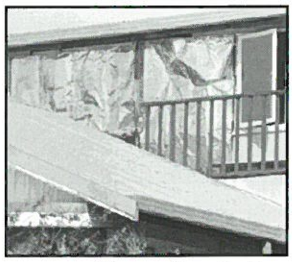
11.11 Glider pilots can often remain in the air for many hours by staying in regions of air called 'thermals'. A thermal is an upward air current in the atmosphere. Explain the cause of a thermal.



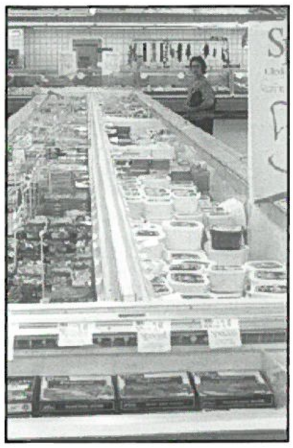
Path of a glider using thermals

Continued over

Notes

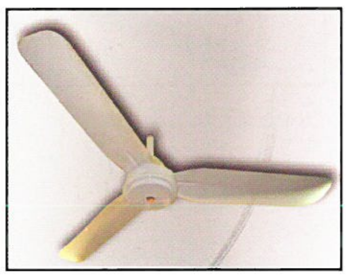


Home insulation



Supermarket freezer

Bar heater



Ceiling fan

Problem Solving and Calculations
Set 11: Heat Transfer


Billy on campfire

11.12 You have to pour a cup of tea ten minutes before your guest comes to drink it. Your guest likes milky tea. You want the tea to stay as hot as possible during the ten minutes. Should you add the cold milk immediately you pour the cup or should you supply milk separately for your guest to add? Explain your choice.

11.13 Why will a blackened billy reach boiling faster on a camp fire than a shiny new one?

11.14 The engine in a motor vehicle converts chemical energy from its fuel to mechanical energy plus a large amount of heat energy. This heat energy must be efficiently removed from the engine to prevent permanent damage from occurring. Consider the major components of a motor vehicle cooling system.
[a] Water is the most common engine coolant. However, many newer vehicles, particularly those with alloy blocks or heads, use ethylene glycol as a coolant in their cooling systems. What property would make glycol a suitable water replacement?
[b] The radiator serves as the main heat exchanger. Discuss the design features of a radiator that help it exchange heat from the cooling system to the surroundings.
[c] The radiator has a fan placed next to it. Explain, using principles of heat transfer, how this makes the cooling system more efficient.
[d] A device called a thermostat is placed between the block and the top radiator hose. This device is closed when the engine is cold and opens when the operating temperature of the motor is reached. Explain how this device operates, and why it is there.
[e] Motor vehicle designers spend a lot of money to develop motors that have more efficient heat transfer. One such program involves a ceramic motor that needs little or no coolant. What properties must ceramic have to make it suitable for making a motor?


Teacup and saucer

11.15 How would you explain to a friend who does not study physics why:
[a] you can cool a hot cup of tea faster by pouring the tea into a saucer.
[b] blowing onto the tea helps cool it more quickly.

11.16 After a warm day you hold you hand above a brick wall exposed to the Sun for some time. You can feel the warmth even though your hand does not touch the wall.
[a] How is the energy getting from the wall to your hand?
[b] How did the energy get from the Sun's surface to the wall?


Double glazing

11.17 Many houses in cold countries have double glazing. Double glazing manufacturers make windows with two layers of glass separated by a sealed air gap.
How does double glazing reduce heat transfer?

11.18 You take an aluminium can of drink and a bottle of drink, both containing equal volumes of drink, from the same refrigerator. Which one would you expect to warm up faster? Give reasons for your choice.

11.19 At a picnic a friend asks you for advice about cooling his warm bottle of soft drink. Should he submerge the bottle in a bucket of water or should he wrap the bottle in a cloth and then wet it with the water from the bucket? Explain to him the reasons for your choice.

Investigation 11.4: Motor vehicle cooling systems

Notes

How does the design of a car affect the temperature inside the passenger compartment? Indicate the physics concepts or principles involved and discuss its significance to the passengers.
The cooling system of a car engine involves pumps, thermostats, radiator and coolant. How does each component help to maintain the motor at a relatively constant operating temperature?
A large amount of energy is converted to (low-grade) thermal energy during the driving of a car. Identify the places in the car where energy is converted into thermal energy. Indicate in what form the energy was before it was converted to thermal energy, and how it was converted to thermal energy.

Investigation 11.5: Clothing

Describe the relationship between the clothes people wear and the climate they live in. Use physics concepts or principles to explain why different clothes are worn in different parts of the world.
Describe several examples of special types of clothing worn by people for specific purposes (examples include 'DRIZABONE® rain coats', thermal (reflective) emergency blankets, firefighters clothes, etc.). Use physics concepts or principles to explain the function and usefulness of each example.

Investigation 11.6: Conductors

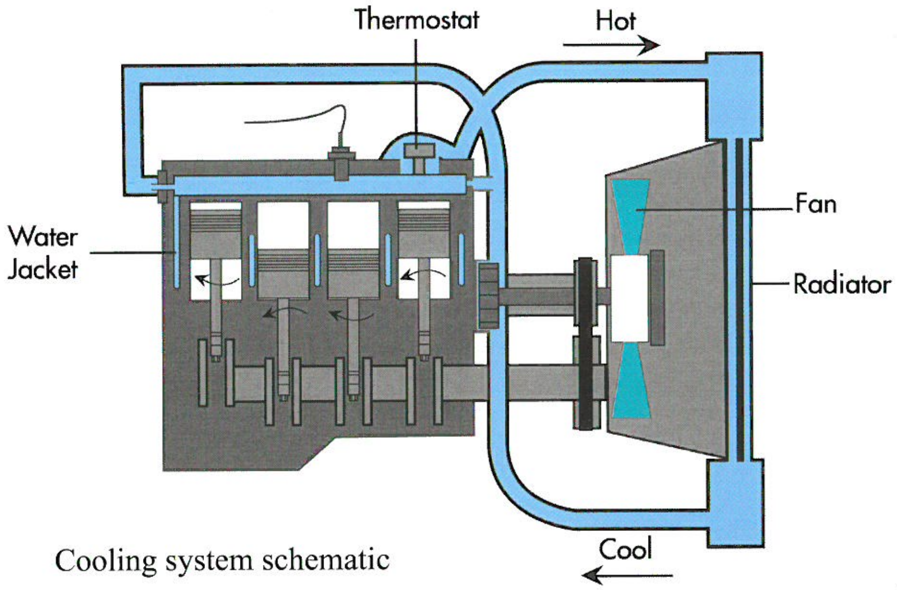
Metals are usually described as 'good conductors of heat and electricity'. Are they equally good conductors, or are some better than others?
Design and carry out an investigation to determine whether metals are equally good at conducting heat. Be sure to consider carefully and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.

Heating and Cooling in Motor Vehicles

Motor vehicles use internal combustion engines. Internal combustion means that a fuel, usually a hydrocarbon such as petrol or diesel oil, burns inside the engine. As fuel molecules react with oxygen molecules, they release a great deal of energy.
The engine absorbs most of this energy as thermal energy. Each time the air-fuel mixture burns in a combustion chamber, the temperature of the gases in the chamber may briefly reach 2200 °C. Normal operating temperatures for most engines range between 80 °C and 95 °C. To prevent overheating, the engine needs mechanisms to help it lose excess thermal energy,

The vehicle's cooling system transfers excess heat from the engine to its surroundings. It must keep the engine at or near its most efficient operating temperature under all weather conditions. The cooling system must also let the engine reach its optimum temperature as quickly as possible after starting.

There are two main types of cooling systems; liquid cooling and air cooling. In either case, a fluid coolant circulates around the hot engine parts, absorbing heat and so cooling the engine. Note that 'fluid' means 'able to flow' and includes both gases and liquids.
Most car and boat engines are liquid cooled. Air cooling is more common in motor cycles, lawn mowers and aeroplanes, although a few car manufacturers use air cooled engines.
Some high-performance engines use evaporative cooling. This process loses coolant to the atmosphere.



Cooling system schematic

The energy produced when the fuel-air mixture burns all ends up as thermal energy in the car's surroundings. However, some of this energy does useful work in the process, to push the pistons down and make the vehicle move. About one third of the total energy released when the fuel burns leaves the engine in the hot exhaust gases. These enter the atmosphere through the exhaust pipe, and we have no way to use the wasted energy that they take with them.
The car uses another third of the energy released by the burning fuel to overcome friction and air resistance. Half of this energy, or one sixth of the total, overcomes friction in the car's moving parts, such as the shafts that connect the engine to the wheels.
The energy needed to overcome air resistance and friction with the road is about one sixth of the total available from the fuel. This is the useful output of the engine that propels the car along the road.
Parts of the engine, such as the cylinder walls, pistons, and cylinder head, absorb most of the remaining third as thermal energy.

Heating and Cooling in Motor Vehicles: Comprehension Questions

Without a cooling system, the engine temperature would increase rapidly, leading to a variety of problems. If some part of an engine gets too hot, its oil film no longer protects it. Such parts wear quickly.
Very high temperatures may soften some components and may crack others. Some engine parts would melt. Eventually the pistons would expand so much they could not move in the cylinders; they would seize.
Conversely, an engine running at too low a temperature is inefficient. Some of the unburnt carbon from fuel burning at a too-low temperature remains in the engine. The circulating oil picks up some of this carbon, increasing wear and reducing the engine power. Dirty oil also moves solid residues around the engine, creating deposits in previously clean places. This increases both fuel consumption and exhaust emissions.
Thus, the cooling system only starts working when the engine temperature is high enough for efficient running.

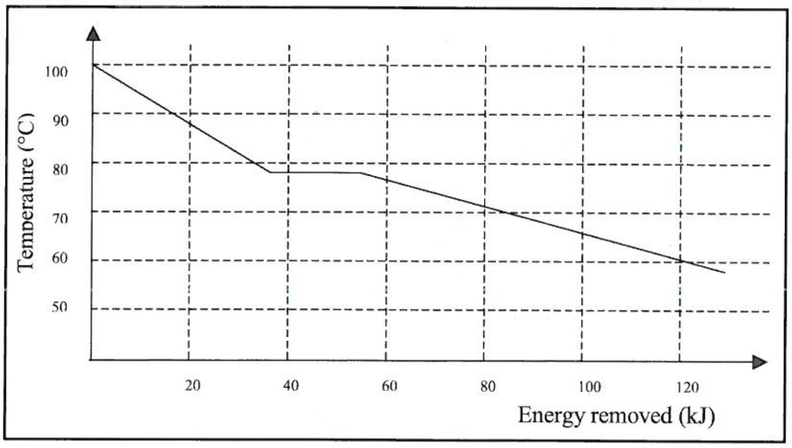
1. [see Chapter 12]
A 200 kg metal engine's temperature increases by 60 °C.
[a] Calculate the heat absorbed by the engine if it is made of aluminium.
[b] Calculate the heat absorbed by the engine if it is made of steel.
[c] Based on your answers to the previous questions, which of these would be easier to cool? Explain.

2. [see Chapter 12]
The useful power output of a steel engine is 100 kW.
[a] Estimate the rate at which energy is being released by the fuel. Show all your working and list any assumptions you make.
[b] Estimate the amount of thermal energy absorbed by the engine in a 10 minute period. Show all your working and list any assumptions you make.
[c] Hence, estimate the temperature rise of the engine in this 10 minute period, if the engine cooling system stopped working. Show all your working and list any assumptions you make.

3. [see Chapter 12]
A 200 kg aluminium engine at 95 °C is cooled by 2.00 kg of ethylene glycol that is initially at 25 °C. Calculate the final temperature of the engine and coolant.

4. [see Chapter 13]
[a] Calculate the energy absorbed by 10 kg water heating from 20 °C to 100 °C.
[b] Calculate the energy absorbed by 10 kg of water boiling at 100 °C.
[c] Why is evaporative cooling rarely used in motor vehicles?

5. [see Chapter 13]
The graph (right) shows the 'cooling curve' for 1.00 kg of naphthalene. Naphthalene is a liquid at 100 °C. Use the curve, and any necessary calculations, to determine:
[a] The freezing point of naphthalene;
[b] The specific heat capacity of liquid naphthalene;
[c] The latent heat of fusion of naphthalene;
[d] Whether the specific heat capacity of solid naphthalene is less than, equal to or greater than the specific heat capacity of liquid naphthalene.
[e] Naphthalene is not used as a coolant in motor vehicles. Suggest a reason why.



Chapter 12: Specific Heat Capacity Explained

Notes

In the SI (international system) the **specific heat capacity** of a pure substance is the quantity of heat energy needed to change the temperature of one kilogram of the substance by one degree Celsius (or one kelvin).
The units we use to measure specific heat capacity are joules per kilogram per degree ($J\ kg^{-1}\ ^{o}C^{-1}$). This is often written as $J\ kg^{-1}\ K^{-1}$; replacing the degrees Celsius with kelvins does not affect the size of the specific heat capacity.
For example, if 4.18×10^3 J of heat is absorbed by 1.0 kg of water it will raise the temperature of the water by one kelvin. The specific heat of water is therefore $4.18 \times 10^3\ J\ kg^{-1}\ K^{-1}$ or $4.18 \times 10^3\ J\ kg^{-1}\ ^{o}C^{-1}$.
We express this mathematically as:

$$Q = m\,c\,(T_{final} - T_{initial})$$

or

$$Q = m\,c\,\Delta T$$

where: **Q** is the quantity of heat absorbed or released, in J
m is the mass of the substance in kg
c is the specific heat of the substance in $J\ kg^{-1}\ K^{-1}$or $4.18 \times 10^3\ J\ kg^{-1}\ ^{o}C^{-1}$
ΔT or (T_{final}-$T_{initial}$) is the change in temperature in K or °C

Use the following data in the problems in this chapter.
Density of water = $1.00 \times 10^3\ kg\ m^{-3}$

Substance	Specific Heat Capacity	Substance	Specific Heat Capacity
air	1000	ice	2100
alcohol (ethanol)	2430	lead (solid)	130
aluminium	900	lead (liquid)	105
brass	380	olive oil	1650
copper	390	pewter	143
ethelene glycol	2400	stainless steel	445
glass	670	steam (at 110 °C)	2010
human body (average)	3500	water	4180

Table of Specific Heat Capacities ($J\ kg^{-1}\ K^{-1}$)

Principle of Mixtures
When two substances with different temperatures mix, the cooler substance will gain heat whilst the hotter substance will lose heat. In an isolated system, this heat exchange will continue until they reach thermal equilibrium, at which time both substances have the same temperature.
If the mixture does not lose heat to or gain heat from its surroundings, then the heat lost by one substance will equal the heat gained by the other substance. This is what we mean by an 'isolated system'.
This works even if the two substances are the same; for example, when we mix hot and cold water. The end result can be predicted by treating the hot water and the cold water as separate items even though they mix completely.

Experiment 12.1: The Specific Heat Capacity of a Liquid

12

Background

When equal masses of different substances are heated in the same way their temperatures rise by different amounts. In the SI the specific heat of a substance is the quantity of heat absorbed or released when the temperature of one kilogram of the substance rises or falls through one kelvin. A rise of one kelvin is also a rise of one Celsius degree. Different liquids have different values for specific heat capacity. This method is a simple way to work out the specific heat of a liquid, assuming that we are confident we know the specific heat of water.

Apparatus for Experiment 12.1

Aim

To measure the specific heat capacity of a liquid.

Apparatus (per group)

- stopwatch
- an electric hotplate
- two 250 mL beakers
- a balance
- water and another liquid (e.g. cooking oil, glycerol, kerosene, diesel fuel, motor oil, cooking oil, methylated spirits, turpentine)

Pre-Lab

- Plan to work safely. Other than water, the liquids on the list below are flammable, and should be disposed of safely.
- In your group, work out how you can determine the specific heat of an unknown substance with the information you will gather.

Lab Notes

- Allow a hotplate to warm to a constant temperature by turning it on ten to fifteen minutes before beginning the experiment.
- Pour 150 g of water into a 250 mL beaker and 150 g of glycerol into an identical beaker.
- Record the initial temperature of each liquid.
- Place both beakers onto the hotplate at the same time. Stir each liquid gently with the thermometers and record each temperature after two minutes. Remove the beakers from the hotplate.

Post-Lab Discussion

1. Draw graphs of the experimental data.
2. Explain which graph shows the liquid cooling at the faster rate.
3. Explain the differences between the cooling rates.
4. How did energy transfer to each liquid compare?
5. Which liquid experienced the greater increase in temperature?
6. Which liquid requires more energy to raise the temperature of one kilogram of it by 1°C?
7. Explain your results in terms of specific heat capacity.
8. Explain your results in terms of the average kinetic energy of the molecules of ` each liquid.
9. In view of your answers to Question 4 and Question 8 account for the 'missing' energy in the liquid which has achieved the lower temperature.
10. How does the specific heat capacity of glycerol compare with that of water?

Notes

Investigation 12.2: The Specific Heat Capacity of a Metal

Notes

Background

In an isolated system, the total energy remains constant. That is, the energy lost by things that cool down must be gained by something else. This is what we know as 'conservation of energy'. A system consists of whatever gains or loses energy. You will use various insulating materials to isolate the system.

Work out how to represent your system mathematically. This is called a 'model'. Your model should include terms that account for heat lost (such as when substances cool down) and heat gained (such as when substances heat up). For example, an expression for the total heat gained by the cool water and a calorimeter being raised to the final temperature, T_2, is

Heat gained by water = $m_{water}c_{water}(T_2 - T_1)$

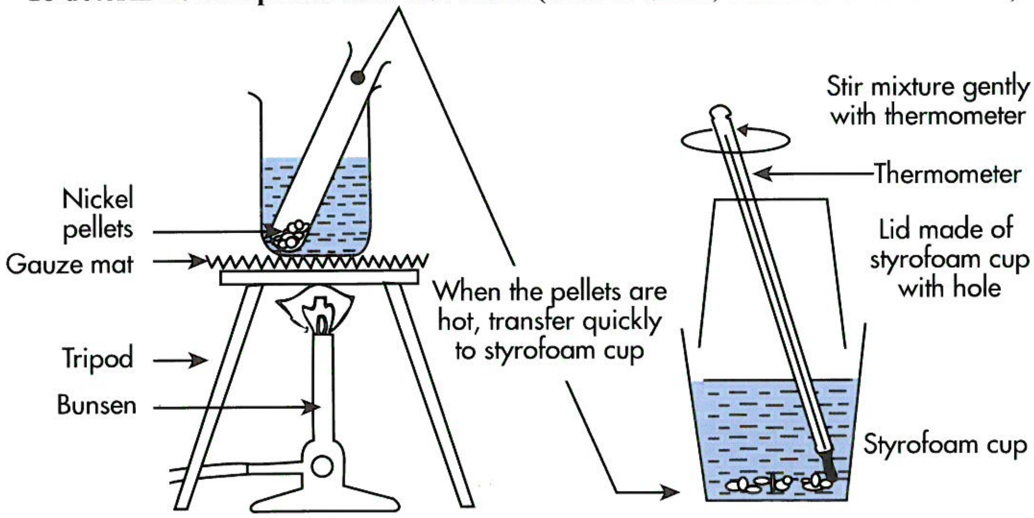
Heat gained by calorimeter = $m_{copper}c_{copper}(T_2 - T_1)$

Therefore:

total heat gained by water and calorimeter = $m_{water}c_{water}(T_2 - T_1) + m_{copper}c_{copper}(T_2 - T_1)$

Aim

To determine the specific heat of a metal (such as brass, nickel or stainless steel).



Apparatus for Experiment 12.2

Apparatus (per group)

- Styrofoam cup with a tight-fitting insulating lid
- two thermometers (if available, one 0 - 100 °C and one 0 - 50 °C)
- test tube (large)
- metal pellets (75 to 100 g)
- beaker (250 mL)
- Bunsen, tripod and gauze mat
- test tube holder
- cool water (about 50 mL)
- balance

Continued over

Investigation 12.2: The Specific Heat Capacity of a Metal

12

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent varlable, and which variables (if any) you intend to control.
- Discuss with your lab partners how you will accurately measure masses and temperatures.

Lab Notes

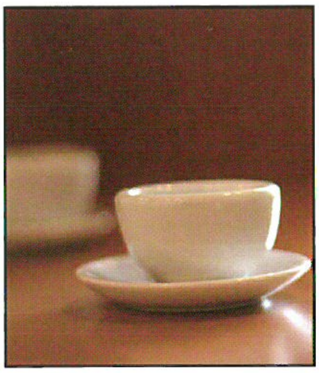
- Find and record the mass of the dry Styrofoam® cup and lid.
- Add about 50 mL of cool water to the Styrofoam cup.
- Find and record the mass of the Styrofoam cup, lid and water.
- Find and record the mass of a large, dry test tube.
- Fill the test tube about one quarter with metal pellets and find the mass of the test tube containing the metal pellets. Hence determine and record the mass of the metal pellets.
- Set up the apparatus as shown in the diagram (*on page 116*). Stir mixture gently with thermometer. Take care – the thermometer is fragile.
- Heat the test tube containing the metal pellets until the temperature of the metal pellets is above 90 °C.
- Record the temperature of the water in the styrofoam cup. Use the 0-50 °C thermometer if you have one.
- Record the temperature of the metal pellets. Use the 0-100 °C thermometer. Using a test tube holder, quickly transfer the metal pellets to the Styrofoam cup. Be careful to avoid splashing any of the water out of the cup, and to avoid breaking the fragile thermometer.
- Gently stir the contents of the Styrofoam cup (remember the thermometer breaks easily) and record the highest temperature reached.

