PHYSICS

Exploring Physics Year 11 – Experiments, Investigations & Problems

SECOND EDITION

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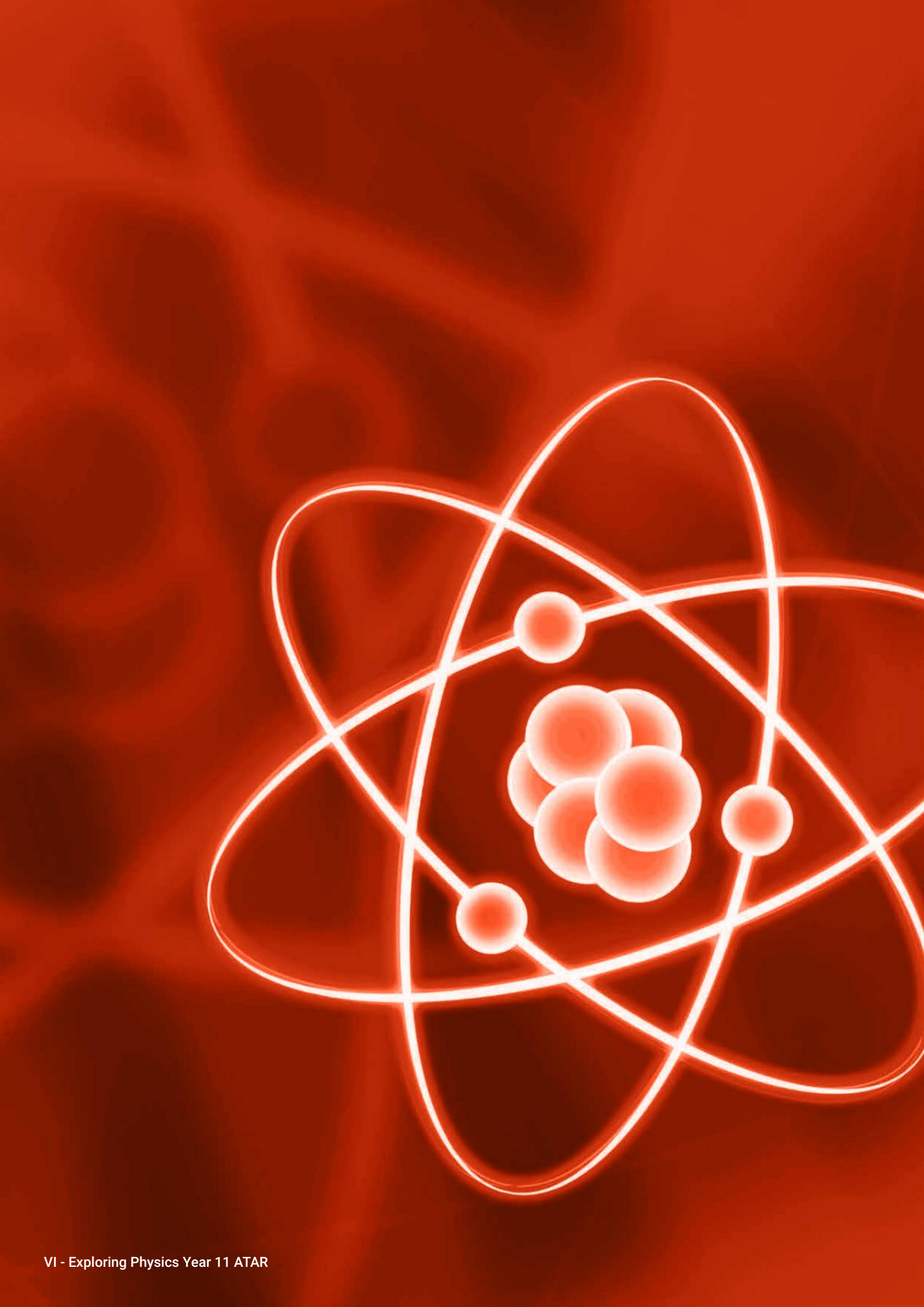


Chapter 1 – How to use this book

1

Content organisers

Exploring Physics Year 11 covers the two units in the WA syllabus as shown in the contents. Each content area is highlighted in a different colour to help you to find your way around the book.

Explanations of major ideas

Each chapter begins with a short summary of key concepts, equations and techniques.

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.

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.

Comprehension

Some content areas have a comprehension activity. Each describes how Physics ideas can be seen in the world around you. A set of questions accompanies each context passage. 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.

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.

S.I. units

Physics measurements are usually expressed in S.I. (Systeme Internationale) units. Units using peoples' names are not capitalised when written in full, e.g. becquerels, newtons, volts; but the symbols for these units are capitalised, e.g. Bq, N, V. Measurements are written with a space between the amount and the unit, and a space between parts of the unit, e.g. 9.80 m s^{-2}.

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 calculations, the final result should contain no more significant figures than the data with the least number of significant figures.

Scientific notation

Standard form ("powers-of-ten") is often used for very small numbers (< 0.01) and very large numbers (>1000). Scientific notation also removes any ambiguity in the number of significant figures.

For example, 0.000230 m is written as 2.30 x 10^{-4} m,; 54 500 m written as 5.45 x 10^{4} m removes the ambiguity, clarifying that the number has 3 significant figures.

Sometimes it's appropriate to use unit prefixes to represent powers of ten – these can be found in your data booklet. For example, the prefix kilo (k) represents a multiplication factor of 10^{3} so, a quantity such as 5000 m can be written as 5 x 10^{3} m or simply 5 km.

Exactness, accuracy, precision, uncertainty

The only exact measurements occur when we count whole numbers, e.g. the number of eggs in a carton. Every other measurement has some uncertainty in it, no matter what type of instrument is used. We try to minimise the level of uncertainty (i.e. maximise the accuracy).

Both the accuracy and precision of a measurement depends on the limits of the measuring device among other things. Precision refers to the fineness of an instrument's scale, such as the number of decimal places of a voltmeter. When considering the accuracy (closeness to the real-world value), the calibration of the instrument and the skill of the measurer matters. All of these factors affect the uncertainty of any measurement.

Source of Uncertainty	Technique to Lower Uncertainty
Skill of measurer	Use good scale reading techniques
Accuracy & Precision of measuring device	Use calibrated instruments with high precision
Random errors	Use repeated measurements and average them

Estimating the uncertainty

The uncertainty in a measurement is always expressed as a single digit, and cannot be exact - we are measuring the value, but estimating the uncertainty.

Method 1: When taking one measurement from an instrument, the uncertainty can be estimated as half of the smallest scale division. For example:

A set of scales which provide mass (m) in kilograms with 1 decimal point: Uncertainty: $\Delta m = 0.05kg$

A Newton meter which provides force (F) has lines marking every 10 Newtons: Uncertainty: $\Delta F = 5$ N

Method 2: From repeated measurements. For example, Jane measures the focal length of a lens six times and records the values:

41.4 cm, 40.8 cm, 41.3 cm, 40.6 cm, 37.0 cm, 40.9 cm.