Post-Lab Discussion

1. Calculate the total thermal energy gained by the water in the Styrofoam cup.
2. Write a mathematical expression to represent the heat lost by the metal pellets in cooling.
3. Assuming insignificant heat loss to the Styrofoam cup and the surroundings, the heat lost by the metal pellets cooling is equal to the heat gained by the water. Equate these and hence calculate the specific heat of the metal.
4. Look up the accepted value for the specific heat of this metal. Compare your experimental result with this value.
5. What was the greatest source of error in the experiment?
6. Suggest two ways of reducing the source of error in this experiment.
7. Why is it important to have the hot metal dry before adding it to the Styrofoam cup and water?
8. The specific heat of water is one of the highest of all substances. Why does this make water a useful liquid to use in hot water bottles?
9. Could you use a lump of metal to warm your bed instead of a hot water bottle? Which would be better, a metal lump or a hot water bottle? Explain why.

Notes

Problem Solving and Calculations Set 12: Specific Heat Capacity



Cups

Microwave oven

Meat pie crust and filling

12.1 Two different objects are in thermal equilibrium. If you remove equal amounts of heat from each, will they still be in thermal equilibrium? Explain.

12.2 In each of the following, state and explain which container will have the hotter liquid in it after thirty seconds.
[a] You pour equal amounts of hot coffee into two cups from a percolator. The cups are the same general size and shape. One is made from heavy china and the other from very thin, delicate china.
[b] You pour equal amounts of hot olive oil into two urns. The urns are the same general size and shape. One is made from pewter and the other from brass.

12.3 Solar hot water systems convert electromagnetic energy from the Sun into thermal energy in the water in the heater. How much solar energy does a solar heater need to absorb to raise the temperature of 153 kg of water from 15.0 °C to 75.0 °C? Assume that the system converts all the solar energy to thermal energy of the water.

12.4 A chef removes a saucepan from an electric stove element made from stainless steel. He then immediately switches off that element. How much waste heat passes from the 782 g element to the air as it cools from a temperature of 445 °C to 20.0 °C?

12.5 A gas heater produces 1.54 MJ of heat in a room that contains 72.6 kg of air. Calculate the rise in air temperature in the room.

12.6 An engineer is doing an energy audit on a kitchen. She needs to work out how much electrical energy a 0.355 kg stainless steel electric kettle needs to heat 0.850 L of water from 15.0 °C to its boiling point. Calculate the energy needed, assuming that the kettle converts all the electrical energy to thermal energy and that it loses no heat to its surroundings.

12.7 A foundry operator finds that it takes 55.3 MJ of heat to heat a 286 kg mass of steel from 22.0 °C to 452 °C. Calculate the specific heat capacity of that steel.

12.8 A gas burner supplies 2.84×10^5 J of heat to 2.75 kg of soup. The specific heat capacity of the soup is 4.13×10^3 J kg^{-1} K^{-1}. Determine the final temperature of the soup.

12.9 Refrigerators remove heat energy from objects you put in them. How much heat energy must a refrigerator remove from an empty aluminium pot of mass 865 g to cool it from a temperature of 120.0 °C to 55.0 °C?

12.10 You want to cook a potato in a microwave oven. If you put a 385 g potato in an oven at 18.0 °C, the potato absorbs 118 kJ of microwave energy and converts it to thermal energy. The final temperature of this potato is 98.6 °C. Calculate the potato's average specific heat capacity.

12.11 Explain why the filling in a meat pie can burn your mouth while the crust will not, even though they are both at the same temperature.

Continued over

Set 12: Specific Heat Capacity

Notes

12.12 Describe how you could measure the specific heat capacity of a new alloy.

12.13 Motorists may use ethylene glycol instead of water in their cars' cooling systems.
[a] Compare the time it takes for the coolant to reach 100 °C in two identical cars, each producing the same amount of heat. One car has ethylene glycol in its radiator, while the other car has a water filled radiator.
[b] Which is the more efficient coolant? Explain why you make this choice.
[c] Explain how manufacturers could improve the cooling system of the car with the less efficient coolant without changing the type of coolant they use.

12.14 You need to design a system of solar collectors that will collect and store thermal energy during the day and will deliver it as heat at night. Specify the essential properties of the thermal energy storage medium.

12.15 A camper wants to use water to remove 2.93 MJ of heat from an overheated metal barbecue plate. The water they want to use has a temperature of 20.0 °C. What is the smallest mass of water the camper can use without the water boiling?

12.16 Ahmed is a heating consultant. One of his clients has a boiler that is 62% efficient and uses heating oil that releases 4.15×10^7 J kg^{-1} of heat energy when it burns in air. What mass of heating oil does the boiler need to heat 245 kg of water from 12.0 °C to 68.0 °C?

12.17 On a cold winter night, why is it poor economy to allow the bathtub to drain immediately after you take a hot bath?

12.18 Land and sea breezes result from the differential heating and cooling of land and water. Explain why water and land heat and cool at a different rate.

12.19 You want to heat a glass mug of water at 18.5 °C to 98.5 °C in a microwave oven. The mass of the glass is 215 g and it contains 145 g of water. How much microwave energy would the glass and water need to absorb? Assume the water converts all the microwave energy to thermal energy.

12.20 A cook pours 800 g of soup at 98.0 °C into a 100 g bowl of specific heat capacity 320 J kg^{-1} K^{-1}. The soup raises the temperature of the bowl from 10.0 °C to 97.0 °C. What is the specific heat capacity of the soup?

12.21 The host at a party gives you a 185 g cup of tea in a foam plastic cup. The tea is very hot at 85.5 °C. You decide to cool the tea by adding 35.0 g of water at 18.0 °C. Calculate the resulting temperature of your drink. Assume the tea has the same specific heat capacity as water, and that no heat is lost to the cup or the surroundings.

12.22 An engineer is designing a pumping system for a large aquarium. Water passes through a pump at the rate of 1.30 kL min^{-1}. The pump transfers energy to the water passing through at a rate of 10.0 kJ s^{-1}. 65.0% of the pump's energy becomes kinetic energy of the water; the rest of the energy becomes thermal energy in the water. Calculate the increase in the water's temperature over one hour if all the thermal energy remains in the water.

Continued over

Problem Solving and Calculations Set 12: Specific Heat Capacity

Notes

12.23 A stainless steel kettle of mass 5.25 kg contains 1.55 kg of water. If the kettle converts 65.0% of the supplied electrical energy to thermal energy in the water and itself, calculate the total amount of electrical energy needed to raise the temperature of the kettle and water from 12.0 °C to 96.0 °C.

12.24 You want to raise the temperature of a bath containing 40.0 kg of cold water at a temperature of 16.5 °C to 45.0 °C. What mass of hot water at a temperature of 75.3 °C must you add to the cold water if the bath and its surroundings absorb 15.0% of the heat lost from the hot water as it cools to its final temperature?

12.25 A mechanic adds 655 g of ethylene glycol antifreeze at 22.0 °C to your car's radiator. The radiator already contains 6.75 L of water at 92.0 °C. If the 4.50 kg radiator is made of copper, calculate the final temperature of the mixture.

Investigation 12

Investigation 12.3: Specific heat capacity of brick

Background

Brick houses remain relatively cool even after a very hot day. After a few days of high temperatures, however, the houses remain very hot even during the night. Bricks tend to take a long time to cool down. The reason for these observations could be that bricks have a large specific heat or that they are poor conductors of heat.
The specific heat of a brick may be calculated if the amount of heat lost, the mass and the change in temperature are known.


Bricks in oven

The task

Determine the specific heat of brick so that you can work out what is happening in the situation described above.

Apparatus (per group)

- copper calorimeter with insulation (Note: a Styrofoam® cup with lid may be used instead)
- beaker (100 mL)
- balance
- small pieces of brick approx. 10-20 mm across (to a total mass of about 50 g)
- distilled water
- thermometer (0 - 110 °C)
- drying oven
- measuring cylinder (100 mL)

Lab Notes

- Accurately measure the mass of approximately 50 g of dry brick pieces and put them into a 100 mL beaker.
- Put the beaker in an oven set at about 90 °C for at least 5 hours. Overnight would be best.
- Before opening the oven read and record the temperature inside the oven.
- Measure the mass of the clean dry calorimeter then return it to its container.
- Pour about 100 mL of water into the calorimeter, measure its mass and after a few minutes measure the temperature of the water.
- Remove the beaker with the brick pieces from the oven (remember, they are hot!) and quickly but carefully tip the brick pieces into the calorimeter, taking care not to splash any water out of the calorimeter.
- Measure and record the final temperature of the system (calorimeter, brick and water) as soon as it stops rising.

Continued over

Notes

Investigation

Notes

Post-Lab Discussion

1. Using the specific heat of water (4.18×10^3 J kg^{-1} K^{-1}), calculate the amount of heat absorbed by water.

2. Using the specific heat of copper (3.90×10^2 J kg^{-1} K^{-1}), calculate the amount of heat absorbed by copper.

3. The total heat absorbed (heat absorbed by copper plus heat absorbed by water) is the heat lost by the brick. Using this value, calculate the specific heat of brick.

4. Find a table of specific heats in a suitable reference. Note the range of values and, bearing in mind that water has a large specific heat, would you say that brick has a high, moderate or low specific heat? Support your statement with examples from the table.

5. Brick houses tend to warm up slowly and cool down slowly. From your investigation result, would you say that the reason is because brick has a high specific heat? Explain.

6. What other factors might account for the observed rates of heating and cooling of brick houses?

7. Why were you instructed to:
   [a] break up the brick into small pieces instead of using one larger piece?
   [b] leave the brick in the oven for several hours?

8. What did you notice about the water level when you added the brick to the calorimeter? What does this indicate about the structure of brick?

9. Would it be an advantage to build houses from brick in an area where high temperatures occur for long periods of time? Explain the reasons for your answer.

Investigation 12.4: Estimating the solar constant

Background

Scientists confidently state how much solar energy reaches each square metre of the Earth's surface each second. We can call this the 'solar constant'. How can they possibly know what the solar constant is?
To estimate the solar constant, you must collect solar energy over a known area, in a known time period. If you can measure the amount of energy captured by the collector, you can work out the ratio of incoming solar energy to the collecting area. You will have to do this on a sunny day.

The task

Work out how you could measure the energy input into the collector, the surface area of the collector and the time over which you will gather the data. Negotiate with your teacher or laboratory technician for the equipment you will need.
Collect the data, process it and determine your best estimate of the solar constant.
Compare your value with an 'accepted' value, and suggest ways to improve the accuracy of your estimate.
Hint: You can use water in a Styrofoam® cup as a collector of solar energy. Add food colouring to make the water a dark colour (about five drops each of red, green and blue colouring should be about right.) This will maximise absorption of solar energy by the water. Should you use a lid?


Cup and thermometer

Notes

Chapter 13: Changes of State and Latent Heat Explained

State Changes
Physicists call the quantity of heat you need to change a unit mass of a substance from one state to another without a change in temperature the specific latent heat of that substance. For example, you need 3.34 x 10^5 J of heat to convert 1 kg of ice at 0 °C to water at 0 °C. The latent heat of fusion of ice is therefore 3.34 x 10^5 J kg^{-1}.

In general,
- the **latent heat of fusion** of a solid is the amount of energy per kilogram absorbed by the solid as it melts, or the amount of energy per kilogram lost by the liquid as it freezes.
- the **latent heat of vaporisation** of a liquid is the amount of energy per kilogram absorbed by the liquid as it boils or evaporates, or the amount of energy per kilogram lost by the vapour as it condenses.

Melting and boiling points
If the pressure remains constant,
- the melting point of a pure substance is the same as its freezing point, and
- the boiling point of a pure substance is the same as its condensation point.

Latent heat calculations
The relationship between amount of heat energy, latent heat and mass during a state change is given by:

Notes

Q = m L

where: **Q** is the amount of heat energy absorbed or lost (measured in joules)
m is the mass of substance changing phase (measured in kilograms)
L is the latent heat of the substance (measured in joules per kilogram)
We have to take care to use the appropriate latent heat value, since the latent heats of fusion and vaporisation for any substance are significantly different.

Principle of Mixtures
If we mix substances in an isolated system together (remember, an isolated system does not lose heat to or gain heat from its surroundings) then the heat lost by one substance will equal the heat gained by the other substance.

We can extend the idea of mixtures to a system in which one or more components changes state. Thus, for example, if you put some ice into a cup of warm water, the changes in the system will involve heat loss and heat gain.

Heat is lost by the warm water, and by the container.

Heat is gained by the solid ice as it warms up to its melting point, then as it melts. More heat is gained by the cold water produced by the melting ice.

The heat transfer in the system stops when everything in it is at the same temperature.

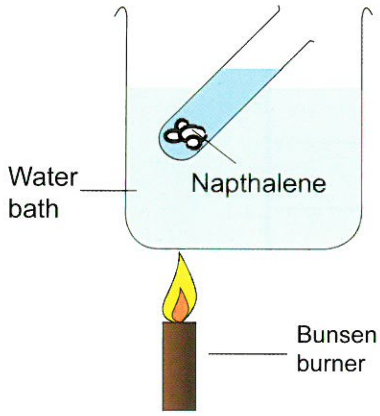
Continued over

Chapter 13: Changes of State and Latent Heat Explained 13

Substance	Latent Heat of Fusion (at the normal melting point)	Latent Heat of Vaporisation (at the normal boiling point)
aluminium	3.90×10^5	1.05×10^7
alcohol (ethanol)	1.05×10^5	8.41×10^5
copper	2.05×10^5	4.8×10^6
iron	2.76×10^5	6.34×10^6
lead	2.5×10^4	8.6×10^5
silver	1.05×10^5	2.35×10^6
water	3.34×10^5	2.26×10^6

Latent heats of fusion and vaporisation for a number of common substances, in J kg^{-1}.

Experiment 13.1: Changing State



Apparatus for Experiment 13.1

Background

Pure substances tend to melt and boil at specific temperatures. Mixtures (such as cheese and butter) tend to soften when heated and often have no definite temperature at which the solid becomes liquid. Some substances (such as wood) decompose chemically instead of melting.

Aim

To investigate the melting behaviour of naphthalene.

Apparatus

- access to naphthalene
- boiling tube or Pyrex® test tube and test tube tongs
- beaker
- heat source, e.g. Bunsen burner or hotplate
- tripod and gauze mat (not required if using a hotplate)
- thermometer
- several boxes of matches

Notes

Pre-Lab

- make sure your work station is well ventilated – hot naphthalene has a strong odour.

Lab Notes

- Place some solid naphthalene in a test tube.
- Heat the test tube in a beaker of boiling water until the temperature of the naphthalene is about 80 °C.
- Remove the test tube from the water, stir gently and record the temperature of the naphthalene every 30 s until the temperature has fallen to 30 °C.

Post-Lab Discussion

1. Draw a graph of temperature *vs* time.
2. Why does the temperature of the naphthalene decrease?
3. Is the rate of cooling constant? Explain.
4. Do your results suggest that naphthalene is a pure substance, or a mixture? Explain.
5. What happens to the naphthalene during the interval in which the temperature stops decreasing? Is any energy being lost at this stage? If so, where is it coming from?
6. Explain where the energy transferred to the naphthalene from the hot water is going during the interval where the temperature of the naphthalene is not increasing.
7. Explain the meaning of 'latent heat of fusion'.

Extension

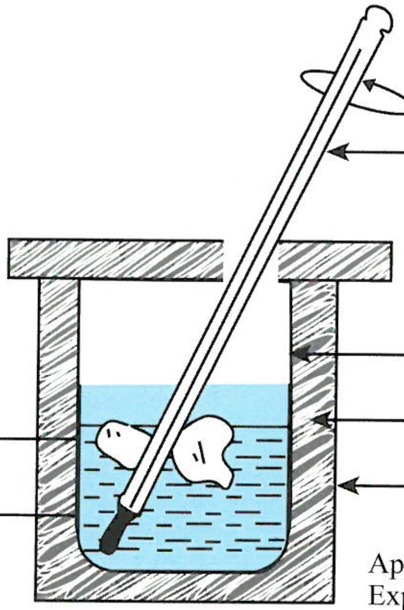
Put the test tube and naphthalene back into the beaker of boiling water and record the temperature of the naphthalene every 30 s until the temperature has risen to 80 °C.
Draw a graph of temperature *vs* time.
How does latent heat of fusion relate to the cooling and heating of naphthalene?

Experiment 13.2: Melting Ice

13

Background

When substances change phase, heat is either absorbed or released. If heat energy is supplied to a solid its temperature will rise until it begins to change phase. Further supply of heat energy does not result in any increase in temperature until the phase change is complete, after which the temperature of the liquid will begin to rise. The quantity of heat required to change unit mass of solid to a liquid without a change in temperature is called the 'latent heat of fusion' of that substance.



Apparatus for Experiment 13.2

Aim

To determine the latent heat of fusion of ice.

Apparatus

(per group)

- copper calorimeter with insulating Styrofoam cap
- insulated container for the calorimeter
- ice (a few cubes)
- thermometer (0 - 100 ºC or 0 - 50 ºC)
- warm water (about 35 ºC)
- blotting paper or paper towel

Notes

Pre-Lab

- Is it important to know the starting temperature of the ice?
- Prepare a data table suitable for recording all the data you will gather.
- Discuss what you must include in the system when you calculate the latent heat of water. The system consists of whatever gains or loses energy. You will use various insulating materials to isolate the system.
- In an isolated system, the total energy remains constant. That is, the energy lost by things that cool down must be gained by something else. This is what we know as 'conservation of energy'.
- Work out how to represent your system mathematically. This is called a 'model'. Your model should include terms that account for heat lost (such as when substances cool down) and heat gained (such as when substances heat up, or melt). For example, an expression for the total heat gained by the ice melting and the melted ice being raised to the final temperature, T_2, is
  Heat gained by melting ice = $m_{ice}L_{fusion}$
  Heat gained by melted ice warming up = $m_{ice\ water}c_{water}(T_2 - T_1)$
  Therefore:
  total heat gained by melting ice = $m_{ice}L_{fusion} + m_{ice\ water}c_{water}(T_2 - T_1)$

Continued over

Experiment 13.2: Melting Ice

Notes

Lab Notes

- Measure and record the mass of the empty calorimeter.
- Fill the copper calorimeter about two-thirds full of water at about 35 °C, and then measure the mass of the calorimeter and water. Hence determine the mass of water in the calorimeter.
- Place the calorimeter into the insulated container as shown on page 125. Stir gently with thermometer.
- Measure the temperature of the water in the calorimeter. This will also be the temperature of the calorimeter itself. Take temperature readings to the nearest 0.2 °C.
- Wipe a small cube of ice with a paper towel to remove any moisture adhering to it.
- Crush the ice cube to obtain small lumps. Carefully place the dried crushed ice into the calorimeter, avoiding splashing the contents. Place the insulating cap on the calorimeter.
- Gently stir the mixture until the ice has melted.
- Continue to add small pieces of ice in the same way until the temperature falls to about 5 °C. Record the final temperature.
- Find the mass of the calorimeter and its contents and hence determine the mass of ice added.
- Repeat to obtain a second set of results.

Post-Lab Discussion

1. Calculate the total heat lost by the calorimeter itself, and the warm water in the calorimeter, as it cools to the final temperature, T_2. This heat melts the ice and then raises the temperature of the resulting water.

2. If you assume that the amount of heat lost to the surroundings is insignificant, then the total heat gained will be equal to the total heat lost. Hence, calculate the latent heat of fusion of the ice (L_{fusion}).

3. List the sources of error in this experiment and estimate the possible size of each error. Use this information to calculate the probable error in your result for the latent heat of fusion of ice. Why did you not weigh the ice before you added it to the water?

4. The water from which the ice cubes were produced probably contained certain impurities, such as soluble salts and dissolved gases.
[a] How is this likely to affect the ice cubes?
[b] What assumption made in this experiment is most likely to be affected by these impurities in the water?
[c] What effect would these impurities have on the value you determined for the latent heat of fusion of ice?

5. Why was it desirable to start with the calorimeter and water above room temperature?

6. Look up the 'accepted' value for the latent heat of fusion of ice. Compare your result with this figure and comment on any differences.

7. Since melting does not result in any temperature change, where does the energy go?

8. Why are ice packs at 0 °C better for cooling a sprained ankle than similar-sized packs containing water at 0 °C?

Problem Solving and Calculations 13
Set 13: Changes of State and Latent Heat

Notes

13.1 Calculate how much heat:
[a] 28.6 kg of ice at 0.00 °C absorbs while it melts completely;
[b] 423 g of steam at 100.0 °C releases when it condenses to water at the same temperature;
[c] 4.58 g of silver absorbs as it boils.

13.2 Metallurgists sometimes refine pure cadmium metal by boiling the metal to a gas and then condensing it back to the liquid. A metallurgist measures that 208 g of cadmium releases 1.85×10^4 J of heat when it condenses at its boiling point. Calculate the latent heat of vaporisation of cadmium.

13.3 A technician freezes some ethanol by removing 9.53×10^4 J of heat energy from it at its melting point. What mass of ethanol is she freezing?

13.4 In different parts of a car air conditioner, a liquid changes to a gas, and a gas changes to a liquid.
[a] Which of these changes causes the cooling?
[b] Describe how the air conditioner removes heat from the car's cabin.

13.5 If you hold your hand in the steam escaping from the spout of a boiling kettle you can receive a severe burn. A splash of water from the same boiling kettle will not burn you as severely. Explain this observation.

13.6 Mario has painfully discovered that if he carelessly touches a hot clothes iron he gets a serious burn. He knows that he should test if his iron is hot by tapping its surface gently with a wet finger. Explain why his testing method stops him from getting burnt.

Mugs on ice

13.7 The instructions for a practical test state you should put two mugs of equal mass, both at room temperature and each with a flat base of equal size, onto a large block of ice. The ice has a temperature of 0 °C. You must then put the ice and mugs into a thermally insulated box. One mug is made of glass and one of pewter, an alloy of lead and tin.
[a] The mugs will sink into the ice. Explain why.
[b] Give one reason why the glass might sink faster than the pewter.
[c] Give one reason why the pewter might sink faster than the glass.

13.8 In the Australian Alps, snow often covers the ground in winter. At such times visitors often notice there is no snow on the ground near the edges of large lakes. Explain what would cause this lack of snow.

Perspiration

13.9 In hot conditions, a person may, through perspiration, lose up to 4.00 L of water every hour. The latent heat of vaporisation of water at skin temperature (33 °C) is 2.42×10^6 J kg^{-1}.
[a] If a person evaporates 4.00 L of water through perspiration, how much heat energy does the person lose? Assume the evaporating perspiration does not absorb heat from anywhere else.

Continued over

[b] By how much would a 55.0 kg girl's temperature rise if the 4.00 L of perspiration did not evaporate from her skin? Assume that her body produces heat at a constant rate and she loses heat in no other way.
[c] Why does the cooling effect of an electric fan depend on you perspiring?
[d] Explain why swimmers often feel colder when they get out of the water, even if the temperature of the air and the water is the same.

Shot tower

13.10 In Melbourne, a huge shopping centre was built around an old 'shot tower'. Hot lead globules were poured from the top of the tower and fell into a large pool of water at the foot of the tower. The surface tension of the liquid lead pulled it into the shape having the smallest surface area, a sphere. In this way spherical lead shot was made; hence the name 'shot tower'.
[a] How tall must the tower be to allow 6.00 s of free fall?
[b] If they wanted to make iron ball bearings by the same method and iron melts at 560 °C, how would the tower design change? State any assumptions you make.
[c] Identify one assumption you made which is probably in error and would result in a different tower height for the iron ball bearing scenario.

13.11 Many anglers make fishing sinkers by pouring molten lead into a mould. Max decided to melt 55.0 g of lead and use it to cast a sinker. Calculate:
[a] how much heat the lead released when it cooled from 427 °C to its freezing point of 327 °C;
[b] how much heat the lead released as it froze;
[c] how much heat the lead, initially at its freezing point of 327 °C, released as it cooled to 21.5 °C;
[d] the total amount of heat released.

13.12 An immersion heater can supply heat at the rate of 48.0 J s^{-1}.
[a] How long will it take to heat 12.5 g of water, originally at 26.5 °C, to its boiling point?
[b] How long will it take to boil away 12.5 g of water at its boiling point?
[c] How long can the heater be left on in 12.5 g of water without boiling the container dry?

Cooking spaghetti

13.13 You are an energy consultant and a client wants to know how well their refrigerator is operating. You put 2.15 kg of water at 21.5 °C into the refrigerator's freezer compartment. You measure that it takes 2.00 h to freeze all that water into ice at its freezing point. Calculate at what rate (in joules per second) the refrigerator is removing heat from the freezer compartment.

13.14 To cook spaghetti, you first boil the water and then add spaghetti to the boiling water. Describe and explain what happens to the boiling water when you add a large amount of spaghetti.

Continued over

Problem Solving and Calculations 13
Set 13: Changes of State and Latent Heat

Notes

13.15 Steamers are vessels you can use to cook food in. Food in the steamer gains heat as the steam condenses on it. A boiler supplies steam at 105 °C to a steamer at the rate of 455 g min^{-1}. Calculate the rate (in J s^{-1}) at which the steam supplies heat to the food if the steam cools, then condenses to water at 100.0 °C.

13.16 A foundry operator finds that it takes 55.6 MJ of heat to heat a 286 kg mass of an alloy steel from 22.0 °C to 452 °C.
[a] Calculate the specific heat capacity of that steel.
[b] If the foundry worker cools the steel by pouring water onto it, the water will heat up to its boiling point, then it will boil. What minimum mass of water, initially at 22.0 °C, would cool the hot steel down to 100 °C?
[c] What assumptions have you made in calculating the answer to [b] above?

13.17 Ice blocks of total mass 23.2 g were taken from a freezer at -10 °C and placed in an empty glass.
[a] Calculate the quantity of heat that must be absorbed to convert them to water at 10 °C.
[b] Explain clearly where this heat has come from.

13.18 You find you have let a 12.0 kg stainless steel barbecue plate become much too hot for normal cooking. You decide to cool the plate from 395 °C to 185 °C by spraying water onto the plate.
[a] Calculate the mass of water at 20.0 °C you will need, assuming all the water evaporates to steam at 100.0 °C.
[b] What mass of ice at 0.00 °C would have the same effect?

Barbecue

13.19 You want to make a cool drink from some 19.7 °C tap water by adding ice.
Calculate the mass of ice at -11.3 °C you need to cool 195 g of such tap water in a 215 g glass to a temperature of 3.60 °C. Neglect any heat that your drink would gain from its surroundings.

13.20 A maintenance worker uses steam to defrost a small freezer that contains 1.50 kg of ice at 0.00 °C. Calculate the mass of dry steam at 100 °C he needs to convert all the ice to water at 24.5 °C. Assume the heat absorbed by the freezer's plastic lining is negligible.

Investigations

Notes

Investigation 13.3: Cooling systems

Preliminary Investigation

[a] Take a liquid-in-glass thermometer and record the temperature. Carefully shake the thermometer or hold it in front of an electric fan. The purpose here is to create air currents over the bulb of the thermometer. Record the temperature again.
Next, enclose the bulb of the thermometer with a small wad of cotton wool, holding it on with an elastic band. Dip the cotton wool-covered bulb in water. Record the temperature again. Now create another air current over the wet bulb, either by shaking it or using a fan. Record the temperature again.
Repeat the last procedure, this time wetting the bulb with alcohol.
Explain your observations.

The Task

[b] Investigate the functioning of a domestic evaporative air conditioner that uses the evaporation of water for cooling. Create a display, such as an electronic presentation or a working model, of such an air conditioner. Describe the function of each part and indicate the physics concepts or principles used in each part of the system.

Investigation 13.4: How much ice should you put in your drink?

When ice is put in a mixed or soft drink to cool it, the temperature of the drink decreases to a minimum and then begins to increase.

The Task

Investigate how the temperature of a soft or mixed drink changes with different ratios of ice mass to original drink mass.
Hints:
1. Cut costs and teacher supervision–use tap water.
2. Temperature-time graphs would be the best way to present results.
3. The degree to which the ice is crushed might introduce another variable; it might be preferable to use identical blocks from a particular ice-block tray.
4. Think about other variables you may have to keep constant.

Investigation 13.5: Air conditioners

The Task

[a] Investigate the functioning of a domestic refrigerated air conditioner that uses the compression and expansion of gases. Describe the function of each part and indicate the physics concepts or principles used in each part of the system.
[b] Investigate the functioning of a domestic evaporative air conditioner that uses the evaporation of water for cooling. Describe the function of each part and indicate the physics concepts or principles used in each part of the system.
[c] Compare the relative energy usage of the two systems and their effectiveness in a variety of conditions.

Continued over

Investigations

Investigation 13.6: Food preparation and preservation

Notes

The Task

Investigate the physics involved in the preparation and preservation of food. You could refer to the physics and physical effects of some of the following processes: microwave cooking, sterilisation, preserving, pasteurisation and UHT, boiling, baking, barbecuing, refrigerating, deep freezing, freeze drying, the vacuum flask, the Esky®.

You should consider the following:

[a] The energy and energy changes involved in cooking and preservation of food.

[b] The physics involved in the technologies for supplying heat to or removing heat from the food.

[c] The effect that the addition or removal of thermal energy has on food.

Investigation 13.7: Boiling water

The latent heat of vaporisation of water is well known; you can find it in tables of latent heats in many physics text books. It is not so easy to measure accurately.

The Task

Design and refine a procedure for measuring the latent heat of vaporisation of water; that is, decide on a procedure, set it up and carry it out. Determine the value of latent heat according to your data, and compare that with the 'accepted' value. Decide what is the major source of error in your procedure, and a way to minimise this error. Try again, and see if your modified procedure gives better results. Your report should explain what you changed and why you changed it, and the effect the change had on your result.

Electric Power

What was it like before we had mains electricity? You may think you would have to ask someone who lived at the beginning of the 20th century to find out, but that is not the case. A glimpse into life without electricity can be seen by looking at some rural communities about thirty years ago. Since Western Australia is such a vast State, many farms were not connected to the electricity supplied by Western Power until recently. Below is a letter written by a farmer's wife who had just arrived from England with her brother. The farm was about 50 km from Ravensthorpe on the south coast. Even today, there are farms that have to generate their own electricity.

Jerdacuttup
West Australia.
12 February 1975

Dear Michael,
We have been here for nearly 6 months and it is nothing like we expected. The nearest shop is 45 km away and all along gravel roads! Ray has to start a generator even if we want a cup of tea. It is very noisy and if it runs out of fuel in the evening we just go to bed. You can tell when the fridge is on 'cos all the lights go dim. Our neighbours have a lot of batteries joined together and all their appliances are 32 V DC. They are expensive! There is no TV but a lovely school nearby. Have no regrets about leaving England..........

Your sister, Pauline

Nearly all homes in WA receive electricity in the form of alternating current (AC) supplied by a power station. Exceptions to this are very remote farms and groups of people interested in alternative energy sources. Western Power's main generating capacity is based at Muja near Collie in the South-West.

All circuits contain a minimum of three components: a source of energy, a load, and a closed conducting pathway. In the case of a motor vehicle, the source of emf is the electrical generator and the loads are the various electrical devices in the car such as the lights, audio system, navigation system, ignition system, etc. In the case of a home, the source of energy is ultimately the generators in places such as Kwinana and Collie but, locally, the 240 V output from the transformer that supplies a number of houses in each suburb.

Portable devices such as MP3 players, toys, notebook computers, and mobile phones have batteries or cells to provide the electrical energy.

The loads are the various electrical devices in your home such as the lights, TV, air conditioner, computer, refrigerator, etc. In each context, car and home, the loads are arranged in parallel in order to share the same emf. In the car, each device is run on 12 V and at home, each device is run on 240 V.

A unit of electrical energy is the kilowatt-hour. It is the unit used by electrical supply companies such as Western Power. The electricity invoice delivered to your house is for the number of kW h of electricity you have used multiplied by the price of one kW h. The price is currently around 13c per kW h.

A simple example of how this might be used in designing a device is the selection of a heating element for a kettle, a heater, or a stove. In each case, the mains voltage will be 240 V and a particular output of heat will be required. An element of the correct resistance will need to be selected in order that the correct power output is obtained.

Your bedroom is a good place to consider when investigating the finer points of electrical energy. Every time you switch on an electrical appliance you close an electrical circuit and allow a current to flow. In the case of the electric blanket the current flows through the heating wires in the blanket and heat is produced. The heating effect is bought about by the resistance in the wires. The supply to your room is most likely 240 volts but the total resistance in the blanket heating coils can be altered by the settings on the switch to produce more or less heat.

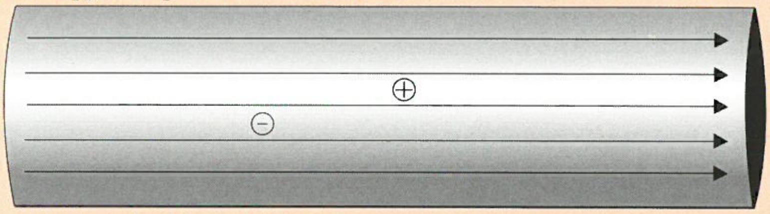
As well as studying in your room you may have time to listen to your MP3 player, portable CD player or portable FM radio. These devices also have resistance and use electrical energy. When, for example, an MP3 player is switched on it converts electrical energy into sound and heat energy. However, an MP3 player consumes energy slowly compared to an electric blanket or a 'boom box' you might hear in some cars. The power rating of a device shows how rapidly it converts energy. The power rating depends on the potential difference, the resistance of the device, and the resulting current. Note that regardless of the power rating, the longer you leave a device 'on' the more energy it consumes.

Electric Power: Comprehension Questions

Notes

1. [see Chapter 14]
   What is 'static electricity'? Is lightning an example of static electricity? Explain.

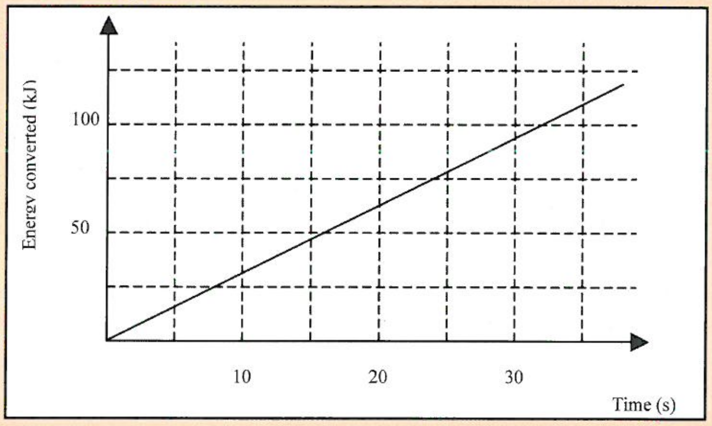
2. [see Chapter 14]
   Electric currents are created in conductors when a potential difference across the ends of the conductor produces an electric field inside the conductor. This electric field exerts forces on the charges in the conductor. All electrical devices work this way.
   The diagram shows an electric field in a section of metal wire. One delocalised electron and one positive atomic nucleus are shown to represent the many trillions of each that would occupy the space inside the wire.



   [a] What effect would this field have on the delocalised electrons in the wire?
   [b] What effect would this field have on the positive atomic nuclei in the wire?
   [c] What would move through the wire if there is a continuous electric current inside this wire?
   [d] What would be the direction of this continuous current?
   [e] What would have to be done to make the current alternate (that is, turn it into AC)?

3. [see Chapters 15 and 16]
   A washing machine operates on 240 V and has a power rating of 520 W. Running the machine through a complete wash cycle takes 45 minutes.
   [a] Calculate the normal operating current of this machine.
   [b] What is the effective overall resistance of the machine?
   [c] Calculate the energy used during one wash cycle, both in joules and in kilowatt hours.
   [d] Estimate the electricity cost of running this machine over a 12 month period. Show all your working and list any assumptions you make.

4. [see Chapters 15 and 16]
   The graph shows the relationship between the energy converted in an electric heater and the time for which it operates.



Continued over

Electric Power: Comprehension Questions

Notes

[a] How long does the heater take to convert 10^5 joules of energy?

[b] Explain what actual energy conversion occurs in the heater as it operates.

[c] Calculate how much energy the heater would convert if it operated for 67 seconds.

[d] Calculate the power consumption of the heater.

[e] The heater works on a potential difference of 240 V. Calculate the current when it operates normally.

[f] Calculate the operating resistance of the heater, at a potential difference of 240 V.

[g] The heater is known to be 70% efficient in heating a room. Calculate its useful power output.

Chapter 14: Electric Charges and Fields Explained

14

Principles of Electrostatics

Combing your hair on a hot, dry day can be frustrating, especially if your hair is long and clean. Such conditions can allow a build-up of static electricity in your hair. Your comb then attracts your hair, making it difficult to keep your hair in place.

What is the physics behind this phenomenon? As you comb your hair, electrons rub off your comb onto your hair, or they rub off your hair onto your comb. The way the electrons move depends on the material of your comb. Because of this electron transfer each strand of your hair becomes charged. The charged hairs exert repulsive forces on each other, preventing the hair from lying flat.

Three factors determine the amount of attraction or repulsion between electrically charged objects:

1. The amount of charge on each object. The greater the charge the greater the force of attraction or repulsion.
2. The distance between the objects. The greater the distance the less the force of attraction or repulsion.
3. Certain characteristics of any medium between the objects.

Notes

Coulomb's Law expresses the mathematical relationship between the charges on two small objects, the nature of the substance between them, the force between them, and the distance between them.

$$\mathbf{F = \frac{kq_1q_2}{d^2}}$$

where: **k** is a constant that depends on the medium between the charges, measured in $N\ m^2\ C^{-2}$
F is the force each charge exerts on the other in newtons (N)
$\mathbf{q_1}$ is the charge on one object in coulombs (C)
$\mathbf{q_2}$ is the charge on the second object, also in coulombs
d is the distance between the objects in metres (m)

In a vacuum or air, k has a value of $9.00 \times 10^9\ N\ m^2\ C^{-2}$.

Principles of Electric Fields

Charges attract or repel one another even if they are some distance apart. This is because each charge has an electric field around it, and it is actually the fields which interact and exert forces on the charge. Point charges produce fields that spread outwards in all directions.

We represent electric fields using lines, whose direction shows the direction in which a small positive charge would be pushed by the field at that point; the stronger the field, the closer together the field lines.

Continued over

Chapter 14: Electric Charges and Fields Explained

Notes

Principles of Electric Current
When charges flow, they constitute an electric current. We define the magnitude of an electric current as the rate of flow of charge. Charges move through a conductor, such as copper wire, in response to an electric field within the conductor.

$$\mathbf{I} = \frac{\mathbf{q}}{\mathbf{t}}$$

where: **I** is the current in amperes (A)
q is the charge in coulombs (C) passing any point
t is the time in seconds (s) it takes for the charge to pass

The charge on one electron is -1.60×10^{-19} C.

Charges travelling through air cause an effect we call an electrical discharge or spark.

Principles of Electric Potential Difference
When charges move from one position to another they may lose or gain potential energy in the process. We define an electric potential difference as the ratio of potential energy change to the charge moved.

$$\mathbf{V} = \frac{\Delta \mathbf{W}}{\mathbf{q}}$$

where: **V** is the potential difference, in volts (V)
q is the charge passing any point, in coulombs (C)
Δ**W** is the potential energy change of the charge, in joules (J)

Experiment 14.1: Creating and Storing Electric Charges

14

Background

Notes

Electric charges can build up on an insulated object such as human hair. When charge build-up happens, we say that this object is 'charged'. One way to build up a charge is to rub two different non-conducting materials together. Examples include rubbing a celluloid rod with cotton (giving the celluloid rod a positive charge) or rubbing a hard rubber rod with fur (giving the rubber rod a negative charge).

Aim

To investigate ways to create and store electric charges.

Apparatus

(per group)

- Electroscope
- Glass rod and silk cloth
- Hard rubber rod and fur
- Celluloid rod and cotton cloth
- Styrofoam or similar packing material
- Tissue paper
- Polythene strips
- Acetate plastic strips

Pre-Lab

- Find out how to charge an electroscope by contact. Write a brief step-by-step description.
- Find out how to charge an electroscope by induction. Write a brief step-by-step description.
- Find out why rubbing two insulating or non-conducting objects, such as a celluloid rod and a piece of cotton cloth, can charge the objects.

Lab Notes

- Hold the ends of two acetate plastic strips in one hand. Run the fingers of your other hand between the two strips.
- Observe and record the behaviour of the strips.
- Repeat this using two polythene strips.
- Repeat this for one acetate and one polythene strip.
- Discharge the electroscope by touching the top with your finger.
- Charge a glass rod by rubbing it with silk. Use the glass rod to charge the electroscope by contact. Observe and record the behaviour of the electroscope as the rod comes closer to it, touches it, then is removed.
- Charge a hard rubber rod by rubbing it with fur. Bring the rod up to the charged electroscope. Observe and record the behaviour of the electroscope.
- Discharge the electroscope.
- Charge a glass rod by rubbing it with silk. Use the glass rod to charge the electroscope by induction. Observe and record the behaviour of the electroscope.
- Charge a hard rubber rod by rubbing it with fur. Bring the rod up to the charged electroscope. Observe and record the behaviour of the electroscope.

Continued over

Experiment 14.1: Creating and Storing Electric Charges

Notes

Post-Lab Discussion

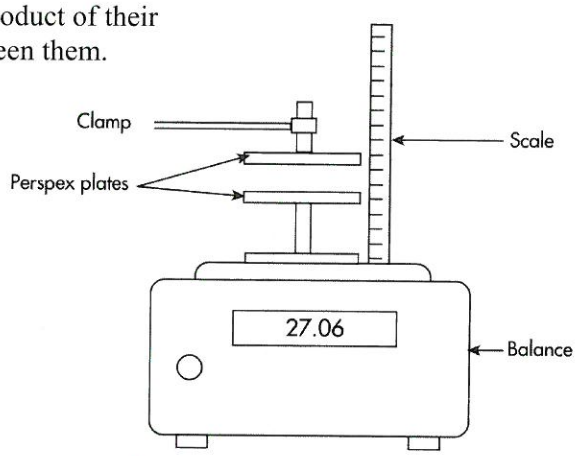
1. Explain the behaviour of the uncharged electroscope when the charged rubber rod was brought up to it.
2. Explain why 'charging by contact' results in a charge being built up on the electroscope.
3. Explain how 'charging by induction' results in a charge being built up on the electroscope.
4. Explain the behaviour of the positively charged electroscope when a positively charged rod is brought up to it.
5. Explain the behaviour of the negatively charged electroscope when a positively charged rod is brought up to it.