Jane is confident that the value is somewhere in the range 40.6 - 41.4 cm. She discards the outlier (37.0 cm) and calculates the average value to be 41.0 cm. To show the uncertainty, she writes the measurement as 41.0 ± 0.4 cm.

Absolute and Percentage Uncertainties

Uncertainties can be represented as either absolute (given in the same units as the associated measurement) or as a percentage of the measurement.

The percentage uncertainty of a measurement is found by dividing the absolute uncertainty into the measurement itself.

For example, the time taken for an event to occur is measured to be 5.23 ± 0.3 s. The percentage uncertainty of this time is $0.3/5.23 \times 100 = 5.74\%$

Similarly, a digital force meter user manual states an uncertainty of 4% for all measurements, and the instrument yields a value of 65.0 N. This would mean the absolute uncertainty of this measurement is 0.04 x 65 = 2.6 N to give a final value of 65.0 ± 2.6 N

Propagating Uncertainties

When using measurements in calculations, the uncertainties associated with each measurement can be passed through the calculation. There are some rules that apply:

When multiplying or dividing (scaling) a measurement by a number, the uncertainty is multiplied or divided accordingly, to ensure the percentage uncertainty of that measurement remains the same.

$$\textit{If } A = xB, \textit{then } \Delta A = x\Delta B \quad \textit{or} \quad \textit{if } A = \frac{B}{x} \textit{ then } \Delta A = \frac{\Delta B}{x}$$

When adding or subtracting measurements, the associated absolute uncertainties must be added together:

$$\textit{If } A = B + C \textit{ or } A = B - C \qquad \Delta A = \Delta B + \Delta C$$

When multiplying or dividing measurements, the associated percentage uncertainties must be added together.

$$\textit{If } A = B \times C \textit{ or } A = \frac{B}{C} \qquad \Delta_{\%} A = \Delta_{\%} B + \Delta_{\%} C \quad \textit{or} \quad \frac{\Delta A}{A} = \frac{\Delta B}{B} + \frac{\Delta C}{C}$$

Example

Grant needs to measure the perimeter and area of a television. He measures the television to be 1.23 ± 0.02 m long and 0.540 ± 0.01 m wide.

The perimeter of the television can be given by:

Perimeter = 2L + 2W = (2 x 1.23) + (2 x 0.540) = 3.54 m

The absolute uncertainty of this value would be

$$\mathbf{2(0.02) + 2(0.01) = 0.06\ m}$$

So, the final value would be 3.54 ± 0.06 m

The area of the television can be given by

$$\mathbf{A = L \times W = 1.23 \times 0.540 = 0.664\ m^2}$$

The percentage uncertainty of this calculation would be

$$\Delta_{\%} A = \Delta_{\%} L + \Delta_{\%} W = \frac{0.02}{1.23} \times 100 + \frac{0.01}{0.54} \times 100 = 3.5\%$$

This means the absolute uncertainty would be 0.0023 m^2

So, the final value for the area of the television would be 0.664 ± 0.023 m^2

Questions

1. State the number of significant figures and then rewrite the following measurements in Scientific Notation.

Measurement	Significant Figures	Scientific Notation
540.2 m	4	5.402×10^2 m
0.0000042 J		
222.3 °C		
1400 kg		
41.213 km		
1300.2 m s^{-1}		

2. By using your data booklet, remove the unit prefixes of the following values and represent the values using Scientific Notation with the correct number of significant figures

Value	Prefixes Removed	Value	Prefix Removed
232 ms		300 nm	
10.0 km		20.3 GHz	
0.9 µSv		85.2 MN	

3. Estimate the uncertainty in the following scenarios:

Scenario	Final Measurement	Scenario	Final Measurement
Julie stands on a pair of digital scales that read "50.2 kg"	50.2 ± 0.05 kg	Timothy uses a set of callipers with 0.1 mm markings. He measures the width of a pencil to be 0.91 mm	
Erin takes 3 measurements of speed using a photogate: 30.4 m s^{-1}, 31.2 m s^{-1}, 33.0 m s^{-1}		Jamal uses a thermometer to measure temperature in °C	

4. Determine the percentage uncertainty for the following measurements:

20 ± 2 m _____**%** **180 ± 20 kg** _____**%**

5. Rewrite the following measurements with absolute uncertainty:

8 K ± 5.5% _____ **20.2 N ± 20%** _____

6. The radius of a hula hoop is measured to be 0.35±0.01 m.

(a) Determine the circumference of the hula hoop and the associated absolute uncertainty. (Circumference = πr^2)

Answer _____ ±_____m

(b) Determine the area of the hoop and the associated absolute uncertainty. (Area = πr^2)

Answer _____ ±_____m^2

7. Kade and his physics group set out to determine the speed of sound by recording a loud clap being made at a distance using a camera. They analyse the footage and determine the sound took 0.1367 ± 0.020 seconds to travel 50.0 ± 0.2 m. Using the formula for velocity (v=s/Δt), determine the speed of sound and the associated absolute uncertainty.

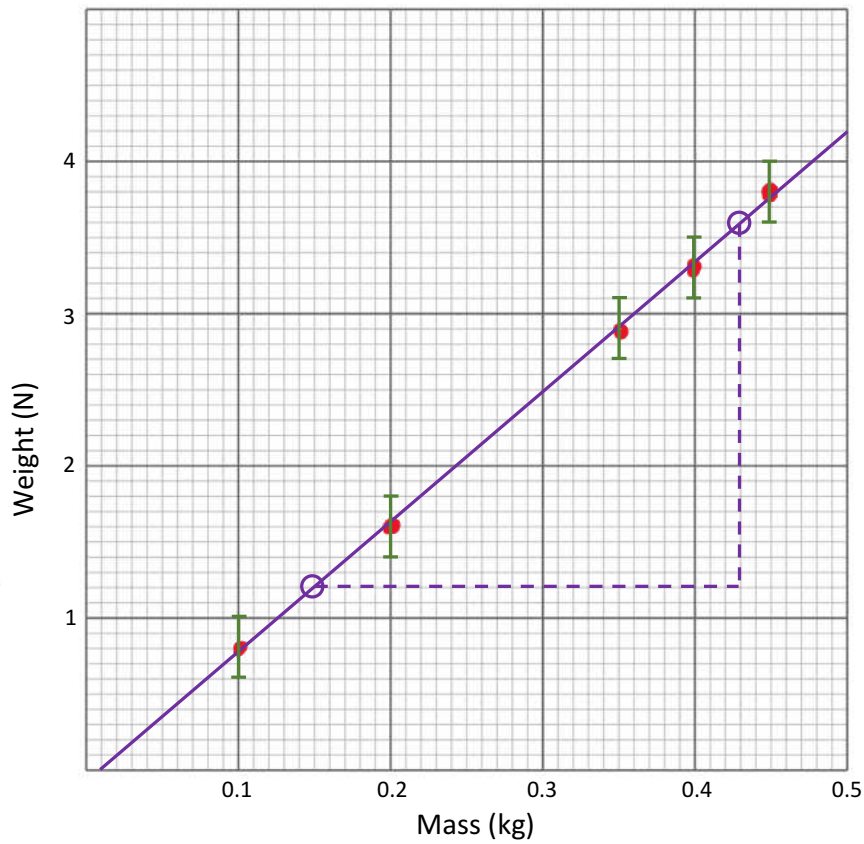
Answer _____ ±_____ m s^{-1}

Graphing Data with Uncertainties

Error bars can be used to propagate uncertainties into graphical analysis, each showing the range that a particular point on a graph can take. **For example**, the following graph shows vertical error bars that represent the uncertainty in the Weight Force shown in the table.