Experiment 14.2: The Force Between Electric Charges

14

Background

The force between two point electric charges is proportional to the product of their charges and inversely proportional to the square of the distance between them.



Apparatus for Experiment 14.2

Aim

To investigate the effect of separation distance on the size of the force between charged plates

Apparatus (per group)

- digital balance
- metre ruler
- two mounted Perspex® plates
- silk cloth
- retort stand and clamp

Pre-Lab

- For this experiment, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table suitable for recording the data you will gather (i.e. the separation distance, and the mass reading on the balance). Include columns for the processed data (e.g. the force that corresponds to the balance mass reading).
- The plates hold their charges better if they have been dried by warming.

Notes

Lab Notes

- Set up the apparatus as shown in the diagram.
- Charge one of the Perspex plates by rubbing it with the silk cloth, and place the charged plate on the balance.
- Press the 'TARE' button on the balance to set the balance reading to zero.
- Charge the second Perspex plate and clamp it in place as shown, 10cm above the other Perspex plate.
- Record the separation distance and the balance reading.
- Move the clamped plate downward in steps of 1 cm. Record all the values you measure.

Post-Lab Discussion

1. Was the force that you measured an attraction or a repulsion? What is the evidence for your answer?

2. Draw a graph of the separation distance *vs* the force.

3. The force between point charges follows an 'inverse square' relationship. Do your experimental data fit the inverse square model? Discuss how you would find out.

4. Discuss any possible sources of error or uncertainty in gathering or processing the data.

Problem Solving and Calculations Set 14: Electric Charges and Fields

Notes

14.1 Sketch the electric field distribution in the following cases:
[a] around an isolated small negatively charged sphere;
[b] between a small negatively charged sphere and a small positively charged sphere;
[c] between two small positively charged spheres;
[d] between a small positively charged sphere and an earthed conducting plate.

14.2 On a dry day people may get small electric shocks as they enter or leave a car. Use your knowledge of static electricity to account for this effect.

14.3 Two dust particles being drawn up into a vacuum cleaner collide, causing 1000 electrons to transfer from one particle to the other.
[a] Calculate the magnitude of the electric charge that each dust particle has now acquired.
[b] After collision, the particles separate so they are 0.010 mm apart. Calculate the magnitude of the electric force between the particles, and state whether this will lead to attraction or repulsion between the particles.
[c] Draw a diagram showing the nature of the electric field in the space around the particles.

14.4 A certain semiconductor chip in a computer stores one bit of data by retaining a charge of 0.7 pC. A cosmic ray hits the chip releasing the equivalent of 7×10^6 electrons in the semiconductor material. Can such a random event lead to a computer error? Explain.

14.5 'L plates' for learner drivers are often made of a flexible plastic. If you rub the plastic on some clothing it then sticks to the windows of the car.
[a] What effect does rubbing have on the charges in the plastic?
[b] Why does the plastic L plate stay on the window?
[c] Explain which types of surfaces the L plate would not stick to.
[d] Is there an even distribution of charge on the L plate? Why, or why not?

14.6 On a dry day the movement of a charge of 2.0×10^{-9} C between your hair and your comb causes a spark. The spark lasts for 1.0 μs. What is the magnitude of the current that flows in this case?

14.7 A service station charged a car battery for four hours, using a current of 2 A. Calculate:
[a] how much charge passed through the battery during that time;
[b] how many electrons passed through the battery during that time.

14.8 An electric toaster operated for 90 seconds with a current of 4.0 A.
[a] Calculate the total charge that passed through the toaster element.
[b] If the potential difference across the toaster element was 240 V, calculate the amount of energy released by the toaster element.

14.9 Max was on coffee duty at church, and had to put out, as close together as possible, 150 empty polystyrene cups to be filled later. They were initially stacked 25 high in cartons. Suggest a reason why Max found it difficult to set them out so they stayed stable.

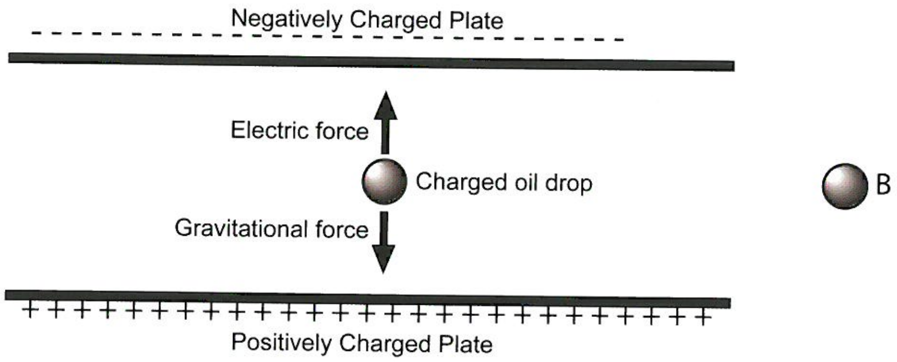
Continued over

Problem Solving and Calculations Set 14: Electric Charges and Fields

14

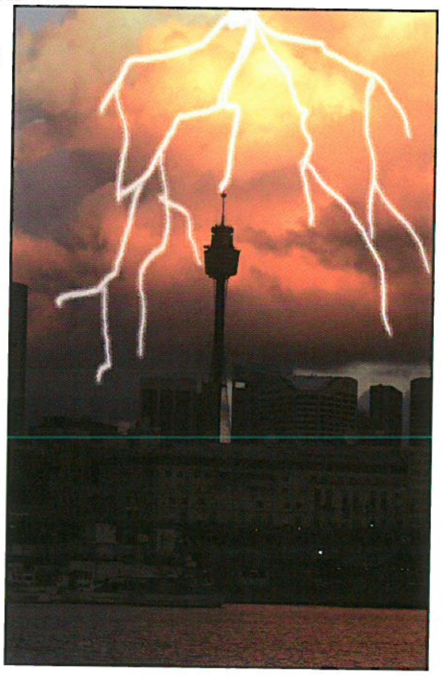
Notes

14.10 Nic finds that his clothes are clinging together when he removes them from a clothes drier. This results from the static charges in the clothes that built up during drying. Nic needs to exert a force of 0.5 N to pull apart two articles of clothing.
[a] Assuming that the charges are equal in magnitude and that the distance between the two articles is 0.8 mm, estimate the charge on each.
[b] Explain why this calculation must be an estimate.



14.11 Millikan's oil-drop experiment (*above*), can be used to determine the charge on an electron. A charged oil drop is suspended between two parallel charged plates, separated by 2 cm of vacuum as shown above The force of attraction between the oil drop and the top plate is exactly balanced by the weight force acting downwards.
[a] What **sign of charge** must the oil drop in the above diagram have?
[b] If the gravitational force on the oil drop is 2×10^{-3} N, state the magnitude of the electrostatic force that must be acting on the drop.
[c] Predict what would happen if the charge on the oil drop was doubled, if all other variables remain unchanged.
[d] If the charge on the oil drop was found to be 6.4×10^{-18} C, how many electron charge units are on the oil drop?
[e] If another oil drop, carrying the same charge as in [d] was then injected at B as shown in the diagram, what would be the force exerted on it due to the original oil drop? They both have the same charge as in [d].
[f] Suggest a way by which an oil drop could be initially charged.

14.12 Lightning is a natural phenomenon involving huge potential differences and currents. For a spark to flow through humid air, an electric field of the order of 10^6 V m^{-1} is required.
[a] Identify the physical principles involved and **estimate** the potential difference between the ends of a typical lightning strike.
[b] How is this enormous potential difference produced?
It has been estimated that the energy in a lightning bolt is enough to light a 100 W globe for three months.
[c] Calculate the quantity of energy involved in such a lightning bolt.
[d] Using your calculated value from [c] and your **estimated** potential difference from [a], what charge must be generated in the clouds?
[e] Assuming that the lightning bolt lasts for 50 microseconds, what current must flow between the clouds and the Earth?



Lightning

Investigations

Investigation 14.3: Creating very large charges

van de Graaff generator

Lightning and the van de Graaff generator both involve the separation of very large charges, resulting in the creation of very large potential differences. Choose one of these and report on:

- How the charges are separated;
- Where the charges come from;
- What happens when the potential difference becomes large enough to ionise air;
- How you can minimise the hazard from such large charges and potential difference, and why these safety techniques work.

Your report should include references acknowledging all of your sources, and should concentrate on the physics of the phenomena.

Notes

Investigation 14.4: Computer printers (bubble and laser)

Printers and photocopiers use electric fields to control and manipulate the formation of images on paper.

Bubble-jet printers use electric fields to apply forces to tiny drops of ink and place them precisely onto paper to form an image. Laser printers and photocopiers use electrostatics to accurately place toner onto a sheet of paper.

The Task

1. Find out about the physics of electric fields and forces on charged particles in electric fields.
2. Find out about the mechanics and the electrical circuitry of a bubble-jet printer.
3. Find out about the mechanics and the electrical circuitry of a laser printer or photocopier.
4. Prepare a written presentation about these two devices. Make your style and layout suitable for inclusion in a high school physics textbook. Your presentation should be scientifically detailed but no more than four pages.

Chapter 15: Electrical Energy and Power Explained 15

Notes

Principles of Power and Work

Power is the rate of doing work, which is a way of measuring the rate at which energy changes from one form into another. For example:

- An electric aquarium heater gives out 12 J of heat energy every 2 s; its power output is 6 J s^{-1} or 6 W.
- A 1000 W (1 kW) electric hair-drier converts 1000 J of electricity into heat every second.

You can find the electrical power an appliance uses by multiplying the potential difference across the ends of the appliance with the current passing through the circuit. Mathematically, the relationship is:

$$P = IV$$

where: **P** is the power in watts (W)
I is the current in amperes (A)
V is the potential difference in volts (V)

Combining with Ohm's Law, **V = IR,** the power equation can be rewritten as:

$$P = I^2R \quad \text{or} \quad P = \frac{V^2}{R}$$

where **R** is the electrical resistance of the appliance in ohms (Ω).

Principles of Energy

We should really call a household power bill an energy bill. The electricity company, Western Power, which is responsible for the management of Collie Power Station and other electricity production plants, distributes and measures the electrical energy that is produced. The Collie Power Station and the other plants supply electrical energy, not electrical power.

Electrical energy = Power x Time:

$$E = Pt$$

Mathematically:

$$E = IVt \quad \text{or} \quad E = \frac{V^2t}{R} \quad \text{or} \quad E = I^2Rt$$

where: **t** is the time in seconds (s)
E is the energy in joules (J)

The unit of energy is the joule. Electricity bills should state energy consumption in joules, but, for historical reasons, electricity companies in Australia use the kilowatt-hour as the unit of energy. One kilowatt-hour (kW h) is equal to 3.6 MJ (3.6×10^6 J).

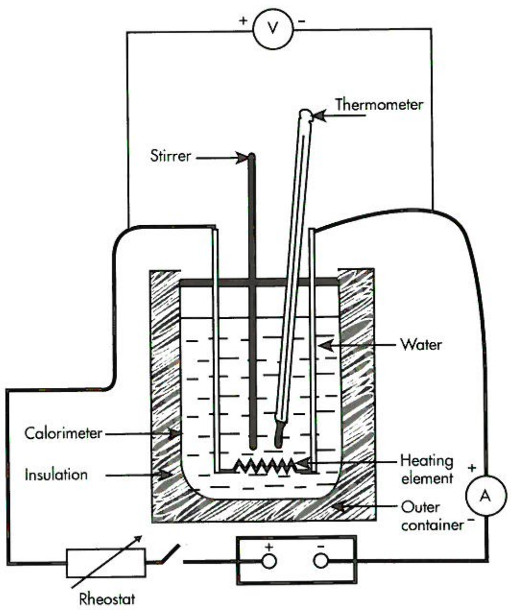
To calculate the cost of running a particular appliance for a set time, convert the power rating of the appliance into kilowatts. Then multiply this by the time in hours you use the appliance. This calculation gives you the energy the appliance used in kilowatt-hours. Multiply this by the cost of one kilowatt-hour to find the cost of running your appliance over the set time. In 2008, domestic users paid about 13 cents for one kilowatt-hour of electrical energy.

Some simplifications have been made in order to apply Ohm's Law to household situations in which mains electricity is used. Mains electricity, as you will learn in Stage 3, is AC and not DC. Further, resistance in an AC circuit is different from that in a DC circuit. The differences are not part of the Stage 2 or Stage 3 syllabuses, and for such questions you should assume that the mains potential is 240 V, and that Ohm's Law is valid.

Experiment 15.1: Measuring Electrical Energy

Background

Electrical energy can be converted into other forms of energy. A common conversion is the heat produced when an electric current flows through a resistor. Electric kettles, electric hot water systems and bar heaters all depend on this energy conversion.



Apparatus for Experiment 15.1

Aim

To investigate the relationship between current, potential difference and electrical energy.

Apparatus (per group)

- Joule's calorimeter
- access to a balance
- thermometer (0 °C – 100 °C)
- 0 - 12 V power supply
- ammeter and voltmeter, or multimeter
- switch
- rheostat
- clock or stopwatch
- seven electrical leads
- water

Pre-Lab

- For this lab, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Prepare a table to record the data you will gather (i.e. initial and final temperatures, the masses of water and the calorimeter, currents, potential differences and times).

Notes

Lab Notes

- Determine and record the mass of the empty calorimeter and its accessories.
- Add about 100 mL of water to the calorimeter and find the combined mass of the calorimeter and water.
- Set up the equipment as shown in the diagram.
- Briefly switch on the power supply and use the rheostat to get a steady potential difference across the calorimeter (e.g. 5 V) and a steady current in the circuit (e.g. 2 A). Switch off immediately after setting this up.
- Gently stir the water and record its temperature to the nearest 0.5 °C.
- Turn the power on again and simultaneously turn on the timing device.
- Stir gently from time to time, and use the rheostat to maintain the steady values of current. Maintain the current for about 10 minutes, or until the temperature has risen by about 30 °C.
- Just before switching the current off, stir gently again and record the final temperature. Make sure that you have recorded the heating time and the steady values of current and potential difference as well as the initial and final temperatures.

Post-Lab Discussion

1. Calculate the electrical energy supplied to the water and calorimeter.
2. Calculate the energy absorbed by the calorimeter and the water, using their masses and increases in temperature
3. Compare the two energy amounts. Account for any discrepancies.
4. Analyse and discuss the major sources of error and uncertainty in this experiment, and some possible ways to reduce them.
5. Calculate the overall efficiency of the heater in warming the water.

Experiment 15.2: The Mechanical Power of an Electric Motor

Background

Notes

Electric motors are used to do work. They are commonly used to lift weights, for example on cranes or in lifts. The input to the motor is electrical energy and the output is mechanical work. In this activity you will measure the input power and the output power of a motor. You will use these measurements to calculate the efficiency of the motor.

The work done in lifting a mass is its change in potential energy, $W = \Delta E_p = mg\Delta h$, where m is the mass (kg) being lifted, g is the gravitational field intensity (9.8 N kg^{-1}) and Δh is the height (m) through which the mass is lifted. The useful power developed by a motor is the rate at which it can alter the potential energy of the mass it is lifting. Hence $\frac{mg\Delta h}{t}$, where t is the time (s) taken to lift mass m through a height of Δh.

The input power to the motor is VI where V is the potential difference across the motor (V) and I is the current (A).

The efficiency of the motor is the ratio of output power divided by the input power. Hence efficiency is given by:

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\left(\frac{mg\Delta h}{t}\right)}{VI}$$

Aim

To investigate the efficiency of an electric motor.

Pre-Lab

- For this experiment, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) that you intend to control.
- Prepare to record the data you will gather.

Apparatus

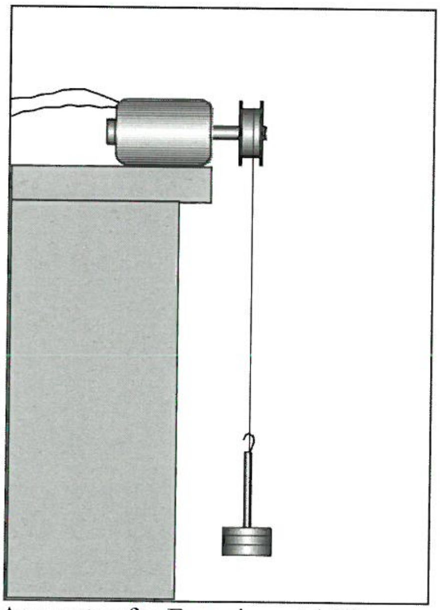
You will need at least the following list. Negotiate with your teacher or technician for other items.

- small electric motor with attached pulley
- DC ammeter (0–1 A) or current sensor
- DC voltmeter (0–5 V) or voltage sensor
- power supply
- cotton or nylon thread
- timer
- masses such as 50 g brass slotted masses on a holder

Lab Notes

- Use a set-up similar to the drawing (*right*).
- Keep accurate records of your procedure and measurements. Photographs of your set-up may be useful for your report. Be sure to investigate rather than simply measure.

Continued over



Apparatus for Experiment 15.2

Experiment 15.2: The Mechanical Power of an Electric Motor

Notes

Post-Lab Discussion

1. You should have a range of measurements of m, Δh, t, V, and I for the motor. Use these to calculate the efficiency of the motor.
2. Summarise your findings.
3. Look carefully at your experimental technique. What might you have improved?
4. Describe any errors that may have affected the validity of your results.
5. Estimate the uncertainty in your measurement of efficiency.
6. Which of the sources of error and uncertainty had the greatest effect on your results? Explain.

Extension

Investigate the relationship between the speed of the motor and its efficiency.

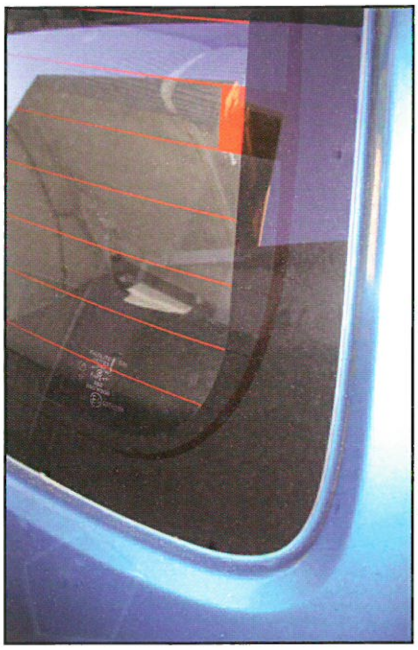
Problem Solving and Calculations Set 15: Electrical Energy and Power 15

15.1 A 1200 W toaster is connected to the 240 V electrical mains.
[a] Calculate the current drawn by the toaster element as it operates.
[b] Calculate the resistance of the toaster heating element.

15.2 A 6 W globe draws a current of 500 mA when operating normally.
[a] Calculate potential difference across the light globe filament as it operates.
[b] Calculate the resistance of the light globe filament.

15.3 Calculate the operating resistance of a 100 W electric mixer motor when you connect it to a 240 V mains supply.

15.4 The rear window demister of a car draws 2.0 A of current from the 12 V car battery and takes 20 minutes to demist the window.
[a] Calculate the quantity of electric energy that is converted into heat energy in that time.
[b] What is the power rating of the demister?
[c] How much charge flows in the 20 minute period?


Car window demister

15.5 A small light globe is marked 17 mA, 4 W.
[a] Is it a household lamp or for a car? What is the evidence for your answer?
[b] What is the operating resistance of the globe?

15.6 The motor from a toy is marked 380 mA, 2.3 W.
[a] What voltage of power supply is it designed for? What is the evidence for your answer?
[b] What is the operating resistance of the motor?

15.7 A typical headlight globe in a car operates at 12 V and dissipates 55 W of heat and light.
[a] Calculate the current passing through the globe filament under normal operating conditions.
[b] Calculate the resistance of the globe under normal operating conditions.

15.8 The unit by which electrical energy is sold and paid for is called the kilowatt-hour (kW h). The electricity bill delivered to your house is for the number of kW h of electricity you have used multiplied by the price of one kW h. The price is currently around 13c per kW h. Calculate how much it costs to operate the following devices at home:
[a] A 60 W desk lamp for 3.0 hours per day, 5.0 days per week, for 9.0 weeks.
[b] An 11 W fluorescent 'energy saver lamp' in the same light fitting as part [a] of this question for the same number of hours.
[c] A 2400 W fan heater for four hours.
[d] A 1700 W electric kettle for the five minutes it takes to boil water to make tea.

15.9 Calculate the cost of running each of the following from the 240 V mains:
[a] an electric fan heater rated at 2 kW, for 3 hours;
[b] an electric water heater whose element has a resistance of 26 Ω, for 4 hours;
[c] an electric drill rated at 8 A, which is run for 30 minutes.

Notes

Continued over

Notes

15.10 Estimate the cost of electric lighting in your house for one year. You will need to list the power ratings of all the globes and fluorescent tubes, and estimate the times for which they operate in one year.

15.11 You fit a 150 W floodlight lamp globe in a 240 V outlet in preparation for a party.
[a] Calculate the current in the filament when the lamp is operating normally.
[b] What is the lamp's resistance?
[c] If it converts 95% of the electrical energy used into heat, how many joules of light energy will it produce in 1.0 h?
[d] Calculate the cost of leaving the light on for 5 hours, at a cost of 13 cents per kilowatt-hour.

15.12 If it costs $800 to insulate the roof of a small apartment, with the result that the 4000 W air conditioner, when needed, is operated for an average of three hours less per day:
[a] calculate how many days' use it will take for the electrical savings to cover the cost of the insulation;
[b] hence estimate how long it will take (in weeks, months or years) for the electrical savings to cover the cost of the insulation.