mass (kg)	Weight Force (N)
0.1	0.8 ± 0.2
0.2	1.6 ± 0.2
0.35	2.9 ± 0.2
0.4	3.3 ± 0.2
0.45	3.8 ± 0.2

Initial plot with uncertainty bars



Rise:

$3.6 - 1.2$
$= 2.4$

Run:

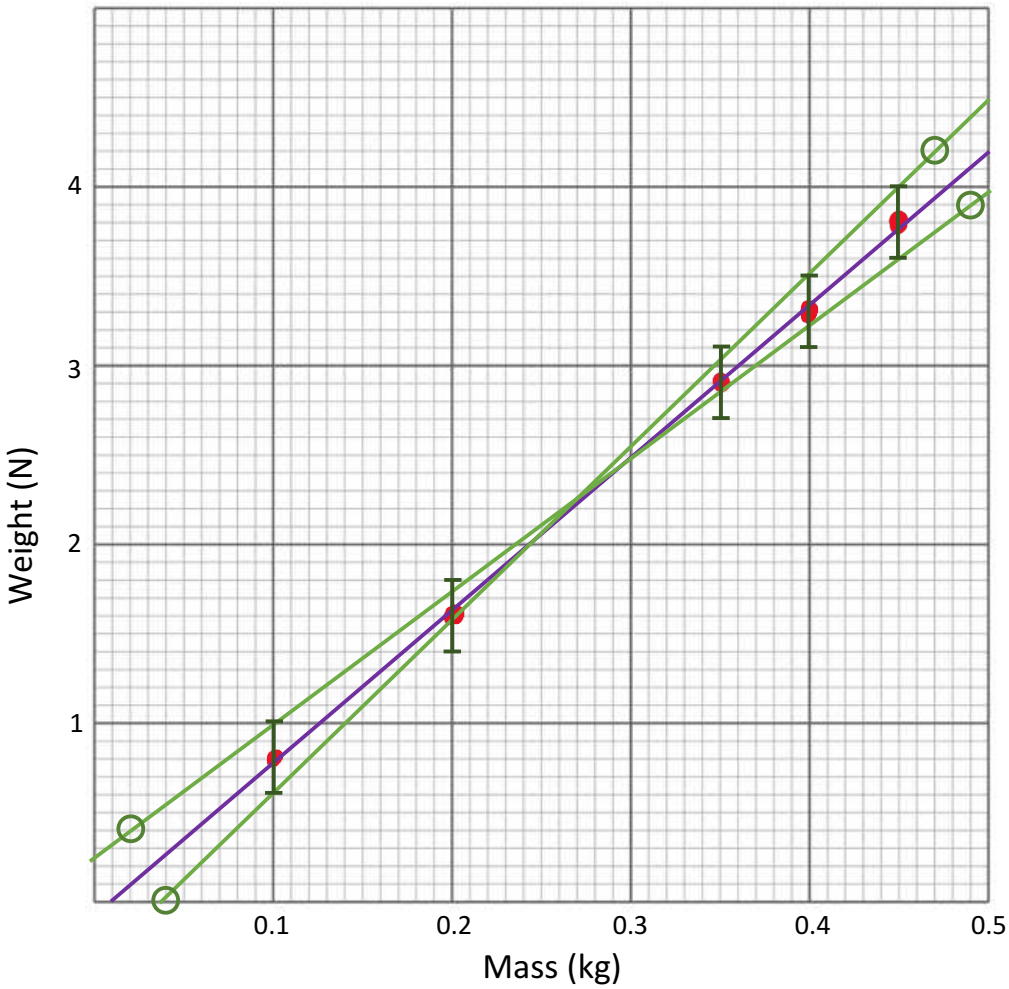
$0.43 - 0.15$
$= 0.28$

When drawing the line of best fit, the line must fit within all the error bars for the analysis to be valid. The gradient is then calculated as per usual.

$$gradient = \frac{rise}{run} = \frac{2.4}{0.28} = 8.6\ N\ kg^{-1}$$

When including error analysis, two additional lines of best fit can be drawn to represent the maximum and minimum possible gradients, ensuring to stay within all error bars, shown below.

Second plot with min/max gradients



Max Gradient:

$$\frac{rise}{run} = \frac{4.2}{0.43} = 9.8$$

Min Gradient:

$$\frac{rise}{run} = \frac{3.5}{0.47} = 7.4$$

Finally, the minimum and maximum gradients can be used to estimate an uncertainty in the gradient of the graph:

$$\max = 9.8\ N\ kg^{-1} \qquad min = 7.4\ N\ kg^{-1}$$

$$\Delta grad = \frac{max - min}{2} = \frac{9.8 - 7.4}{2} = 1.2$$

$$\therefore \boldsymbol{Gradient = 8.6 \pm 1.2\ N\ kg^{-1}}$$

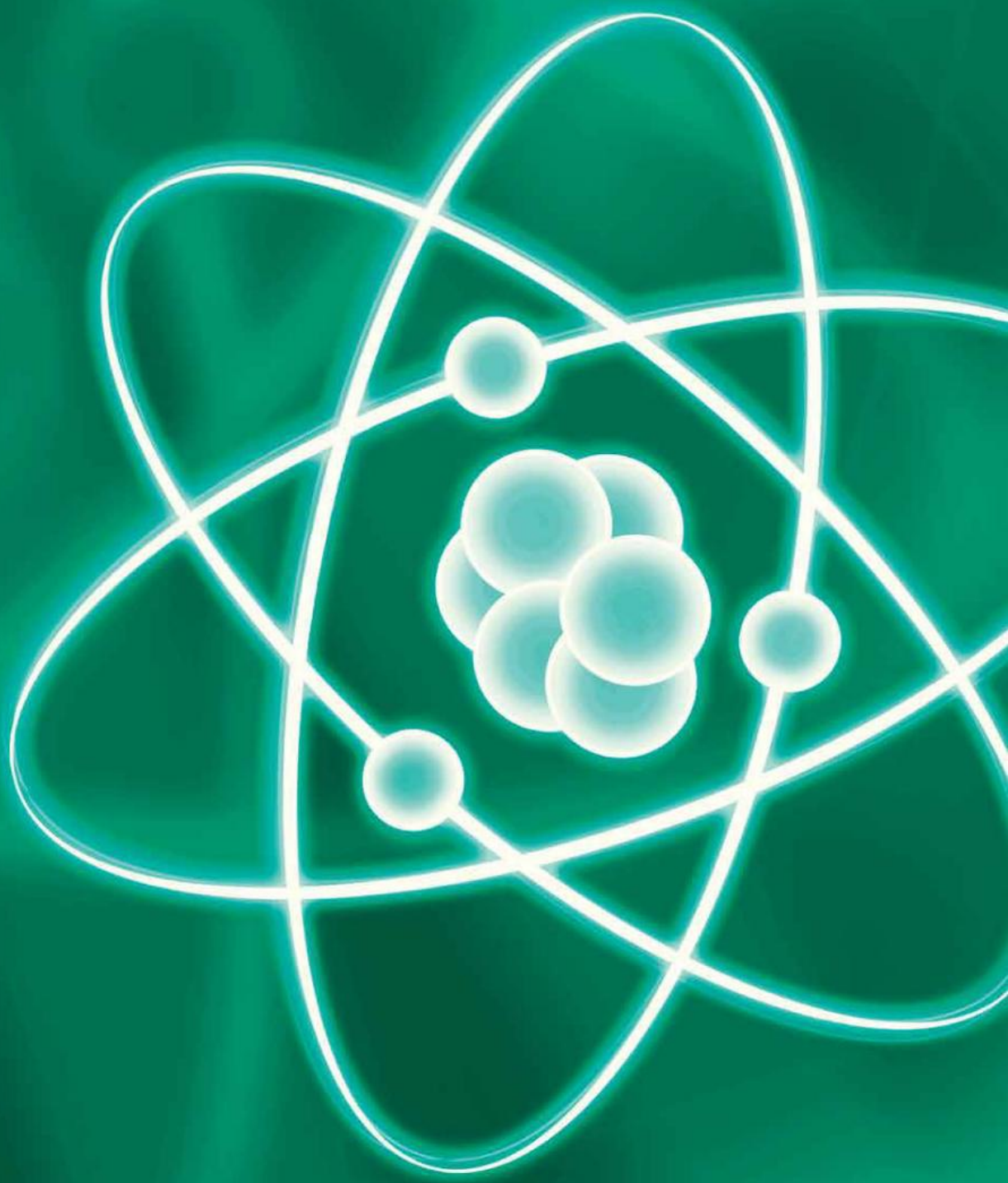
Unit 1 – Motion, Forces & Energy

Motion and Forces

Chapter 2 – Scalars and Vectors

Chapter 3 – Linear Motion

Chapter 4 – Momentum, Impulse and Forces



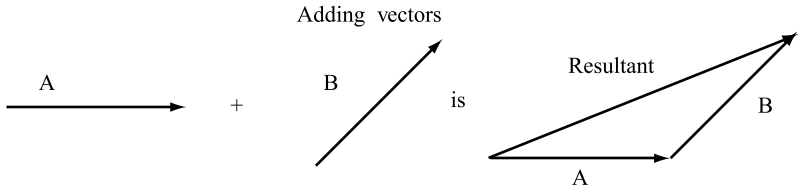
Vectors Explained

Remember the following important principles

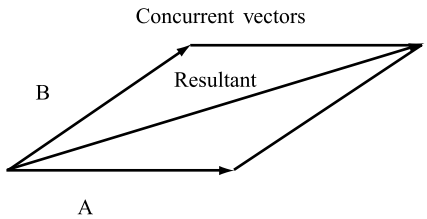
You can represent a vector quantity with an arrow, where the length of the arrow represents the magnitude and the arrowhead represents the **direction**.

You can add or subtract scalar quantities arithmetically but you must **add or subtract vector quantities geometrically.**

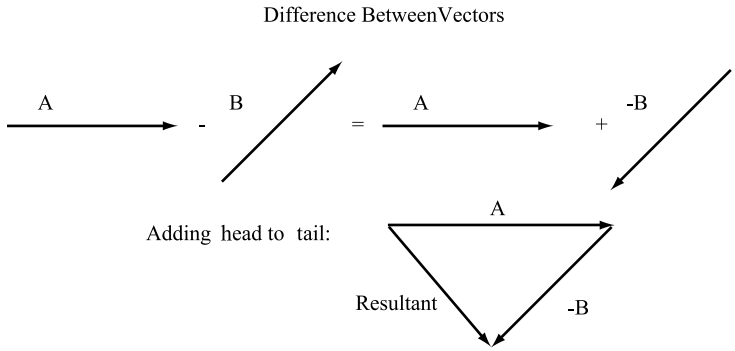
You can add vector quantities by putting the tail of one vector arrow at the arrowhead of the second vector arrow. The sum, or resultant, is a vector that begins at the tail of the first vector you added and ends at the arrowhead of the last vector you added. The diagram shows an example.



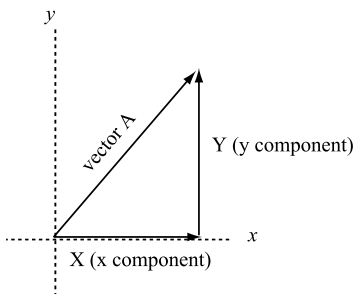
You can add vectors that act through the same point, known as **concurrent** vectors, by completing a parallelogram. The diagral then gives the resultant, as illustrated.



You can find the **difference** between two vectors by adding the negative vector of the vector you are subtracting. A negative vector is one of equal magnitude but opposite direction. You can represent the difference between two vectors A and B as shown below:



A vector quantity can have an effect in directions other than that vector's direction. You can express any vector quantity as two vectors at right angles to one another, as long the sum of those two vectors is equal to the original vector. We call such vectors **rectangular components** of the original vector. For example, vector A can have components Y and X.
You can convert (resolve) any vector into an infinite number of sets of mutually perpendicular components. Note that a vector has no components perpendicular to itself.



Experiment 2.1 – Resolving forces

2

Background

You can resolve or break down a single force into two forces at right angles to one another. The two resolved forces or components when added together will give the original force.

In this experiment you will measure a force, the tension, and its vertical component, the weight, and the horizontal component, the thrust in the boom.

Aim

To show that a single force can be resolved into components at right angles to one another.

Equipment

- large retort stand with 2 boss heads and clamp
- 2 pieces of 10 mm diameter dowel or metal rod about 50 mm long, one with an eye hook in the end and the other with a short piece of plastic tube partly pushed onto one end
- dowel - 8 mm diameter, 400 mm long with an eye hook at one end and a nail in the other end. (A level bubble attached to the boom is an easy way to make sure the boom is level)
- string or fishing line about 500 mm long
- large protractor
- 2 spring balances (10 N)
- a set of slotted masses (e.g. 10 × 50 g)

Pre-Lab

Draw tables similar to Tables 1 and 2 shown below.

	Trial 1	Trial 2	Trial 3
Angle between string and boom			
Tension T (N)			
Weight W (N)			
Thrust P (N)			

Record the weight (W) in newtons in Table 1.