15.13 Batteries are given a form of energy rating – the 'amp-hour'. It is not really an energy rating but when multiplied by the emf of the battery it tells us how much energy can be obtained from the battery before it is 'flat'. For example, a battery might be rated at 10 amp-hours. This means that it can deliver 2 A for 5 hours, or 1A for 10 hours, before its emf drops to a useless level.
[a] A standard 12 V car battery is rated at 40 amp-hour. How much energy, in joules, can it provide before it is 'flat'?
[b] A more expensive 12 V battery is rated at 75 amp-hour. For how long can it be used for emergency lighting comprising of two 55 W headlight globes?

15.14 A nickel metal hydride rechargeable AA cell is rated at 2.3 amp-hour and has an emf of approximately 1.4 V when fully charged. Suppose one such cell is used in a small 3 W 'key light'. How long will the cell last until it needs to be recharged?

Investigation 15.3: Which is the best value battery?

Notes

Background

Electrical energy is supplied to many devices from electrochemical cells. How long do the AAA cells in your calculator last? Does it matter which brand you use? Have you noticed that mechanical devices such as toys and music players that have electric motors 'use up' the batteries quite quickly? Other devices such as scientific calculators use tiny cells that last for years. Devices such as flashlights use large batteries of cells that always seem to be 'flat' at just the wrong time.

In this investigation, you will investigate the cost and availability of the energy from a number of electrochemical cells. Each battery or cell should deliver current over an extended period of time until the emf falls below an acceptable level. We then say that the cell is 'flat'.

Pre-Lab

You will need to do some research on the chemistry and physics of electrochemical cells. One of the challenges that you will face is making the necessary measurements. You will need to be able to record potential differences and currents over the working life of a battery or cell. The times involved can be quite long. This could be made a lot easier if you have access to data-logging equipment that can automate the recording processes.

The Task

Choose a range of batteries and design a way to determine which type represents the best value for money. Your design should include explanations of the hypothesis you will test, the evidence that you will gather to test your hypothesis, the variables that you will investigate and control and the ways that you will minimise uncertainties or errors in your results. You should investigate answers to some of the following questions:

- Which cells or batteries deliver electrical energy at the lowest cost?
- Which cells or batteries deliver the greatest amount of energy?
- Which cells or batteries are most suitable for a particular purpose?
- How does the particular chemistry of the cell affect the availability and price of electrical energy?
- Which brands are better? (What is meant by 'better'?)
- Does the device being powered by the cells or batteries affect the energy available from the cells?
- How does the size of the cell (AAA, AA, C, D, etc,) affect performance?

Report

Report on the results of your measurements as well as the conclusions you have drawn regarding the comparisons between types or brands of cells or batteries.

Extension Topics

- What are the shapes of the discharge curves for various types of cell?
- How does this affect the applications for which the cells are suitable?
- What is the internal resistance of each cell? How does this vary with time and discharge level?
- Which types of cells are most suitable for:
  - emergency lighting in a medical clinic
  - children's mechanical toys
  - electric vehicles
  - power tools
  - computers
  - calculators

Investigations

Notes

Investigation 15.4: Solar electric cars

Each year we see solar vehicles racing in competitions in various parts of the world. Their drivers and designers are university students, engineers and research scientists who have put enormous expertise into some very exciting technology. Where are these vehicles in the everyday transport scene? Electric vehicles seem to be the way of the future.

Surely in a place as sunny as Western Australia, we should be able to get our transport energy from the sun. Solar cells can change light energy into electrical energy. Electrical energy can be stored in batteries. How far are we from having full-time electric vehicles? What is the hold-up?

The Task

1. Find out about the technology of electrically-driven cars, including hybrid cars.
2. Find out about the technology of photovoltaic cells.
3. Find out about the limitations of building and using electric cars in cities and towns.
4. Write a report to the Australian Government recommending the way forward for electrically-driven vehicles. Include the appropriate scientific principles and concepts in your report – either as appendices or within the body of your recommendations.

Investigation 15.5: Car batteries (electrochemical cells)

Storage batteries allow us to 'time shift' our electrical energy. They enable us to generate electrical energy and store it for use at another time. The lead acid battery has been standard equipment in motor cars for nearly a century. It is heavy and can be high maintenance. What are the alternatives to these devices, either in cars or for the myriad of other uses we have found for them? There are many other electrochemical cells in use these days and others under development in various research institutions around the world. What is in the pipeline and what factors affect which battery is used for each application? In this project you will focus on the use of batteries as the primary energy sources for vehicles.

The Task

1. Find out about the chemistry and physics of several types of commercially available electrochemical cell.
2. Find out about at least one type of electrochemical cell currently being researched or developed by scientists or engineers.
3. Find out about the specific requirements of batteries which are for powering vehicles.
4. Prepare a report on the science and technology of electric vehicles and their power sources.

Chapter 16: Circuits and Ohm's Law Explained

16

Notes

If potential difference exists between the ends of a metallic conductor, a current will flow in that conductor.
The size of the current is proportional to the potential difference. We measure potential difference in volts. The resistance of a conductor is the ratio of the potential difference across a conductor to the current flowing in that conductor. The resistance is constant as long as the temperature of the conductor is constant.
Resistance has a constant value for any ohmic conductor.

$$\mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}} = \textbf{constant}$$

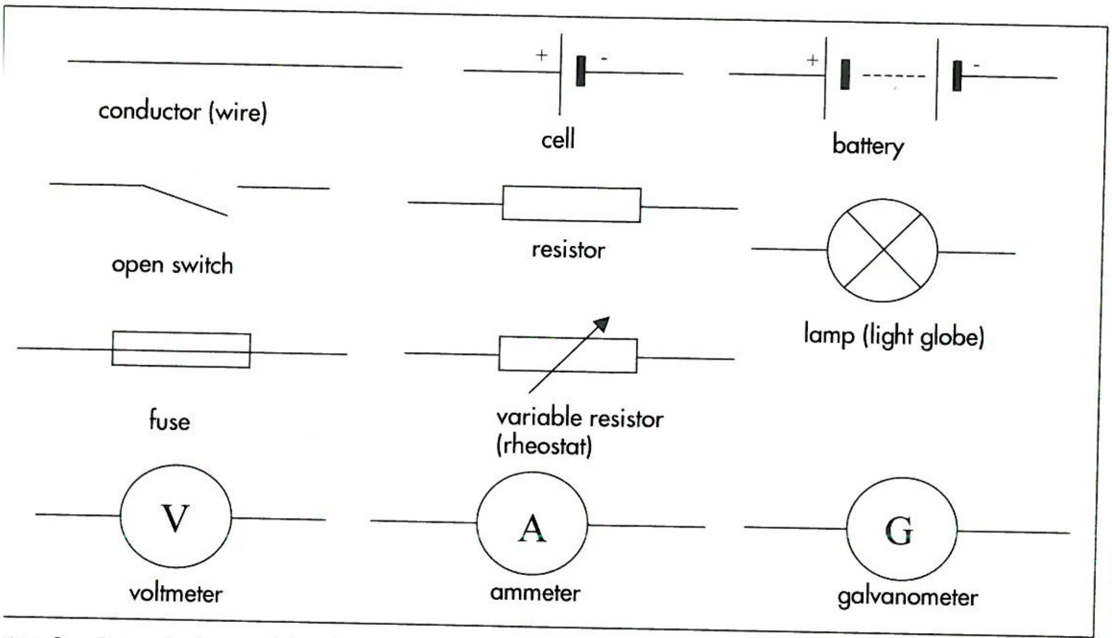
Where: **R** is the resistance in ohms (Ω)
V is the potential difference in volts (V)
I is the current in amperes (A)

You can apply this formula to any part of a circuit and people often write it as:

$$\mathbf{V = IR}$$

Principles of Electric Circuits

All circuits need a source of energy (sometimes called a source of emf) and a closed conducting path to allow the movement of charge from the source of emf through the conductor and back into it. In metallic conductors, the charged particles that move around the circuit are electrons.
When a circuit that contains an emf source is closed, an electric field is created in the circuit. This electric field exerts forces on the charged particles in the circuit. In the emf source, they gain energy from the field. They use energy as they move along the field lines through the rest of the circuit.



tandard symbols used in circuit diagrams

Experiment 16.1: Potential Difference, Current and Resistance

Notes

Background

The simplest way of thinking about an operating electric circuit is to consider the potential difference to be the ***cause*** and the current to be the ***effect***. The resistance is the property of a circuit component that determines the amount of current thatwill flow for a given potential difference. The resistance of a circuit component determines the way it will behave in a particular location in that circuit. The energy dissipated by a component depends on its resistance and the potential difference it experiences when placed into a circuit.

A simple example of how this might be used in designing a device is the selection of a heating element for a kettle, a heater, or a stove. In each case, the potential difference will be 240 V and a particular output of heat will be required.

Aim

To investigate the relationship between the applied difference and the current in a resistor.

An element of the correct resistance will need to be selected in order that the correct power output is obtained.

Apparatus (per group)

- power supply
- switch
- seven electrical leads
- voltmeter or multimeter
- ammeter or multimeter
- three different resistors
- variable resistor (rheostat)

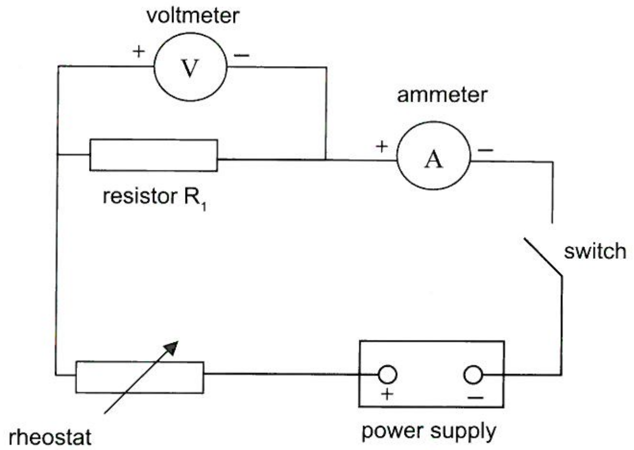
Pre-Lab

- In this practical exercise you will use electrical meters to make measurements of potential difference and current in order to calculate the resistance of some resistors.
- The voltmeter measures the potential difference across a component. This means that the *voltmeter must be connected in parallel* with that component.
- The ammeter measures the current through a component. This means that the *ammeter must be connected in series* with that component.
- Most multimeters can measure DC or AC potential difference, DC or AC current, or resistance depending on the measurement mode selected. You must still take care to connect the meter correctly when measuring potential difference and current.
- In your group, discuss how you will calculate the resistance of each resistor from the measurements you have made. If you use a multimeter, you will be able to check your resistance calculations by direct measurement.

Experiment 16.1: Potential Difference, Current and Resistance

Lab Notes

- Connect the equipment as shown in the circuit diagram (*below*). Make sure that the meters are connected with the correct polarity. Your teacher may wish to check this before you close the switch.
- Set the power supply to the lowest voltage setting.
- Adjust the power supply and rheostat to get a number of different readings of current and voltage (potential difference).
- Record your measurements in a suitable table.
- Note: Do not run the circuit for more than ten seconds at a time. The current will cause an increase in the temperature of the resistor, giving unexpected results.
- Repeat steps 2 and 3 with your other two resistors.



Apparatus for Experiment 16.1

Post-Lab Discussion

1. Calculate and record the resistance values, using:

   $\mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}}$ for each set of readings.

2. Plot a graph of current against potential difference for each resistor.

3. When the current is directly proportional to the potential difference, a conductor is called an 'ohmic conductor'. Were any of your resistors ohmic?

4. How do the graphs for each resistor differ? Why are they different?

5. What types of materials are ohmic?

Notes

Experiment 16.2: Incandescent Globes

Notes

Background

Most torches use incandescent light globes in which a coiled tungsten filament carries a current. This current heats the filament to very high temperatures, (over 2000 °C). The glowing hot metal emits energy in the form of electromagnetic radiation, which we see as light.

Aim

To investigate how the current through a globe varies with the potential difference across the globe.

Apparatus (per group)

- 12 V, 15-20 W incandescent globe and holder
- 12 V power pack
- voltmeter, ammeter and connecting leads

Pre-Lab

- For this experiment, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.
- Briefly discuss how to use Ohm's Law to calculate the resistance of a globe filament.
- Plan the way you will measure the current and the potential difference, and how you will record your data.

Lab Notes

- Set up a suitable circuit.
- Carry out several trials using a range of potential difference values, and record the data.
- Use the data you have recorded to calculate the resistance of the filament under various potential differences.

Post-Lab Discussion

1. What is the normal operating resistance of the globe?

2. Plot a graph of current *vs* potential difference. Why was the graph for the globe not linear? How could you use the graph to determine the filament resistance at a given potential difference?

3. Is there a pattern to the way the resistances vary? Explain.

4. Most digital multimeters can directly measure the resistance of a light globe filament without changing its temperature. They do this by applying a very small voltage across the filament. Outline briefly how you could use a light globe as a thermometer.

Problem Solving and Calculations Set 16: Circuits and Ohm's Law 16

Notes

16.1 Kylie measures the potential difference and current in a circuit.
[a] The potential difference across a resistor is 2.55 V when the current through the resistor is 120 mA. Calculate the resistance of this component.
[b] A resistor is marked as 147 kΩ and has 3.42 V across it. Calculate the current through this resistor.
[c] A 2.0 kΩ resistor has a power rating of 1.6 W. Calculate the maximum current it will tolerate.

16.2 A telephone receiver has a resistance of $8.0 \times 10^3\ \Omega$, and it uses a current of 7.0 mA. What potential difference must the exchange supply to make the receiver work properly?

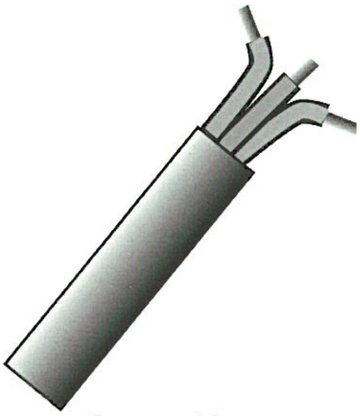
16.3 A technician has to replace the indicator lights in a stereo amplifier. Each light operates on 14.0 V and draws a current of 500 mA. Calculate the resistance of such a light.

16.4 Your nephew, Tom, finds a toy car, but the battery is missing. You read the label on the car's motor. It states the motor uses 320 mA and has a resistance of 4.7 Ω. What potential difference battery would you advise Tom to use in his car?

16.5 The resistance of metals increases as the temperature of the metal increases.
[a] Does the current through the metal element of a bar heater increase or decrease as the element heats up? Explain your reasoning.
[b] What happens inside the heating element that causes the resistance to increase as its temperature rises?
[c] Calculate the resistance of a 240 V bar heater that passes 10 A once it is at its normal operating temperature.
[d] Calculate the power consumption of the a 240 V heater that passes 10 A at its normal operating temperature.
[e] During a 'brown-out' the electricity supply to your house might drop to 170 V. How will this affect the resistance and power consumption of the heater?

Continued over

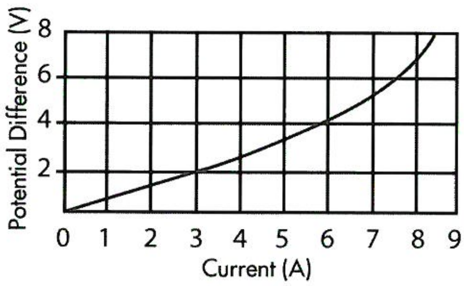
Problem Solving and Calculations Set 16: Circuits and Ohm's Law



3 core cable

16.6 The figure (*left*) shows a three-core general-purpose domestic electrical cable, which electricians use in electrical wiring in a house. The manufacturers design the cable for use with 240 V, but it is still safe at 415 V. The standard for such a cable states that one kilometre of any of the three conductors must have a resistance of not more than 18.1 Ω at 20 °C.
[a] Calculate the maximum resistance of one of the conductors in the cable if it runs 36.0 m from the meter board to a power outlet in a house.
[b] Calculate potential difference that has to be applied across 36.0 m of this cable to maintain a current of 1.00 A through it.

16.7 In an experiment on electrical circuits, the technician represented the data collected in the graph (*below*).



[a] Over which current range does the component act as an ohmic conductor?
[b] Calculate the resistance of the component in the ohmic region.
[c] Explain what happens to the resistance of the component at higher currents.
[d] What could cause such a change in resistance?

16.8 Why is it that the electricity does not kill birds when they perch on high voltage transmission lines?

16.9 A lie detector measures the sweat rate of subjects by detecting changes in their skin resistance. Persons under stress normally produce more sweat, so lie-detector operators assume subjects will sweat more when they tell lies.
[a] Would a lie detector register increased or decreased skin resistance as a typical subject starts to tell a lie? Explain why you chose your answer.
[b] The detector shows this change in resistance as a needle movement, which traces a line on paper. What would this resistance change cause to happen to the current driving the needle motor?
[c] If the potential difference across the detector is 12 V and the current through the detector is 35 mA, what is the resistance of the person's skin?

Notes

Investigation 16

Investigation 16.3: Characteristic curves

Notes

Background

Few electrical devices are truly ohmic. They are designed to operate at a particular potential difference. Two devices, the light globe and the electric motor, are typically used at various potential differences. Changing the potential difference across a motor can control the rate at which it turns. This is how you can control the speed of a ceiling fan. With a dimmer switch, you can change the potential difference across a light globe, controlling its brightness.

Motor speed and light brightness do not vary in a linear manner with the applied potential difference.

Pre-Lab

In this investigation you will devise your own methods to plot the characteristic V-I curve for at least one light globe and one electric motor. You will examine your data to get a better understanding of the physical behaviour of the devices. You can use ammeters and voltmeters to measure the potential differences across and current through the devices.
Since V = I R, you can plot the resistance of the devices for various settings of potential difference and current.
Since P = I V, you can plot the power of the devices for various setting of potential difference and current.
For each device that you examine you must produce, at least, the following graphs:

- Current against potential difference
- Resistance against current
- Power against potential difference

Apparatus

You will need to record at least the following:

Potential difference (V)	Current [A]	Resistance (Ω)	Power (W)

Negotiate with your teacher or laboratory technician to use appropriate equipment to make the measurements. You will need, as a minimum, a voltmeter, a power pack, an ammeter, a globe, a motor and some wires.
Explore the possibility of using data logging equipment to make your measurements.
Your data and graphs should be processed electronically via, for example, a spreadsheet program.

Lab Notes

Make careful records of your data and your procedure.
Record circuit diagrams.
Your report must include a full account of what you did.

Post-Lab Discussion

1. Are these devices ohmic? Explain.
2. What can you say about the filament temperatures when the light is operating at various potential differences?
3. How does the resistance of each of these devices vary with current?
4. How does the resistance of the light globe vary with its temperature?
5. What happens to the electrical power dissipated by the motor as its current varies?
6. What else did you notice that was interesting?

Investigation 16.4: Resistance and Resistivity of Insulators

Notes

Investigation 16.4: Resistance and resistivity of insulators

Background

Electrical safety can depend on the insulating properties of the materials used. The most obvious example of this is the insulating coating on electrical wires. Electrical cables are usually made from copper wire coated with plastic or varnish. It is also necessary sometimes for people to wear insulating shoes, clothing or gloves when working with electricity. Apart from metals and graphite, we classify most other solids as insulators, but this really just means that they have high resistance. A high enough potential difference will cause a current to flow in any material.

Your dry skin is an insulator but you will get a shock if the voltage is great enough. Typically, you won't get significant current passing through the tissue under your skin unless the potential difference driving the current is more than around 50 V. That is why you won't get a shock from a 12 V car battery but you will get a shock if you touch the terminal on the ignition coil that delivers around 20 kV.

Aim

To investigate the suitability of various materials as electrical insulators.

Pre-Lab

Resistivity is the property of a material that results in its resistance to the flow of electric current. The resistance, R, of any piece of material depends on its length, ℓ, its cross sectional area, A, and the resistivity of the material from which it is made, ρ.

Hence: $$R = \frac{\rho \ell}{A}$$

Since resistance can be determined using V = I R (Ohm's Law), you can measure the resistance of a piece of material if you can measure a potential drop across it and the consequent current through it.

The Task

In this investigation, you are to select a number of materials and investigate their resistance and hence calculate the resistivity of the material. You could, for example, test several black erasers, different pencil 'leads' (B, HB, etc).

Report

Report on the suitability of various materials as electrical insulators, taking into consideration:

- the physical characteristics of the material;
- the cost of the material; and
- the contexts in which the material might be used.

16 Electricity Around the Home

Have you ever wondered what happens when you adjust the switch on your electric blanket? Have you noticed that when one light in your house goes off because the globe has blown, the other house lights stay on? Have you ever been frustrated when there is an electrical blackout and all the electrical devices don't work?
The appliances in your home that are connected to the mains make up a rather complicated electric circuit with sections that are in series and sections that are in parallel. All of these complicated circuits consist of a common set of circuit components: a source of energy, one or more resistors, and one or more closed conducting pathways.

A portable torch uses a simple series circuit. There is only one path the current can take, so if that path is interrupted (for example by a broken filament) the torch will not work.

By using ammeters and voltmeters, you can measure current and potential difference and then calculate resistance and hence the power dissipated. Multimeters allow you to measure resistance as well.