	Trial 1	Trial 2	Trial 3
Vertical component of tension ($T_V = T \sin \theta$)			
Horizontal component of tension ($T_H = T \cos \theta$)			
Difference between T_V and W			
Difference between T_H and P			

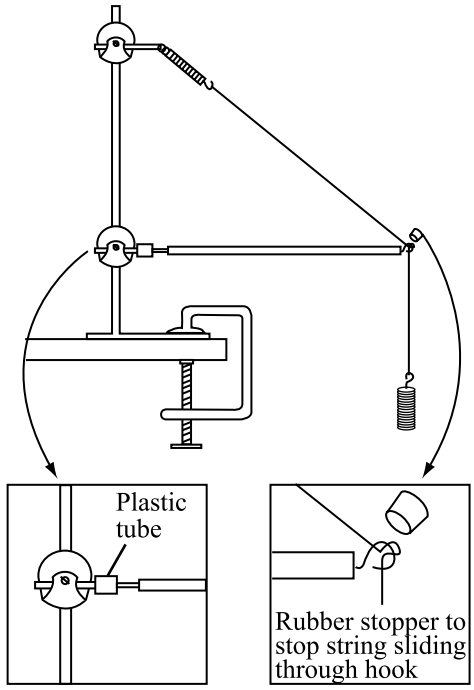


Figure 2.1:Set up

Lab Notes

- Adjust the upper balance and string length until the boom is horizontal and the string is at an angle of between 40° and 65° to the boom.
- Measure and record the angle Θ between the string and the boom.
- Attach the spring balance to the end of the boom and slowly pull it horizontally until the nail in the boom just moves free inside the plastic tube. Measure and record the horizontal force to achieve this. This is the thrust (P). Measure and record the tension (T) in the string.
- Repeat the experiment using two other values of the angle.

Processing of results

- For each set of readings, complete the calculations set out in Table 2.
- Represent one of these situations graphically by selecting one set of results and drawing an accurate scale diagram showing all forces acting in this situation.

Post-Lab Discussion

1. On the basis of your results, write a general conclusion relating a vector to its components.

2. What happens to the tension in the string and the thrust on the boom as the angle is made smaller?

3. The weight of the beam in this experiment was ignored. Is this reasonable? Explain.

4. List the major sources of errors in this experiment.

5. Express the average difference between T_V and W as a percentage of W. Do the same for T_H and P compared to P. Are these errors acceptable?

6. Describe a practical situation you have seen that uses the principles examined in this experiment.

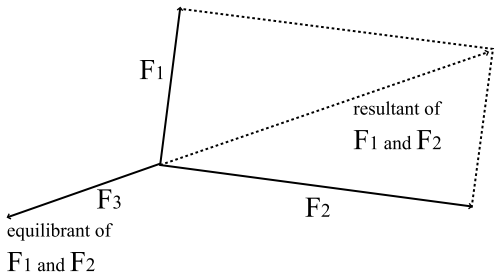
Experiment 2.2 – Adding forces

2

Background

We define the resultant as the net force experienced by an object when two or more forces act at the same point on the object.

We call the single force that will balance the combined effect of the two or more forces, the equilibrant. Remember, forces are vector quantities so we can add them geometrically and since you will be investigating concurrent forces you may add the vectors by completing a parallelogram as shown below.



Aim

In this experiment you will measure three concurrent forces then compare the resultant of two of the forces with the third force. This third force is the equilibrant.

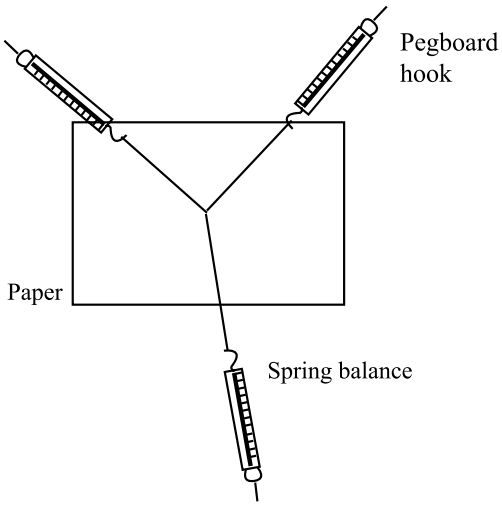
You will need to find the resultant and equilibrant of two forces acting at an angle to each other, and work out the relationship between them.

Equipment

- force table or pegboard approximately 1 m × 1 m
- three pegboard hooks
- three spring balances (10 N or 20 N)
- 1 m of string or fishing line
- protractor
- paper
- rule

Pre-Lab

- Place the pegboard on a flat bench
- Connect the three spring balances using the string or fishing line as shown.
- Arrange the three balances so that each balance reads more than half the full scale reading and each reading is different from the others. You will find this easier if you first position two of the balances then adjust the position of the third.
- Arrange a sheet of paper under the strings so that the knot joining the strings is in the middle of the sheet. Carefully mark the point at which the strings meet and the other end of each string.

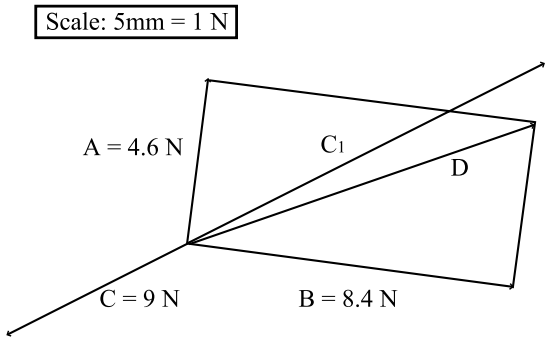


Lab Notes

- Using a pencil and rule, you can now join the points to show the positions of the strings. Label the lines A, B and C in any order and write the balance reading near each string.
- Using a new piece of paper for each set of readings, change the position of the balances so you can measure three additional sets of results.

Processing of results

- For each of your four sets of results select a suitable scale and draw a vector diagram to represent the forces you measured. Make sure you measure and draw the angles between the forces accurately.
- Add vectors A and B by constructing a parallelogram as shown in the example. Then draw D, the resultant of A and B.
- You can now draw the equilibrant of C and label it C_1. The equilibrant has the same magnitude as C but is in the opposite direction.



- Complete the table below using your results from each trial.

	Trial 1	Trial 2	Trial 3	Trial 4
Magnitude of A (N)				
Magnitude of A (N)				
Magnitude of D = A + B (N)				
Difference in magnitude of C_1 and D (N)				
Angle between D and C_1				

Post-Lab Discussion

1. From your results state the relationship between the resultant and equilibrant for forces acting concurrently on a stationary object.

2. Choose one set of results. Add A and C using the same method used above. Compare the sum of these with B. Does the evidence support your conclusions?

_____

_____

_____

_____

_____

3. Under what circumstances would A, B and C be equal in magnitude? Show this in a scale diagram.

4. Explain why differences exist between C1 and D, and why the angle between C1 and D is not always zero.

5. List the main sources of error in your experiment. How does each source of error contribute to the variation in your results?

6. From the context you are studying choose two examples where two forces act concurrently.

   (a) Describe each example and draw a vector diagram to show the force vectors and the resultant in each case.

   (b) For each example indicate whether the resultant force is unbalanced or not.

2 Experiment 2.3 – Navigating vectors

Aim

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

Apparatus

- 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?

_____

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2 Problem Set 2.1 – Vector calculations

1. Explain why it is essential to describe both magnitude and direction of a quantity such as velocity.

_____

_____

_____

2. An archer stretches a bow so the string makes angles of 45° to the arrow.
   If the tension in the string is 208 N, what force is exerted on the arrow at the time of release?

3. A canoeist can paddle a slalom kayak for short bursts at a speed of 2.70 m s^{-1} in still water. He wants to cross a stream in which a 2.00 m s^{-1} current flows.

   (a) At what angle to the current must he point his canoe if he wants to land on the other bank directly opposite to where he started? Assume he paddles at top speed throughout his crossing.

   (b) Calculate his resultant velocity if he heads directly across the stream at top speed.

   (c) The stream is 40.0 m wide. How far downstream will he land on the opposite bank?

4. A tennis player serves a ball at 80 km h^{-1} towards his opponent, who returns it directly back to the server at 90 km h^{-1}. Calculate the ball's change in velocity.

5. A batter hits a cricket ball at right angles to its original direction. The bowler bowled the ball at 30.0 m s^{-1}. If the ball leaves the bat at 30.0 m s^{-1}, determine the ball's change in velocity.

6. An archer fires an arrow with a velocity of 45 m s^{-1} at an angle of 18° to the horizontal. Estimate its velocity in the horizontal direction.

7. A golfer hits a ball with a velocity of 25.0 m s^{-1} at an angle of 35.0° to the horizontal. Immediately after she hits the ball, at what rate does it rise and at what rate does it move towards the pin?

8. A roller skater starts down a slope inclined at 25.0° the horizontal. The skater is not significantly affected by frictional forces. Determine the skater's acceleration.

9. A truck driver supported a plank horizontally by its two ends. He then loaded bricks on its centre and found that the weight of 166 kg of bricks was just enough to break the plank. He wanted to use an identical plank as a ramp to load a full fuel drum of total mass 197 kg onto a truck.

   (a) Explain why the driver could still use this plank to load the fuel drum.

   _____

   _____

   _____

   _____

   (b) What is the minimum angle to the horizontal at which he could still use the plank to load the drum?

Chapter 3 – Linear Motion

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

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

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,

$$v_{av} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

or, for an object whose velocity changes smoothly from an initial velocity v_i to a final velocity v_f:

$$v_{av} = \frac{v_i + v_f}{2}$$

Where: $\mathbf{v_{av}}$ is the average velocity measured in metres per second (m s^{-1})
$\mathbf{v_i}$ is the initial velocity measured in m s^{-1}
$\mathbf{v_f}$ is the final velocity measured in m s^{-1}
$\mathbf{\Delta x}$ is the change in position of the object (displacement) measured in metres (m)
$\mathbf{\Delta t}$ is the time interval measured in seconds (s)

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:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

The same equation can be rearranged to give:

$$v_f = v_i + a\Delta t$$

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

v_i 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:

$$s = v_i\Delta t + \frac{1}{2}a\Delta t^2$$

and

$$v_f{}^2 = v_i{}^2 + 2as$$

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:

$$v_f = v_i + a\Delta t$$

$$h = v_i\, t + \frac{1}{2}a\Delta t^2$$

$$v_f{}^2 = v_i{}^2 + 2g\Delta h$$

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

3 Experiment 3.1 – Going faster

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

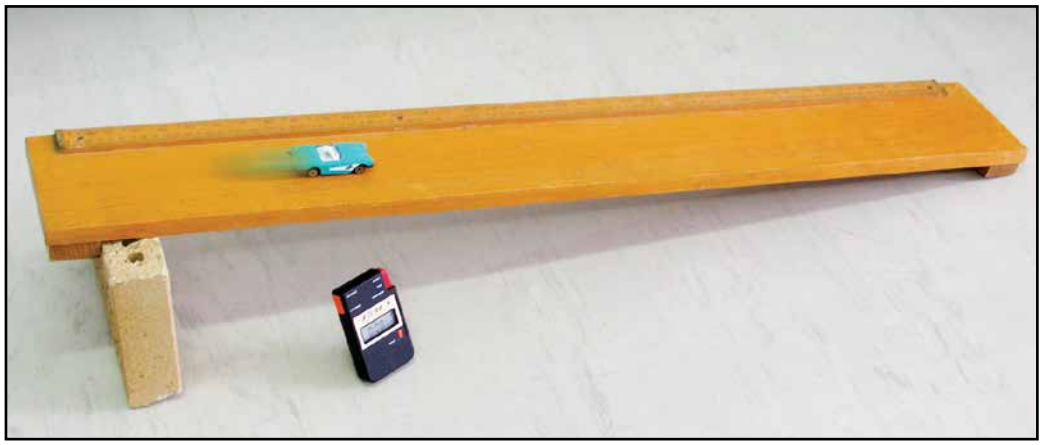
- an air track, air track glider and blower
- metre ruler and stop watch

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.
- 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.



Apparatus for Experiment 3.1

Lab Notes

- Carry out several trials and record the data in a suitable table.
- 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 draw a line graphs of speed and velocity, *vs* time on separate graph paper. 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.

   _____

   _____

3 Experiment 3.2 – Reaction Time

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 Discussion

- 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.

_____

_____

_____

_____

- Determine 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. Prepare a table for your results
- 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 this data in the table.
- 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 reasons 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.

3 Problem Set 3.1 – Uniform Motion

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.

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.

3. 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) Calculate her velocity.

4. 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 1.00 km; then east for 600 m; and finally 200 m north. The competitors found that this journey took them 20.0 minutes.

   (a) Calculate the total distance they travelled between the starting position and the check point.

   (b) Calculate their average speed for this journey.

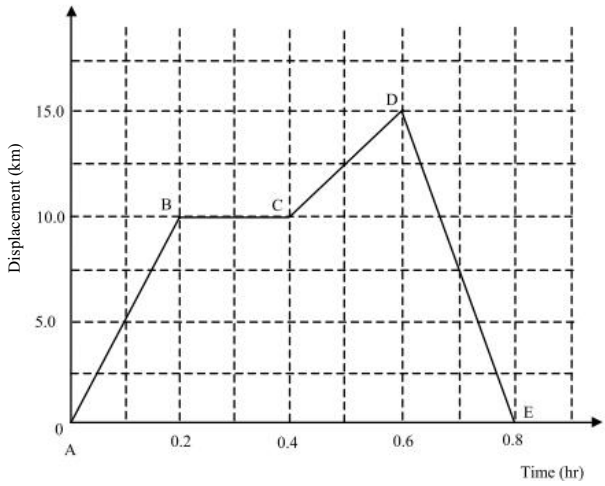
   (c) Calculate the location of the check point, relative to their starting position. Give both the distance and the direction.

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

5. 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?

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?

7. The graph (right) 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) By how much did the motorbike's odometer increase for the whole journey

(e) Calculate the motorcyclist's average speed for the journey.

8. 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.

Problem Set 3.2 – Accelerated Motion

3

1. A train starts from Mandurah with an acceleration of 0.800 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}.

2. 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?

3. An aeroplane flies at a constant height and speed.

   (a) Calculate the time it would take to fly 50.0 km at a constant 200 m s^{-1}.

   (b) The aeroplane is now accelerated at 2.00 m s^{-2}. Calculate the time it would take to increase its speed to 250 m s^{-1}.

   (c) The plane flies for another 50.0 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.