The simplest way of thinking about the relationships in an electric circuit is to consider the potential difference to be the cause and the current to be the effect. Resistance is a feature of a circuit component that determines the amount of current that will flow through it for a given potential difference. The resistance of a circuit component determines the way it will behave in a particular location in that circuit. The energy dissipated by a component depends on its resistance and the potential difference it experiences when placed into a circuit.

Finding enough power outlets in your bedroom can be a problem. Recharging all your portable devices, plus perhaps a computer, printer and bedside lamp may require more electrical outlets than are available. You can overcome this by plugging in a double adapter to an outlet and running two devices off the same plug. This creates a parallel connection. If one of the devices 'blows' then the other device should not be affected and will continue to operate.

A residual current device, or RCD, breaks the circuit if the current in the active wire is not the same as the current in the neutral wire, in which case some current is going somewhere that it should not, such as through a person to ground. An RCD can possibly prevent electrocution–if the wiring is installed correctly, and if the time the RCD takes to activate is sufficiently short.

Investigating why an appliance failed can be a tricky business and should usually be left to a qualified electrician. Sometimes the cause is obvious: for example, when there is a break in the circuit such as a broken filament in a globe. Recently constructed houses are fitted with two different types of circuit breakers, called fuses and RCDs. These are always installed in series with the circuit they protect.

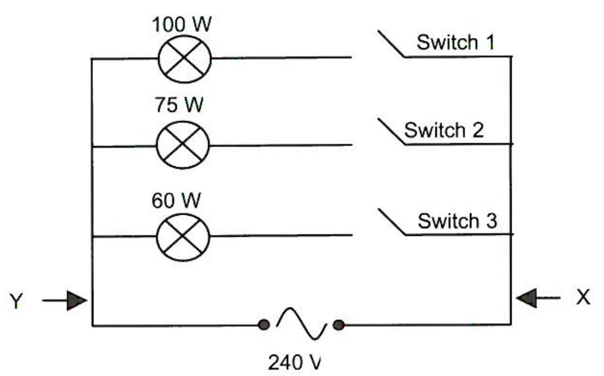
A 'fuse' breaks the circuit if the current is too big. A fuse does not protect people from electrocution. Its purpose is to prevent 'electrical fires' that start if a large current heats the wires so much that the insulation ignites. Overload currents like this usually result from 'short circuits' caused by equipment faults or exposed conductors touching other conductors. Most houses have two or more fuses for both lighting and power circuits.

When building or investigating electrical circuits, electricians may use circuit diagrams to interpret the wiring. A circuit diagram is a system of symbols and line diagrams that represent a circuit, such as those you construct in the laboratory.
The pamphlets that accompany the appliances you have bought may include circuit diagrams to show how the components of the appliance are arranged. With a bit of practice you can interpret the diagrams and learn more about electricity and electronics.

Electricity Around the Home: Comprehension Questions

1. [see Chapters 17 and 18]

Three light bulbs in a room are connected as shown.



Circuit for question 1

[a] Calculate the normal operating resistance of the 75 W bulb.

[b] Calculate the current drawn by the 100 W bulb.

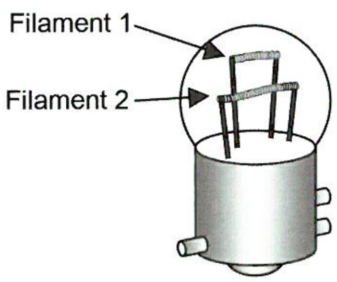
[c] Determine the minimum current rating of a fuse that could be inserted at point X and still allow the circuit to operate.

[d] The home owner decides to fit a fuse at X with the minimum rating (see [c] above). Can the home owner replace both the 60 W and the 100 W bulbs with 75 W bulbs without blowing this fuse? Explain your reasoning.

[e] The fuse should be fitted in series with the power supply and the light bulbs. What difference would it make if the fuse was fitted in parallel (that is, connected between X and Y)? Explain.

[f] Explain briefly what the fuse actually does to 'protect' the circuit.

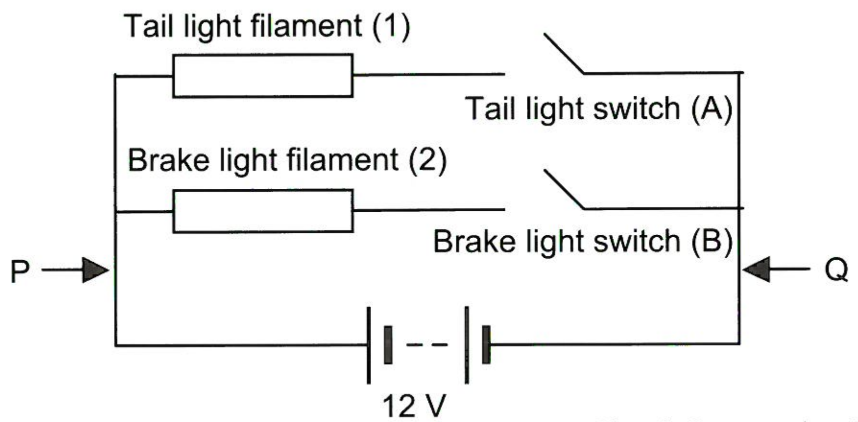
[g] In addition to the fuse, the 240 V power supply may be fitted with a further safety feature called a residual current device (RCD). Does this do the same job as the fuse? Explain.



Combined tail & brake light

2. [see Chapters 17 and 18]

A motor vehicle has a combined tail light and brake light that contains two separate filaments in the same glass envelope. Filament 1 has a resistance of 18.0 Ω and filament 2 has a resistance of 32.0 Ω.



Circuit for question 2

Electricity Around the Home: Comprehension Questions

Notes

[a] Are the filaments connected in series, or in parallel? Why did the manufacturers choose this arrangement?

[b] Calculate the overall resistance of the lamp when switches A and B are both closed.

[c] Calculate the total current supplied by the 12 V battery when both switches are closed.

[d] Calculate the total power consumption of the lamp with both switches closed.

[e] Does the power consumption of filament 1 change when switch B is opened or closed? Explain.

You close both switch A and switch B, and the filaments light up.
If you then connected points P and Q with a conductor (such as a screwdriver):

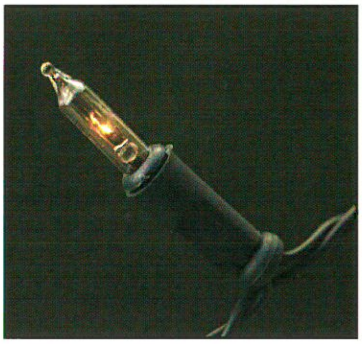
[f] What would be the effect on the lights? Explain.

[g] What would be the effect on the battery? Explain.

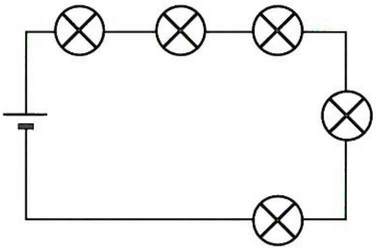
[h] Could a fuse, inserted in the circuit between the battery and Q, protect either the lamp or the battery from damage in this situation? Explain.

3. [see Chapter 18]
The electricity supply in parts of Western Australia sometimes experiences 'spikes' A spike occurs when the mains potential increases suddenly to well over 240 V, then quickly drops back. Under what circumstances could a spike cause a household mains fuse to blow? Would it trigger an RCD?
Explain in terms of potential difference, resistance and current.

Chapter 17: Parallel and Series Circuits Explained



One of the 20 globes in a series circuit. Note that the return wire is nowhere connected to the globe.



Circuit diagram of fairy lights

There are two ways you can join electrical components together in **series** or in **parallel**. A **series circuit** allows the current to flow continuously along only one path, from the source through the components and back through the source. Fairy lights are a good example of a series circuit.

The relationships between the potential difference across each component, current through each component, resistance of each component, and the total potential difference, current and resistance in a **series** circuit are:

$$R_t = R_1 + R_2 + \cdots$$

- If you sum the potential difference across each component, you get the total potential difference across the circuit.
- The same current flows through each component.
- The total resistance of the circuit is equal to the sum of the resistance of each component.

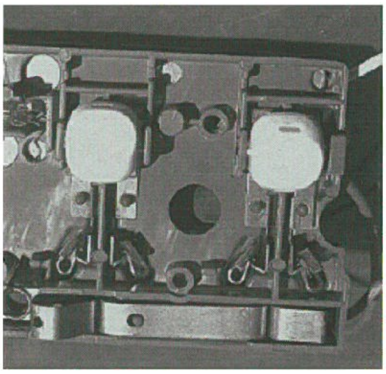
A series circuit has several disadvantages. The most important disadvantage is that if something breaks the circuit, the current stops. For example, if one fairy light 'blows', the other lights stop working. Because of this problem, most electrical circuits are connected in parallel.

In a **parallel circuit** the current has a separate path through each component. An example of a parallel circuit is a power board. Each component in a parallel circuit receives the same potential difference (PD or voltage).
With a constant potential the resistance of a component determines how much current flows in that component. If you switch off or remove one component, a path through every other component remains, still allowing current to flow through them.
The relationships between potential difference, current and resistance of a **parallel** circuit are:

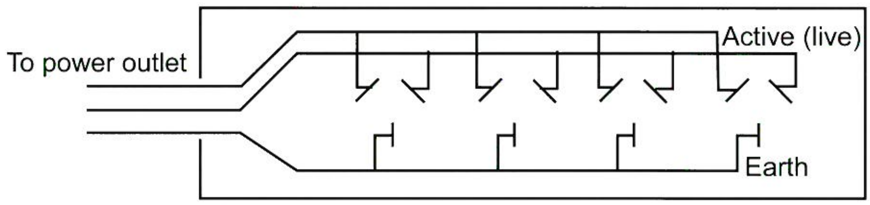
- The potential difference across each component is the same.
- The sum of the currents through each component gives the total circuit current.
- The total resistance of the circuit drops as you add more components.

The mathematical relationship between parallel resistances is:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$



Inside part of a typical power board. The strip near the bottom is the earth connector. Directly above this strip are the sets of active and neutral connectors. Each active and neutral conductor passes through a switch above.



Circuit diagram

Experiment 17.1: Resistors in Series

17

Background

Notes

Strings of decorative lights known as fairy lights may be wired in series. A number of low power, low potential difference voltage globes can be operated at one time across a higher potential difference if they are connected in series.

Aim

To investigate the characteristics of resistors connected in series.

Apparatus (per group)

- ammeter or multimeter
- voltmeter or multimeter
- 3 resistors of known values
- power supply
- one switch
- 8 electrical leads

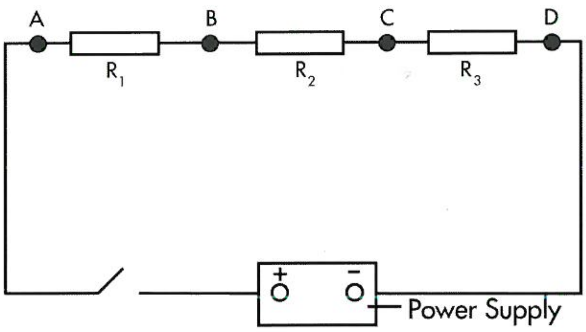
Pre-Lab

In any series circuit, the the sum of the potential difference across each component equals the total potential difference across the circuit and each globe passes the same current. In this exercise you will use meters to examine and interpret the measurements of potential drop and current in a simple series circuit.

- In your group, plan the type of table that you will use to record your data.

Lab Notes

1. Connect the three resistors in series with the power supply as shown in the diagram.
2. Record the values of the resistors R_1, R_2, and R_3.
3. Set the power supply to 6 V.
4. Connect the ammeter in series at point A in the circuit.
5. Switch the power supply on and record the current reading at A.
6. Repeat step 4 but connect the ammeter in series at points B, C, and D.
7. Connect the voltmeter in parallel with R_1. Turn the power on and record the potential difference V_1 across R_1. Record your results.
8. Repeat step 7 to find the potential drops across the other two resistors.
9. Connect the voltmeter across the three resistors to determine the total potential difference V_{total}.
10. Repeat steps 4 to 9 with the power supply at two other settings or with three other resistors if you have access to them.



Apparatus for Experiment 17.1

Post-Lab Discussion

1. What is the relationship between current and resistance in a series circuit?

2. What is the relationship between potential difference and resistance in a series circuit?

3. Quote from your data to verify that within the precision of your measurements $R_{total} = R_1 + R_2 + \ldots$ for resistance in series.

4. Why do you think that components are sometimes arranged in series in circuits?

Experiment 17.2: Resistors in Parallel

Notes

Background

Devices are typically wires in parallel when they share the same power supply. All of the appliances in your house are attached to power sockets that are wired in parallel.

Aim

To investigate the relationship between the characteristics of individual resistors and the characteristics of a group of resistors connected in parallel.

Apparatus (per group)

- ammeter or multimeter
- voltmeter or multimeter
- 3 resistors of known values
- power supply
- one switch
- 10 electrical leads

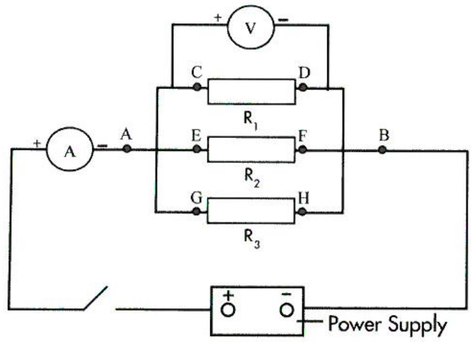
Pre-Lab

In a parallel circuit, the potential differences across each component are the same while each component passes its own separate current. In this exercise you will use meters to examine and interpret the measurements of potential drop and current in a simple parallel circuit.

- In your group, plan the type of table that you will use to record your data.

Lab Notes

- Connect the three resistors in parallel with the power supply as shown in the diagram (*left*).
- Record the values of the resistors R_1, R_2, and R_3.
- Set the power supply to 6 V.
- Connect the ammeter into the circuit at A as shown, and record the total current I_{total} when the switch is closed.
- Connect the ammeter so as to determine the current I_1 (through resistor R_1), then I_2 and I_3.
- Connect the voltmeter across AB and record the potential difference, V_{total}, across the three resistors.
- Connect the voltmeter across R_1, R_2, and R_3 to record V_1, V_2, and V_3.
- Repeat the entire experiment for at least one other setting of the power pack or with another three resistors if you have access to them.



Apparatus for Experiment 17.2

Post-Lab Discussion

1. What is the relationship between current and resistance in a parallel circuit?

2. What is the relationship between potential difference and resistance in a parallel circuit?

3. Quote from your data to verify whether, within the precision of your measurements, $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ for resistors connected in parallel.

4. What reasons are there for connecting components in parallel in circuits?

5. What do you notice about the total resistance of a parallel circuit compared with the individual resistances of the separate components?

Experiment 17.3: Sources of emf in Series and Parallel

Background

Many portable devices, such as remote control units and torches, contain more than one source of emf (that is, more than one cell).

Aim

To investigate the effects of connecting sources of emf in series and in parallel.

Apparatus (per group)

- ammeter or multimeter
- voltmeter or multimeter
- three 1.5 V dry cells
- electrical leads

Pre-Lab

In this exercise you will use meters to examine and interpret the measurements of potential drop and current when cells are connected in series and in parallel.

- Design a laboratory investigation to measure the current and the emf provided by combinations of cells in series and in parallel. Make sure you include a resistor in your circuit.
- Plan the type of table that you will use to record your data.
- Check your plan with your teacher before proceeding.

Lab Notes

- Be careful not to exceed the current and potential limits of your meters, and close the circuit for short time periods to prevent overheating.

Post-Lab Discussion

1. How does connecting cells in series affect the current produced?
2. How does connecting cells in series affect the total emf provided?
3. How does connecting cells in parallel affect the current produced?
4. How does connecting cells in parallel affect the total emf provided?
5. 12 V car batteries commonly contain cells arranged in series and in parallel. Investigate the structure of a car battery and explain the possible advantages to the user of each of these arrangements.

Notes

Problem Solving and Calculations Set 17: Parallel and Series Circuits

Notes

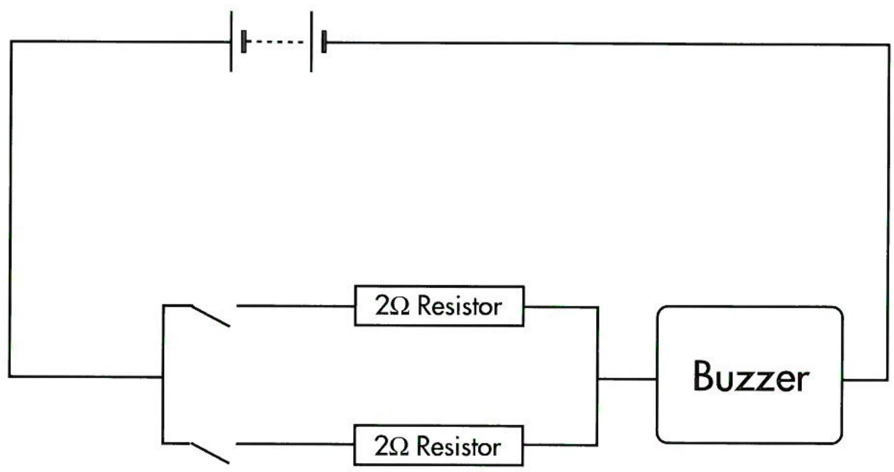
17.1 Are the appliances in your home connected to the electricity supply in series or in parallel? Give evidence to support your answer.

17.2 Calculate the total resistance of a string of twelve fairy lights connected in series, if the resistance of each lamp is 30 Ω.

17.3 An auto electrician connects two 12 V car batteries in series.
[a] What is the total potential difference provided by this combination?
[b] She now connects three sidelights in series with the two batteries.
Each sidelight has an operating resistance of 20 ohms. What current will flow through each light?
[c] If she connects the sidelights in parallel instead of in series, calculate the total resistance of the three sidelights.
[d] How does the intensity of light in [c] compare with [b]?

17.4 A farmer wants to run a 12 V car radio on the 32 V farm electricity supply. The radio uses 4.0 A. What resistance must the farmer use in series with her radio?

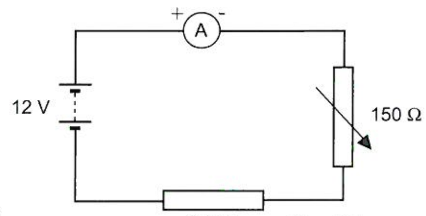
17.5 Claire has a personal alarm with her for safety. It consists of two 9 V batteries, two switches each connected to a 2 Ω resistor and a buzzer of resistance 3 Ω. The circuit diagram is shown below:



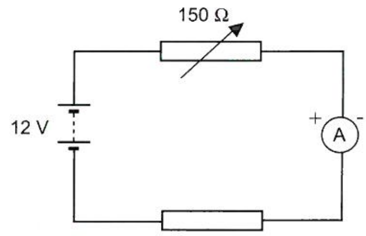
[a] Calculate the total resistance of the personal alarm circuit when both of the switches are closed.
[b] Calculate the current passing through the buzzer when both of the switches are closed.
[c] The buzzer is louder when it carries a larger current. Which arrangement of switches (e.g. both closed, both open, one closed and one open) would result in the buzzer sounding the loudest? Explain your answer.
[d] Claire is concerned that the batteries might 'go flat'. Calculate the energy consumed if the buzzer is left on for 3 minutes at the **softest** setting.

Set 17: Parallel and Series Circuits

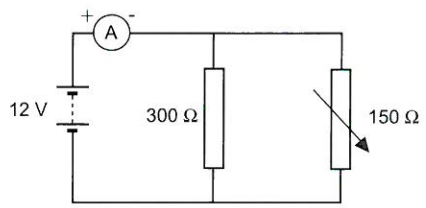
17.6 Heath, Jenni and Shani's teacher sets them a practical test. Each student has a tray containing a 150 Ω rheostat, a 300 Ω resistor, a 12 V power supply, a 2.00 Ω ammeter, and enough wires to connect any circuit. They have to connect a circuit that lets the rheostat control the greatest possible range of current through the apparatus.
[a] Heath builds circuit A. What is the least and greatest current he can achieve?
[b] Jenni builds circuit B. What is the least and greatest current she can achieve?
[c] Shani builds circuit C. What is the least and greatest current she can achieve?
[d] Which circuit (A, B or C) gave the greatest range of current?



Circuit A



Circuit B



Circuit C

17.7 A client describes for you a circuit over the phone. 'A six ohm resistor is in series with a parallel combination of a ten ohm resistor and a fifteen ohm resistor. The whole three-resistor combination connects across a six volt supply. A voltmeter measures the potential difference across the smallest resistor and an ammeter measures the current through the largest resistor.'
[a] Draw the circuit.
[b] What readings should the voltmeter give?
[c] What readings should the ammeter give?

17.8 A technician connects three resistors of 4.0 Ω, 8.0 Ω and 40.0 Ω in parallel. He measures that the 4.0 Ω resistor carries a 2.0 A current.
Calculate:
[a] the combined resistance of the three resistances.
[b] the potential difference across the parallel set of resistors.
[c] the current in the 8.0 Ω resistor.
[d] the current in the 40.0 Ω resistor.

17.9 You plug a table lamp (resistance 1440 Ω) and a standard lamp (resistance 960 Ω) into a power board.
[a] Are the appliances connected in series or in parallel?
[b] What is the total resistance you connected across the power board?
[c] What is the total current both lamps will draw from the power board?

17.10 A household power circuit is wired so that each appliance is in parallel. The mains voltage is 240 V.
[a] Find the total current flowing in the kitchen circuit if the following appliances are being used: a 600 W microwave oven, a 450 W toaster and a 1000 W electric kettle.
[b] Will the total current increase, decrease or remain the same if a 150 W coffee grinder is also switched on? Explain.

Continued over

Notes

Problem Solving and Calculations
Set 17: Parallel and Series Circuits

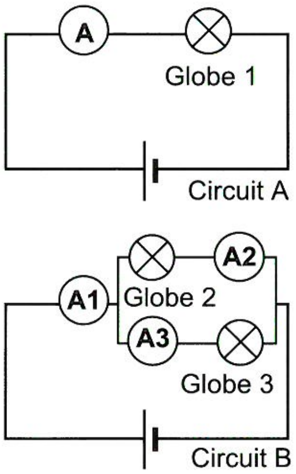


Diagram for Question 17.12

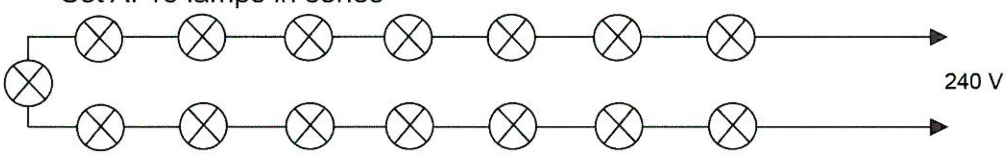
Notes

17.11 You are designing a new type of kettle. The kettle has two identical heating elements, each of 100 Ω resistance.
[a] What is the resistance of the kettle if the heating elements are connected in series?
[b] What is the resistance of the kettle if the heating elements are connected in parallel?
[c] If you wanted to boil water in your kettle in the shortest time, would you connect the heating resistors to the mains in series, or in parallel?
Explain the reasons for your choice.

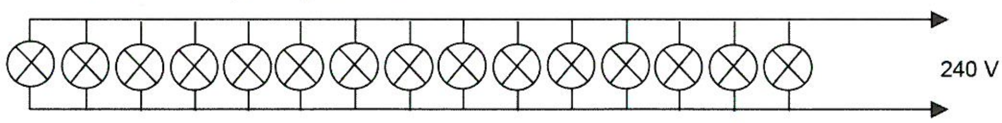
17.12 A student sets up circuit A as shown in the diagram (*left*) The ammeter in the circuit reads 6.00 A. She then uses two globes identical to the one in the above circuit to connect circuit B, as shown in the diagram. Assume the resistance of the ammeter is negligible
[a] How does the resistance of circuit A compare to the resistance of circuit B?
[b] What readings would she find on the three ammeters in circuit B?
[c] How would the intensity of globes 2 and 3 compare with each other and with globe 1 in circuit 1?

17.13 One way to make a set of fairy lights is to connect a number of 12 V lamps in parallel, and run the set from a 12 V transformer.
Alternatively, several low potential difference lamps may be connected in series until the combined potential difference across the lamps matches the power supply being used. For example, you could connect twenty 12 V lamps in series to a 240 V supply. This arrangement is shown in set A.
A third way is shown in set B below. Both set A and set B are made up of 15 lamps, and each set dissipates a total of 60 W. Thus each lamp in either set is rated at 4 W.

Set A: 15 lamps in series



Set B: 15 lamps in parallel



[a] After being connected to the 240 V supply, one lamp in each set burns out. Describe and explain the likely effect of this on the operation of each set of lights.
[b] Calculate the resistance of each of the lamps connected in series in set A.
[c] Calculate the resistance of each of the lamps connected in parallel in set B.
[d] The user wants to replace the burnt-out lamps. By mistake, the lamps are interchanged (that is, a lamp from set B is placed in set A, and a lamp from set A is placed in set B). Describe what is likely to happen when each set is turned on again, and explain your reasoning.

Notes

17.14 One power supply can be used to supply electricity to a number of devices. As long as they are all connected in parallel, they all experience the same potential difference (potential drop). In the car, all of the lights are wired in parallel. One switch connects headlights and tail lights simultaneously so that four globes all light up together. Thus, they are all 12 V globes.
A car has two 60 W headlights and two 10 W tail lights.
[a] Calculate the total power consumption of the four lamps.
[b] Use the total power to calculate the total resistance of the four lamps when connected in parallel.
[c] Calculate the individual resistances of the 60 W lamps.
[d] Calculate the individual resistances of the 10 W lamps.
[e] Calculate the current supplied by the car battery when the car is parked but the lights are left on.

Optional Question:

17.15 Since car batteries are constructed from materials that possess non-zero resistance, it follows that real batteries possess *internal resistance*. We can think of a real car battery as an emf source with a small internal resistance, r, connected in series with an external resistance, R. We can represent the circuit as a whole by the relationship $emf = I(r+R)$.
Hence, in order to understand fully any device in the car that is connected to the car battery, we need to understand that we always have a series circuit in which the resistance of the device being used is in series with the resistance of the power supply.
A typical car battery has an emf of 12 V, and must provide a current of 80 A to the starter motor.
[a] Why is the current the same through both the internal resistance and the external resistance?
[b] If the internal resistance is 0.050 Ω, calculate the potential difference across this internal resistance when the starter motor is running.
[c] Why must the car battery have a very low internal resistance?
[d] Why is starting the car with the headlights on likely to affect their brightness? Use a circuit diagram in your answer.

Investigation

Notes

Investigation 17.4: Internal resistance

Background

Every source of emf has its own internal resistance, which acts like a resistor permanently wired in series with the emf source. Ideally, this internal resistance should be as low as possible. Consequently the emf is distributed across the internal resistance of the emf source as well as the load. The potential drop across a load is always less than the emf of the power source. If the internal resistance is small relative to the resistance of the load then this effect is minimal but when the resistance of the load is closer in magnitude to the internal resistance of the source then the potential difference across the load may be too small. One effect of internal resistance is that the current passing through the emf source heats it up.

In this exercise you will devise a method to measure the internal resistance of some dry cells – both fresh and 'going flat'.

Apparatus (per group)

You will need at least:

- fresh and 'flat' dry-cell batteries of various types
- DC voltmeter and DC ammeter, or a multimeter
- rheostat
- switch
- connecting wires

Pre-Lab

The diagram (*p.173, right*) shows a circuit that you could use to measure the internal resistance of a cell. The voltmeter must have a very high resistance for this method to give accurate results.

When the switch is open, there is no current through the outside circuit, and *the reading on the voltmeter is the cell emf.* This is sometimes called the 'open circuit emf' of the cell and is usually given the symbol ε in equations.

When the switch is closed, the reading on the voltmeter drops slightly; the greater the current, the smaller the voltmeter reading becomes.

Mathematically, emf = (current)(external resistance) + (current)(internal resistance)

or, in symbols, $\varepsilon = IR_{ext} + IR_{int}$

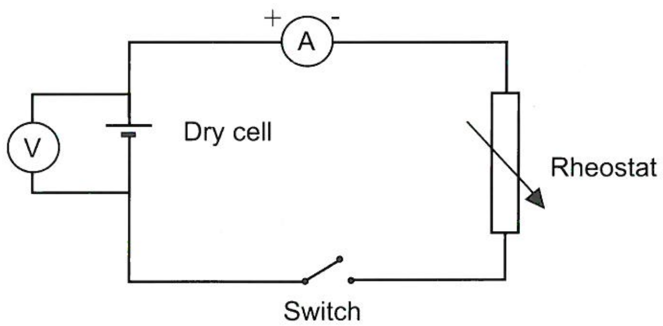
- When the switch is open, the voltmeter reading = ε.
- When the switch is closed, the voltmeter reading = IR_{ext}.

We can also write this as $\mathbf{V} = \varepsilon - \mathbf{Ir}$ where V is the measured potential difference in the external circuit, ε is the EMF of the battery and r is its internal resistance in ohms.

Notes

In order to measure the internal resistance of a cell, you may need to:

- Think of a way to measure the external resistance of the circuit. This should be fairly straightforward if you have access to a multimeter.
- Take a range of measurements of the internal resistance under various external load conditions. Is the internal resistance constant, or does it depend on the current or the external resistance?
- If your teacher or lab technician does not mind you running down the cell, disconnect the measuring instruments and the external circuit, and carefully 'short out' the cell for a few minutes. **Caution: the shorting wire and the cell may get hot enough to damage your skin**. When it is cool enough to handle safely, remeasure the internal resistance. What happens to the internal resistance as the cell approaches 'going flat'?



Apparatus for Investigation 17.4

Lab Notes

Use the circuit shown (*above*), and make a careful record of what you actually do.

Post-Lab Discussion

1. Use a graphical method to obtain emf and r from either slopes or intercepts of your raw or manipulated data. How do these values compare with the values you obtained by direct measurement?

2. How do the emf and internal resistance of a flat dry cell compare with those of a *fresh* dry cell?

3. How does the internal resistance of an alkaline battery compare with that of a heavy-duty battery of the same size and shape?

4. The battery in a torch has been used for a long time. Explain why the torch is dim even though the emf of each cell is the same as when they were first bought.

5. Does a power pack have internal resistance? Explain your answer.

Chapter 18: Circuits and Safety Explained

Notes

Safety Principles

Most electrical fatalities happen in domestic situations. Of those deaths, most are caused by equipment people have connected to power outlets.

The tables below support the view that Residual Current Devices, known as RCDs, should help to reduce electrical fatalities.

Type	Reported Accidents	RCD Preventable
Domestic 240/415V	150	134
Other 240/415V	123	49
High Voltage	76	0
Total	349	183

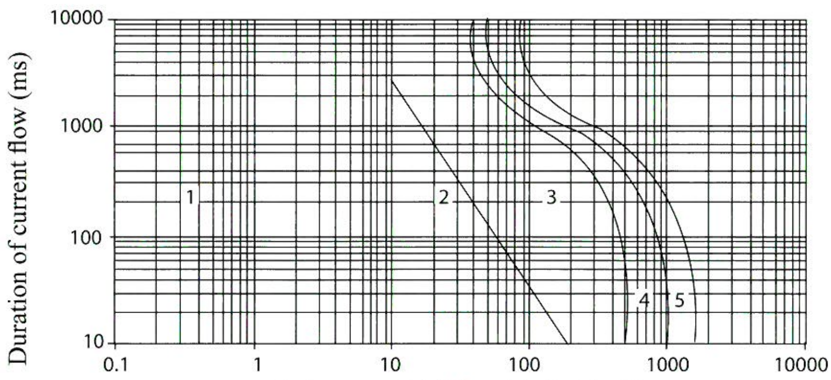
Circuit Type	Reported Accidents	RCD Preventable
Mains & Submains	12	6
Power-point wiring	19	16
Lighting wiring	13	11
Permanently wired equipment	4	4
Equipment connected to a powerpoint	102	97
Total	150	134

Electrical fatality distribution; Australia and Papua New Guinea, 1983 to 1987

The two major dangers of electricity are thermal hazard and shock hazard. Thermal hazard results from the heat the current generates as it passes through your body's electrical resistance. It is the major problem in high potential difference electrocutions. Shock hazard results from the outside current swamping the small electrical currents that normally control your body through your nervous system.

The main problem is that if the current is large enough and lasts long enough it will cause fibrillation in the victim's heart. A fibrillating heart starts to twitch rapidly, instead of contracting rhythmically. A fibrillating heart does not have enough time to fill between each twitch. This means that the heart will not pump any blood. Fibrillation is difficult to treat without specialist equipment. In most accident situations, it leads to the victim's death.

The following graph allows you to determine the current and duration of a shock that will cause fibrillation. Remember that the graph shows average response. This means that half of all humans need less current, or shorter duration, to suffer from fibrillation!



The psychological effects of different ranges of time-current

Zone	Effect
1.	Usually no reaction
2.	Sensation but usually no harmful physiological effects
3.	Likelihood of cramp-like muscular contractions and difficulty in breathing if the current lasts over 2 s. Reversible heart disturbances
4.	Zone 3 effects and probability of fibrillation up to 5%
5.	Zone 3 effects and probability of fibrillation over 50%
6.	Cardiac arrest, breathing arrest and heavy burns.

The current, and the time for which it acts, are sometimes referred to as 'time-current'. Direct current produces biological effects similar to AC current, but the least DC time-current that will cause biological problems is greater than the corresponding AC time-current.

The effects of electric currents through your body are even more severe if you make electrical contact at a point where you have broken skin. Hospital staff take special precautions when they use electrodes, pacemakers and other metal probes. Such treatments channel the current to internal tissues and make patients micro-shock sensitive.

Problem Solving and Calculations
Set 18: Circuits and Safety

Notes

18.1 Name and describe the function of each conductor in a three-wire domestic general power outlet (three-pin socket).

18.2 The severity of an electrical shock depends on the **current** passing through a person. Why is it impossible to say which **potential differences** are dangerous?

18.3 How many 40 W light globes can you operate on a 240 V circuit protected by a 15 A circuit-breaker?

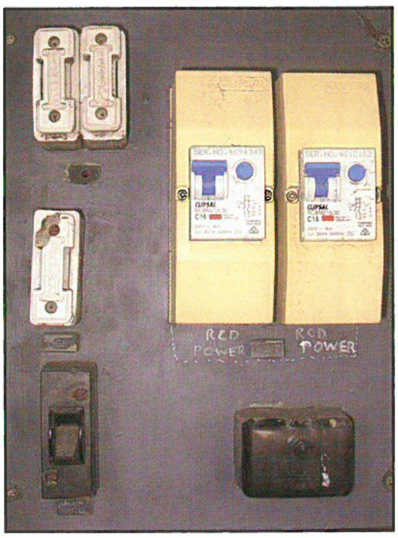
18.4 A car with a 12.0 V electrical system has 2.40 Ω headlights. If you need to protect a single headlight circuit with a fuse, calculate the minimum current rating for such a fuse.

18.5 Explain why:
[a] a short circuit is a thermal hazard instead of a shock hazard.
[b] alternating current is more dangerous than direct current at the same voltage.
[c] doubly insulated appliances reduce the need for a three wire system.

18.6 You plug a 1200 W heater into a 240 V general power outlet.
[a] What current will that heater draw?
[b] Could you plug two such heaters in an outlet protected by a 15 A circuit-breaker? Explain.

18.7 Should you operate a 1000 W iron, a 2400 W clothes drier and a 2000 W washing machine from the same 15 A 240 V power point? Explain.

18.8 When electricity utilities install an electricity supply to a customer they sometimes install a fuse at the start of the line. If the wires to a customer's property have a larger than normal resistance, should the installers use a fuse with larger or smaller current rating?



House fuse-box

18.9 What role, if any, do circuit-breakers, fuses and residual current devices play in preventing shock hazards?

18.10 The fuse in the lighting circuits of a house will break the circuit if the total current exceeds 10 A and the fuse for the power points will break those circuits if the total current exceeds 15 A.
[a] How many 100 W light globes can be placed into one lighting circuit before the fuse will 'blow'?
[b] A 1800 W vacuum cleaner and a 2400 W clothes drier are used simultaneously on two sockets in the same power circuit. Will the fuse 'blow'? Explain.
[c] In the above two circumstances, what is the purpose of the fuse?
[d] Explain why it is very silly to replace a blown fuse with a piece of thick copper wire.
[e] The fuse will always blow in the event of a short circuit. It is often claimed that this may prevent electrocution. Explain the circumstances under which a fuse might prevent electrocution.

Problem Solving and Calculations Set 18: Circuits and Safety 18

Notes

8.11 Alec wants to connect several devices to one 240 V power board for a party. The devices are a 35 Ω heater, a 110 Ω lamp, a 750 Ω CD player, a 640 Ω cassette player, and a 350 Ω amplifier. The power board has an overload protection device that switches the board off when the total current exceeds 10 A. Will Alec's circuit work?

18.12 Andrew foolishly uses a metal-handled knife to remove a burning slice of bread from his toaster. The knife touches the toaster element, which carries 240 V AC. Fortunately for him, a residual current device (RCD), also known as a 'safety switch', is installed in his home. His body resistance would allow 40 mA of current to pass through him to the earth. This is enough current to trip the RCD, which switches off all power in his house.
[a] What was the total resistance of Andrew's body, shoes and floor?
[b] If the current was 1.50 A in the active line, what would the 'return current' in the neutral line be for the RCD to detect the difference?

18.13 It is common practice in commercial installations to have a separate circuit for a refrigerator so no other appliance can trip the circuit-breaker and shut off the fridge. However, Jill turns on a 1.5 kW griller on the same circuit at the same time as a fridge that draws 10.0 A when it starts. A 15.0 A circuit-breaker protects the fridge circuit.
[a] Calculate the current drawn by the griller.
[b] What is the resistance of the fridge as it starts up?
[c] Will the circuit breaker be activated when the fridge starts up?

18.14 Some school laboratories have EHT (Extra High Tension) power packs that can give up to 3000 V. For safety, they are provided with a 50 MΩ resistor in series with the supply.
[a] What is the maximum current able to be supplied by this power pack?
[b] Estimate the potential difference there would be across a 3 V, 500 mA torch bulb connected across such a supply.
[c] Explain how the 50 MΩ resistor acts as a safety device.

18.15 John is barefoot on a wet laundry floor. His right hand accidentally touches a frayed live 240 V AC wire. John's body has a resistance of 4400 Ω to ground. He has not protected his house with a residual current device (RCD).
[a] What current will flow through him?
Carmen tries to rescue John without first switching off the power. She grabs his left wrist. Carmen has a resistance of 8000 Ω and the resistance of John's body between the wire and his left wrist is 400 Ω.
[b] Does the current through John's heart increase, decrease or stay the same?
[c] What current will flow through Carmen?
[d] What should Carmen have done?
[e] Explain why the fuse in the house circuit was no protection against electrocution.

Investigations 18

Notes

Investigation 18.3: RCDs and circuit breakers

There are a number of safety issues associated with the use of electrical energy. The most significant of them are electrocution and fires. Residual current devices have recently become compulsory in all new buildings and are probably responsible for saving many people each year in Australia from electric shock, burns or even death. Circuit breakers, in the form of fuses, have been required in all electrical installations in buildings for a hundred years. They have saved thousands of buildings from burning down and possibly saved many from electrocution.

The Task

1. Find out how fuses work.
2. Find out how circuit breakers work.
3. Find out how RCDs work.
4. Discover and discuss the purpose of each of these devices.
5. Prepare a report on the purpose and the physics behind the operation of these safety devices.

Investigation 18.4: Careers with physics

Where can a degree with a major in physics get you? Many science teachers and university lecturers have physics degrees. Many research scientists have degrees with a major in physics. You might be surprised to discover that industrial companies employ physicists because a background in physics gives people excellent problem solving skills. Government departments also employ Physics graduates for their analytical and problem solving skills. Even in areas such as foreign affairs, diplomacy and trade relations, science graduates are sought after for their analytical skills and their ability to rapidly assimilate quantitative information.

The Task

1. Identify one physics graduate in an industry other than secondary education, tertiary education, or fundamental research and make contact with him or her.
2. Create a set of interview questions that they would be able to answer by email. Find out as much as you can about their work and their career history, without invading their privacy or asking impertinent questions.
3. Further research the area in which they work and gain a good understanding of the science concepts associated with their work.
4. Create an A2 poster about this aspect of their work and include in the poster information about the qualifications needed to work in that professional field.