4. Mei Lin can accelerate her bicycle from rest at the rate of 0.770 m s^{-2}. How far will she have travelled from her starting point by the time she achieves a speed of 7.00 m s^{-1}?

5. 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.

6. 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.

7. A motorist is driving his vehicle at 60.0 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 0.500 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 4.50 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 55.0 km h^{-1}.

(g) Calculate the speed that the car, initially travelling at 60.0 km h^{-1}, will still have when the car travelling at 55.0 km h^{-1} has stopped.

(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 5.00 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.

8. 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.

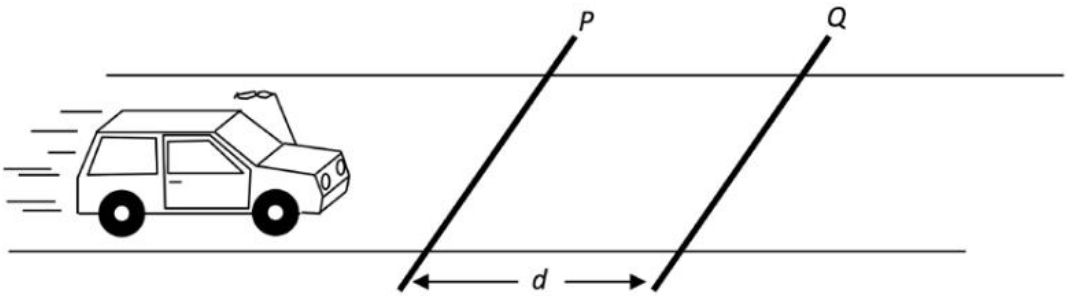
9. Cindy pedalled her bike for 10.0 s at a constant speed of 5.00 m s^{-1} and then decided to increase the speed. By pushing firmly on the pedals she accelerated her bike at a rate of 2.50 m s^{-2} for 4.00 s. Cindy then applied the brakes so that her bike decelerated at the rate of 6.00 m s^{-2} until it came to rest.

   (a) Calculate Cindy's speed after 14.0 s.

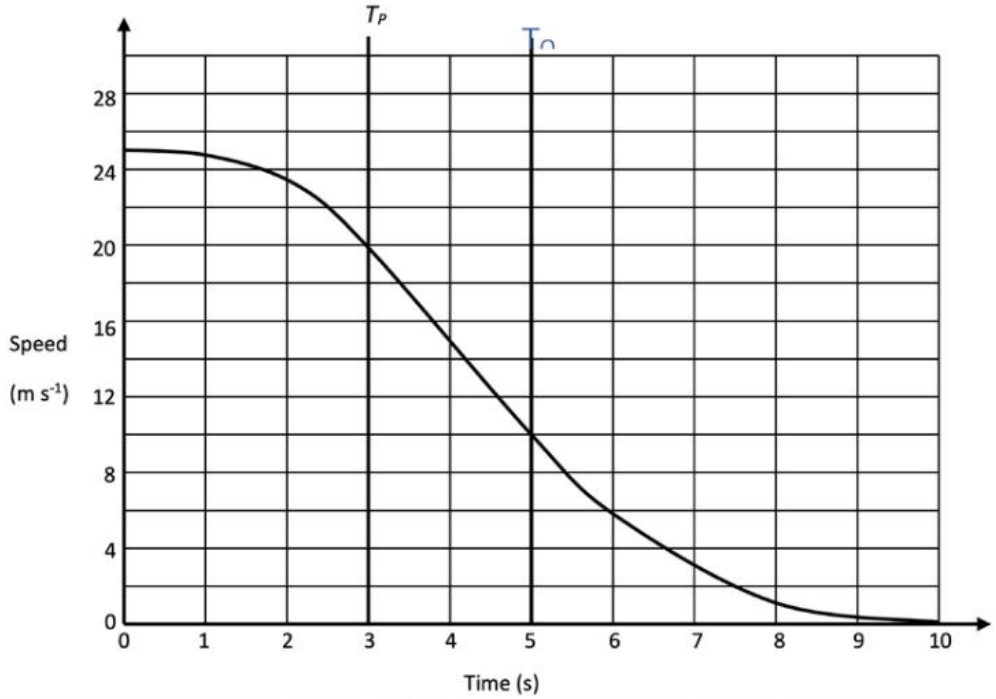
   (b) Plot a velocity-time graph for Cindy's bike.

   (c) Use the graph to work out how far Cindy travelled before she stopped.

10. An amphometer is a device used to find the speed of a car. It registers the time interval for the car to cross two tapes, P and Q, as shown below, from which the average speed is determined.



The graph below shows the speed of the car as a function of time. The times TP and TQ at which the car crosses P and Q are shown.



(a) What is the distance d between the tapes P and Q?

(b) What is the magnitude and direction of the acceleration of the car in the time interval TP to TQ?

(c) What is the speed as measured by the amphometer?

(d) Estimate the distance from the tape Q to the point at which the car comes to rest. Briefly describe how you did this.

3

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:

$$\Sigma F = ma$$

Where: **ΣF** 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.

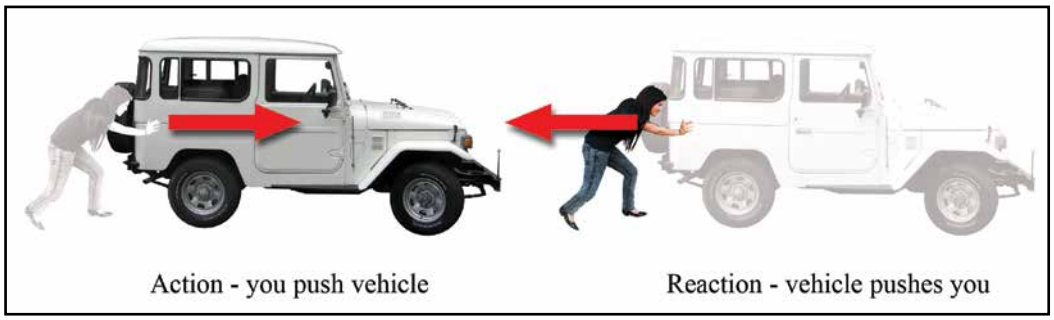
This is often shortened to:

- 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.