Brief Answers to Problems

Numerical and Brief Answers

Set 1

1.1 [a] 26.8 m s^{-1} [b] 96.5 km h^{-1}
1.2 [a] 110 km h^{-1}
1.3 3.0 x 10^{3} km
1.4 [a] 15.0 km east [b] 30 km h^{-1} east
1.5 5.0 km west
1.6 16.7 h
1.7 9.5 h
1.10 [a] 3.2 km [b] 2.7 m s^{-1} [c] 2 km north [d] 1.7 m s^{-1} north
1.11 15 minutes
1.12 [a] 0.67 m s^{-1} [b] 3 33 m s^{-1} [c] 4 2 h [d] 23 minutes
1.13 [a] D to E [b] B to C [c] D [d] 30 km [e] 37.5 km h^{-1} [f] direction of travel
1.14 [a] 1.5m s^{-1} [b] 56 minutes

Set 2

2.1 [a] 32 m s^{-1} [b] 24.4 km [c] 115 km h^{-1} [d] 30.3 m s^{-1}
2.3 [a] 3.53 m s^{-2} [b] 4.72 m s^{-2}
2.4 [a] 114 m s^{-1} upwards [b] its initial velocity
2.5 [a] 250 s [b] 25 s [c] 200 s [e] 5.6 x 10^{3} m
2.6 32 m
2.7 [a] 1.11 m s^{-2} [b] 8.6 s
2.8 all equal (9.8 m s^{-2} downwards)
2.9 [a] 38.4 m s^{-1} [b] 5.90 s
2.10 [a] 16.7 m s^{-1} [b] 8.35 m [c] -3.70 m s^{-2} [d] 37.7 m [e] 45.8 m [f] braking time = 4.13 s; stopping time = 4.63 s; stopping distance = 39.3 m [g] 1.39 m s^{-1}
2.12 [a] 10 m s^{-2} [b] 25 m s^{-1} [c] it was dropped from a rest position
2.13 [a] 24.5 m s^{-1} up [b] 24.5 m s^{-1} down
2.14 [a] 15 m s^{-1} [c] 109 m
2.15 [b] 2.9 x 10^{2} m
2.16 33.1 s

Set 3

3.4 7.5 N kg^{-1}
3.5 [a] equal [b] $F_{w(Earth)}$ = 2.63 times greater than $F_{w(Mars)}$ [c] equal, F = 80 N [d] yes
3.6 [a] 5.1 m s^{-1} upwards [b] 34.0 m s^{-2} upwards [c] 17 N upwards
3.7 65 N in opposite direction to motion
3.8 9.5 m s^{-1} east
3.9 [a] forces are same size [b] the small car
3.10 [a] (i) accelerating upwards at 0.98 m s^{-2} (no information about velocity)
(ii) stationary or moving at constant speed up or down
(iii) accelerating downwards at 0.49 m s^{-2} (no information about velocity)
[b] (i) 58.2 kg (ii) 50.0 kg (iii) 43.4 kg (iv)58.2 kg
3.11 [a] 1715 N upwards [b] 1978 N upwards [c] 1715 N upwards [d] 1190 N upwards
3.13 [a] 743 N [b] 222 N [c] 0.244 m s^{-2} [d] 94 N [e] 1.0 m s^{-2}
3.15 Tension in rope between truck and first car = 3480 N
Tension in rope between first and second car = 1740 N

Set 4

4.1 608 kg m s^{-1} north
4.2 2.2 x 10^{4} kg m s^{-1} west
4.3 [a] 0.107 m s^{-1} south [b] 16.0 m s^{-1} south
4.4 [a] 6.3 N s in direction of the bat's velocity [b] 0.50 kg m s^{-1} away from the cushion
[c] 5.05 x 10^{5} kg m s^{-1} north east [d] 600 N s east
4.5 15.0 N
4.6 8.4 m s^{-1} in the original direction of motion
4.7 [a] 1.05 kg m s^{-1} towards Sam [b] 1 05 kg m s^{-1} towards Max
4.8 [a] 16.4 m s^{-1} in the original direction of motion [b] 18.0 m s^{-1} in the original direction of motion
4.11 [a] 1.2 N
4.12 [a] 19.8 m s^{-1} [b] -6.53 x 10^{3} m s^{-2} [c] -9800 N [d] 3.03 ms [e] 29.7 N s [e] 29.7 kg m s^{-1}
4.14 766 m s^{-1} in the original direction of motion
4.15 [a] 750 kg m s^{-1} in the direction of motion [b] zero [c] zero [d] 0.15 m s^{-1} in the opposite direction to the shell
4.17 8.8 m s^{-1} in original direction

Brief Answers to Problems

4.18 3.00 m s^{-1} west
4.19 1.11 m s^{-1} in the original direction of motion
4.20 14.1 kg m s^{-1}
4.21 [a] Walter's ball: 0.60 m s^{-1} in its original direction; Linda's ball: 1.20 m s^{-1} in the opposite to its original direction of motion
[b] Walter's ball: 3.00 m s^{-1} in the opposite to its original direction of motion; Linda's ball: 6.00 m s^{-1} in its original direction
4 22 2.4 m s^{-1}

Set 5

5.1 287 J
5.2 29.4 kJ
5.3 [a] 16.0 J [b] 236 J
5.4 [a] 2.16 MJ
5.5 [a] 324 kJ [b] 6750 N in the opposite direction to its motion
5.6 [a] 16 J [b] 6.6 J [c] 45 J [d] 3.08 MJ [e] 420 J
5.7 33.5 J
5.8 [a] 216 J [b] 125 N upwards [c] 40.0 m
5.9 0.800 m
5.10 120 N
5.11 980 kJ
5.12 [a] 417 W [b] 62.0 W [c] 59.2 W [d] 150 W
5.15 [a] 14.0m s^{-1}
5.16 [a] 4390 W [b] 0.163 m s^{-1}
5.17 22.8 kJ
5.18 [a] 157 kJ [b] 31 4 kJ [c] 31 3 m s^{-1}
5.19 [a] 300 W [b] 150 W [c] 66.7 W
5.20 8,58 x 10^{11} J
5.21 [a] 152 J [b] 90.0 J [c] 62.2 J [d] 5.18 N up the ramp
5.22 [a] 31.7 kJ [b] 15.0 kW
5.23 764 J

Set 6

6.1 [a] 8 protons, 9 neutrons, oxygen [b] 19 protons, 21 neutrons, potassium
[c] 92 protons, 142 neutrons, uranium [d] 95 protons, 146 neutrons, americium
6.2 [a] ${}^{1}_{1}H$ or ${}^{1}_{1}p$ [b] ${}^{239}_{94}Pu$ [c] ${}^{0}_{1}e$ (positron) [d] ${}^{131}_{53}I$ [e] ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$
6.3 [a] ${}^{10}_{5}B+{}^{1}_{0}n \rightarrow {}^{4}_{2}He+{}^{7}_{3}Li$ [b] lithium
6.4 ${}^{234}_{92}U \rightarrow {}^{4}_{2}He+{}^{230}_{90}Th$
6.5 ${}^{42}_{19}K \rightarrow {}^{0}_{1}e+{}^{42}_{20}Ca$
6.6 ${}^{141}_{56}Ba \rightarrow {}^{0}_{1}e+{}^{141}_{55}Cs$
6.7 ${}^{131}_{53}I \rightarrow {}^{0}_{1}e+{}^{131}_{54}Xe$
6.8 ${}^{99}_{42}Mo \rightarrow {}^{0}_{1}e+{}^{99m}_{43}Tc$
6.9 ${}^{222}_{86}Rn \rightarrow {}^{4}_{2}He+{}^{218}_{84}Po$
6.10 [a] ${}^{2}_{1}H+{}^{3}_{1}H \rightarrow {}^{4}_{2}He+{}^{1}_{0}n$ [b] neutron
6.11 neutron
6.12 ${}^{239}_{94}Pu \rightarrow {}^{4}_{2}He+{}^{235}_{92}U$; ${}^{235}_{92}U \rightarrow {}^{4}_{2}He+{}^{231}_{90}Th$; ${}^{231}_{90}Th \rightarrow {}^{0}_{1}e+{}^{231}_{91}Pa$
6.13 ${}^{232}_{90}Th \rightarrow {}^{4}_{2}He+{}^{228}_{88}Ra$; ${}^{228}_{88}Ra \rightarrow {}^{0}_{1}e+{}^{228}_{89}Ac$; ${}^{228}_{89}Ac \rightarrow {}^{0}_{1}e+{}^{228}_{90}Th$; ${}^{228}_{90}Th \rightarrow {}^{4}_{2}He+{}^{224}_{88}Ra$;
${}^{224}_{88}Ra \rightarrow {}^{4}_{2}He+{}^{220}_{86}Rn$
6.14 ${}^{1}_{0}n+{}^{235}_{92}U \rightarrow {}^{141}_{56}Ba+{}^{92}_{36}Kr+{}^{3}_{0}x$ so x must be three neutrons
6.15 [a] ${}^{1}_{0}n+{}^{235}_{92}U \rightarrow {}^{134}_{51}Sb+{}^{95}_{39}Y+3{}^{1}_{0}n+{}^{4}_{2}x$ [b] x must be an alpha
6.16 ${}^{238}_{92}U+{}^{1}_{0}n \rightarrow {}^{239}_{92}U$; ${}^{239}_{92}U \rightarrow {}^{0}_{1}e+{}^{239}_{93}Np$; ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu+{}^{0}_{1}e$
6.17 the emitted particle can only be a neutron, so the equation must be ${}^{4}_{2}\alpha+{}^{11}_{5}B \rightarrow {}^{14}_{7}N+{}^{1}_{0}n$

Set 7

7.1 [a] 22 hours [b] 50% [c] 75%
7.2 [a] 6 hours [b] about 48 hours

Brief Answers to Problems

7.3 120 years

7.4 300 kBq

7.5 [a] 37.5 minutes

7.6 [a] 3.2×10^6 Bq [b] 2×10^5 Bq

7.7 [a] 5×10^{23} atoms [b] $^{239}_{94}Pu \to ^{4}_{2}He + ^{235}_{92}U$

7.8 [a] 26.8 GBq [b] 53 years

7.9 sample X

7.10 [a] 1.33 MBq [b] $^{198}_{79}Au \to ^{0}_{1}e + ^{198}_{80}Hg$

7.12 17 200 years ago

7.13 [a] 18 minutes [b] beta

7.14 [a] $^{24}_{12}Mg + ^{1}_{0}n \to ^{24}_{11}Na + ^{1}_{1}H$ or $^{1}_{1}p$; $^{24}_{11}Na \to ^{24}_{12}Mg + ^{0}_{1}e +$ [b] 50 h

7.15 [a] 120 Bq

7.16 125 years

7.17 [a] about 11 000 years

Set 8

8.1 about 1 u

8.2 [a] $^{0}_{0} \to ^{0}_{1}e + ^{0}_{+1}e$ [b] 1.64×10^{-13} J

8.3 7.39 MeV $nucleon^{-1}$

8.4 B

8.5 [a] total BE = 37.7 MeV; BE $nucleon^{-1}$ = 5.38 MeV $nucleon^{-1}$

[b] total BE = 1082.4 MeV; BE $nucleon^{-1}$ = 8.26 MeV $nucleon^{-1}$

8.6 tritium

8.7 carbon-12

8.8 [a] positron [b] 3.50×10^{-30} kg [c] 1.97 MeV

8.9 [a] 0.0183 u [b] 17.1 MeV

8.10 4.29 MeV

8.11 [a] $^{235}_{92}U + ^{1}_{0}n \to ^{142}_{54}Xe + ^{90}_{38}Sr + 4^{1}_{0}n$ [b] 169 MeV

8.13 [a] $^{235}_{92}U + ^{1}_{0}n \to ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$ [b] 174 MeV [c] 3.90×10^{-25} kg [d] 2.56×10^{24} atoms

[e] 7.1×10^{13} J [f] 1.37 kg

8.14 [a] $^{1}_{1}H + ^{2}_{1}H \to ^{3}_{2}He$ [b] 5.00 MeV [c] 2.99×10^{26} atoms [d] 2.39×10^{14} J

8.15 1.65 MeV

8.16 [a] $^{14}_{7}N + ^{1}_{0}n \to ^{14}_{6}C + ^{1}_{1}p$ [b] 2.04×10^{-30} kg decrease [c] 1.15 MeV [d] 1.48×10^{7} m s^{-1}

Set 9

9.6 0.72 Sv

9.8 [a] 0.206 Gy [b] 4.12 Sv [c] yes

9.9 0.070 mJ y^{-1}

9.12 [a] 0.447 Gy [b] 0.447 Sv [c] no

9.13 [a] $^{198}_{79}Au \to ^{198}_{80}Hg + ^{0}_{-1}e$ [b] 0.865 MeV

9.14 [a] 2.0×10^{-5} J s^{-1} [b] 0.029 Gy day^{-1} [c] 0.029 Sv day^{-1} [d] 50% chance of living 6 months

9.17 [a] 121 days per year

Set 10

10.2 21.8%

10.4 [a] 60%

10.11 6912 tonnes

Set 12

12.3 38.4 MJ

12.4 148 kJ

12.5 21.2 °C

12.6 315 kJ

12.7 450 J kg^{-1} K^{-1}

12.8 25.0 °C

12.9 50.6 kJ

12.10 3.80×10^3 J kg^{-1} K^{-1}

12.15 8.76 kg

12.16 2.23 kg

12.19 60 kJ

12.20 3.48×10^3 J kg^{-1} K^{-1}

Brief Answers to Problems

12.21 74.8 °C
12.22 3.86×10^{-2} °C
12.23 1.14 MJ
12.24 44.3 kg
12.25 88.5 °C

Set 13

13.1 [a] 9.55×10^{6} J [b] 9.56×10^{5} J [c] 1.08×10^{4} J
13.2 8.89×10^{4} J kg^{-1}
13.3 908 g
13.9 [a] 9.68 MJ [b] 50.3 °C
13.10 [a] 176 m
13.11 [a] 578 J [b] 1.38×10^{3} J [c] 2.18×10^{3} J [d] 4.14×10^{3} J
13.12 [a] 80 s [b] 590 s [c] 670 s
13.13 127 J s^{-1}
13.15 1.72×10^{4} J s^{-1}
13.16 [a] 452 J kg^{-1} K^{-1} [b] 21.5 kg
13.17 [a] 9.21 kJ
13.18 [a] 432 g [b] 383 g
13.19 41.4 g
13.20 254 g

Set 14

14.3 [a] 1.6×10^{-16} C [b] 2.30×10^{-12} N attraction
14.4 yes, the charge released exceeds 0.7 pC
14.6 2.00 mA
14.7 [a] 2.88×10^{4} C [b] 1.8×10^{23}
14.8 [a] 360 C [b] 86.4 kJ
14.10 [a] 5.96×10^{-9} C
14.11 [a] +ve [b] 2×10^{-3} N [d] 40 [e] 9.22×10^{-22} N
14.12 [a] if d=1 km, V = 10^{9} V [c] 7.8×10^{8} J [d] 0.78 C [e] 15.6 kA

Set 15

15.1 [a] 5.00 A [b] 48.0 Ω
15.2 [a] 12.0 V [b] 24.0 Ω
15.3 576 Ω
15.4 [a] 2.88×10^{4} J [b] 24.0 W [c] 2.40×10^{3} C
15.5 [a] house [b] 13.8 kΩ
15.6 [a] batteries or transformer[b] 15.9 Ω
15.7 [a] 4.6 A[b] 2.6 Ω
15.8 [a] $1.05 [b] 19c [c] $1.25 [d] 1.8c
15.9 [a] 78c [b] $1.15 [c] 12.5c
15.11 [a] 0.625 A [b] 384 Ω [c] 2.70×10^{4} J [d] 9.8c
15.12 [a] 513 hot days [b] 6 years
15.13 [a] 1.73 MJ [b] 8.2 h
15.14 64.5 min

Set 16

16.1 [a] 21.3Ω [b] 23.3 μA [c] 28.3 mA
16.2 56.0 V
16.3 28.0 Ω
16.4 1.50 V
16.5 [c] 24.0 Ω [d] 2.40 kW
16.6 [a] 0.65 Ω [b] 652 mV
16.7 [a] 0-6 A [b] 0.67 Ω
16.9 [c] 343 Ω

Set 17

17.2 360 Ω
17.3 [a] 24.0 V [b] 0.400 A [c] 6.67 Ω [d] brighter
17.4 5.00 Ω
17.5 [a] 4.00 Ω [b] 4.50 A [c] both closed [d] 11.7 kJ
17.6 [a] 26.5-39.7 mA [b] 26.5-39.7 mA [c] 118 mA-6.00 A [d] C
17.7 [b] 3.0 V [c] 200 mA
17.8 [a] 2.5 Ω [b] 8.0 V [c] 1.0 A [d] 200 mA
17.9 [a] parallel [b] 576 Ω [c] 0.417 A

17.10 [a] 8.55 A [b] increase
17.11 [a] 200 Ω [b] 50 Ω [c] parallel
17.12 [a] double [b] A_1 = 12.0 A, A_2 = 6.0 A, A_3 = 6.0 A [c] all the same
17.13 [b] 64 Ω [c] 14.4 kΩ
17.14 [a] 140 W [b] 1.03 Ω [c] 2.40 Ω [d] 14.4 Ω [e] 11.7 A
17.15 [b] 4.0 V

Set 18

18.3 90
18.4 5 A
18.6 [a] 5.00 A [b] yes
18.7 no
18.10 [a] 24 [b] yes
18.11 no
18.12 [a] 6 0 kΩ [b] 1.46 A
18.13 [a] 6.25 A [b] 24.0 Ω [c] yes
18.14 [a] 60 μA
18.15 [a] 54.5 mA [b] increase [c] 28.6 mA

Formulae

Forces and motion

Mean velocity	$v_{av} = \frac{s}{t} = \frac{v+u}{2}$
Equations of motion	$a = \frac{v-u}{t}$; $s = ut + \frac{1}{2}at^2$; $v^2 = u^2 + 2as$; $v = u + at$
Force	$F = ma$
Weight force	$F = mg$
Momentum	$p = mv$; $\Sigma p_{before} = \Sigma p_{after}$
Change in momentum (impulse)	$Ft = mv - mu$
Kinetic energy	$E_k = \frac{1}{2}mv^2$
Gravitational potential energy	$E_p = mgh$
Work done	$W = Fs = \Delta E$
Power	$P = \frac{W}{t} = \frac{\Delta E}{t} = Fv_{av}$

Note: the variable "t" refers to the "time taken" sometimes referred to as the "change in time" or Δt

Particles

Activity	$A = \frac{\Delta N}{t}$
Half-life	$A = A_0(½)^n$
Absorbed radiation dose	absorbed dose $= \frac{E}{m}$
Dose equivalent	dose equivalent = absorbed dose × quality factor
Mass-energy relationship	$E = mc^2$
Change of temperature	$Q = mc\Delta T$
Change of state	$Q = mL$
Absolute zero of temperature	0 K = −273 °C

Electricity and magnetism

Electric current	$I = \frac{q}{t}$
Work and energy	$W = Vq = VIt$
Ohm's law	$V = IR$
Resistances in series	$R_T = R_1 + R_2 + \ldots$
Resistances in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
Power	$P = VI = I^2R = \frac{V^2}{R}$

Constants

Physical constants

Speed of light in vacuum or air	c	$= 3.00 \times 10^{8}$ m s^{-1}
Electron charge	e	$= -1.60 \times 10^{-19}$ C
Electron volt	1 eV	$= 1.60 \times 10^{-19}$ J
Unified atomic mass unit	1 u	$= 1.66 \times 10^{-27}$ kg
Mass of electron	m_e	$= 9.11 \times 10^{-31}$ kg
Mass of proton	m_p	$= 1.67 \times 10^{-27}$ kg
Mass of neutron	m_n	$= 1.68 \times 10^{-27}$ kg
Mass of alpha	m_α	$= 6.65 \times 10^{-27}$ kg
Mass–energy equivalent	1 u	= 931 MeV
Tonne	1 tonne	$= 10^{3}$ kg $= 10^{6}$ g

Physical data

Mean acceleration due to gravity on Earth	g	$= 9.80$ m s^{-2}
Specific heat capacity of water	c_w	$= 4.18 \times 10^{3}$ J kg^{-1} K^{-1}
Specific heat capacity of ice	c_i	$= 2.10 \times 10^{3}$ J kg^{-1} K^{-1}
Specific heat capacity of steam	c_s	$= 2.00 \times 10^{3}$ J kg^{-1} K^{-1}
Latent heat of fusion for H_2O	L_f	$= 3.34 \times 10^{5}$ J kg^{-1}
Latent heat of vaporisation for H_2O	L_v	$= 2.26 \times 10^{6}$ J kg^{-1}

Quality factors

Approximate quality factor for alpha radiation	QF_α	= 20
Approximate quality factor for beta radiation	QF_β	= 1
Approximate quality factor for gamma radiation	QF_γ	= 1
Approximate quality factor for slow neutrons	QF_{sn}	= 3
Approximate quality factor for fast neutrons	QF_{fn}	= 10

Prefixes of the metric system

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p

Exploring Physics Stage 3 specifically supports the new Western Australian Physics Syllabus and is well suited for other senior Physics courses taking a contextual approach.

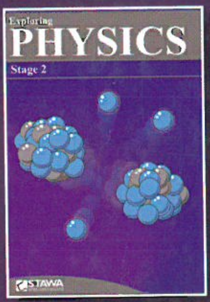
Exploring Physics Stage 3 is organised around the four main areas of content of units 3A & 3B:

- **Motion and Forces in a Gravitational Field;**
- **Electricity and Magnetism;**
- **Particles, Waves and Quanta; and**
- **Motion and Forces in Electric and Magnetic Fields.**

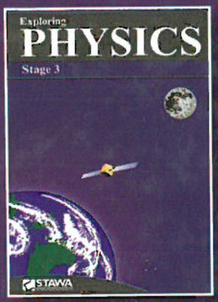
To help navigate around the book, each content area is highlighted in a different colour.

Introductory contexts	Each content area has two introductory context passages. These context passages describe how the Physics ideas that follow can be seen in the world around you.
Comprehension exercises	Each context passage is accompanied by a set of questions that are keyed to the chapters that follow. These questions can be used: • before the teaching and learning of the content, to see how much of the Physics is already known; or alternatively, • to test the main ideas after they have been studied.
Explanations	Sections contain several chapters, each with a short summary of key concepts, equations and techniques.
Laboratory experiments	Each chapter is accompanied by one or more laboratory experiments designed to build practical skills and understanding. Many of these experiments can be adapted to use probes, data loggers and computers to gather and process data with a high degree of precision.
Investigations	Most chapters are also accompanied by one or more investigations. Usually, these are practical exercises or experiments requiring that students make decisions about: • experimental methods; • equipment; and • the way data is to be processed.
Problems	Each chapter is accompanied by a set of problems designed to test student understanding of the main ideas. The problems are a mix of: • numerical exercises that require calculated answers; and • conceptual problems requiring written descriptions and explanations of physical phenomena; or • predictions of what will happen in a particular situation. Brief and numerical answers are provided at the back of the book.

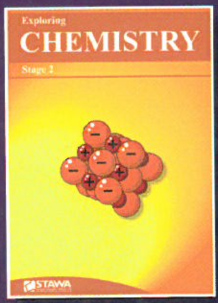
9 780980 370324



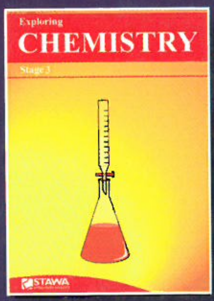
Exploring Physics Stage 2



Exploring Physics Stage 3



Exploring Chemistry Stage 2



Exploring Chemistry Stage 3