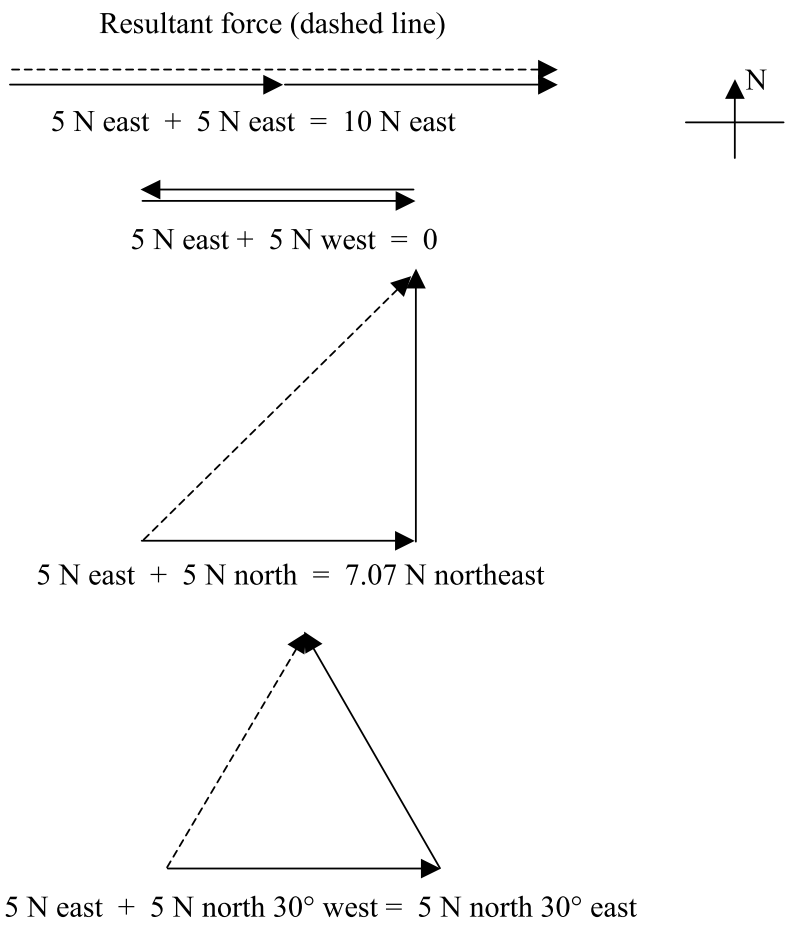


Action and reaction always involves two forces acting on two objects.

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:



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}

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.

$$p = mv$$

or

$$\Delta p = p_f - p_i = m(v_f - v_i) = m\Delta v$$

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

p_i is the initial momentum in kg m s^{-1}

p_f is the final momentum in kg m s^{-1}

Δp is the change in momentum measured in kg m s^{-1}

m is the mass in kg

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

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

Δv 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:

$$F_{net} = \frac{\Delta p}{\Delta t}$$

Thus

$$F_{net}\Delta t = \Delta p = m(v_f - v_i)$$

and

$$F_{net} = \frac{m(v_f - v_i)}{\Delta t} = m\left(\frac{v_f - v_i}{\Delta t}\right) = ma$$

where Δp is the change in momentum measured in kg m s^{-1}

Δt is the time measured in s

F_{net} is the overall or resultant force (ΣF) measured in newtons (N)

m is the mass measured in kg

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

v_i 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.

Impulse

This 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.

$$Impulse = F\Delta t = m(v_f - v_i) = \Delta p$$

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)

Δt is the time in s

m is the mass in kg

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

v_i 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:

$$\Sigma p_i = \Sigma p_f$$

or

$$\Sigma mv_i = \Sigma mv_f$$

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

$$(mv_i)_1 + (mv_i)_2 = (mv_f)_1 + (mv_f)_2$$

where: m_1 is the mass of object 1 in kg

m_2 is the mass of object 2 in kg

$(v_i)_1$ is the initial velocity of object 1 in m s^{-1}

$(v_i)_2$ is the initial velocity of object 2 in m s^{-1}

$(v_f)_1$ is the final velocity of object 1 in m s^{-1}

$(v_f)_2$ is the final velocity of object 2 in m s^{-1}

Experiment 4.1 – Newton's Second Law

4

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.

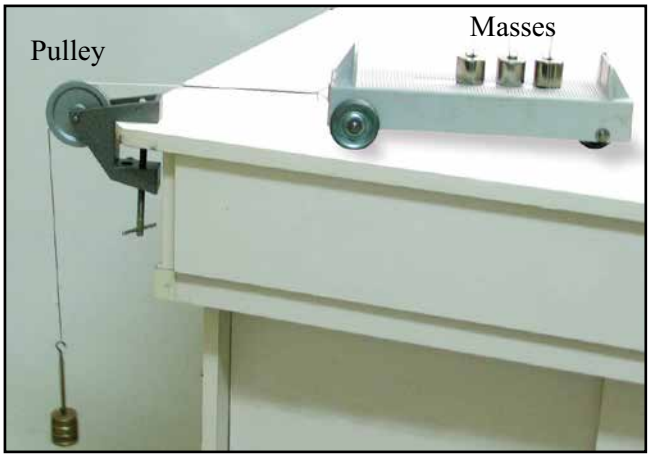
It works best if you can adjust the set-up to 'compensate' for friction. The simplest way to adjust for friction is to tilt the ramp or air track just a little bit, until a cart or glider put on it and gently pushed down the slope rolls or glides down at a constant speed. If you have access to computers, 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.

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
- slotted masses (e.g. 5 g, 10 g, 20 g, 50 g) and hanger
- string



Apparatus for Experiment 4.3

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.

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.

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

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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.

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Experiment 4.2 – Friction

4

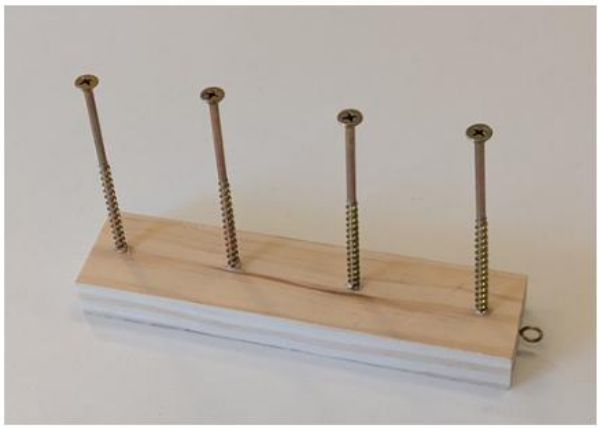
Background

Friction plays a role in almost every movement on Earth that you can imagine – it is largely inescapable on Earth. There are different types of friction: kinetic, static, rolling and fluid. In this experiment we are going to investigate kinetic and static friction. If two surfaces are in contact and moving relative to one another (sliding past each other), then the friction between them is called **kinetic friction**. When objects are stationary, **static friction** can act between them. The static friction is always greater than the kinetic friction acting between objects. How much friction exists between two surfaces depends greatly on the texture and type of materials in contact.

Part A – Kinetic Friction

Aim

To determine the coefficient of kinetic friction between wood and a bench.

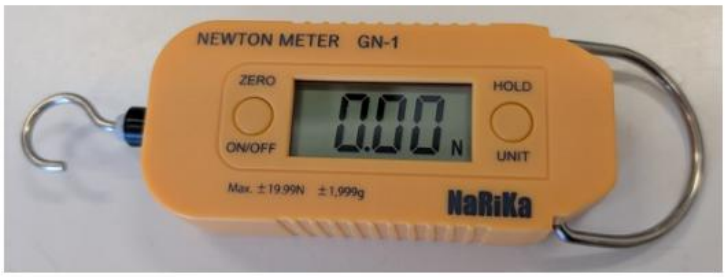


Apparatus (per group)

- A wooden block or tray able to carry slotted masses
- Electronic scales
- A Digital Newton Meter or a 5 newton spring balance.
- 2 sets of slotted masses

Pre-Lab discussion

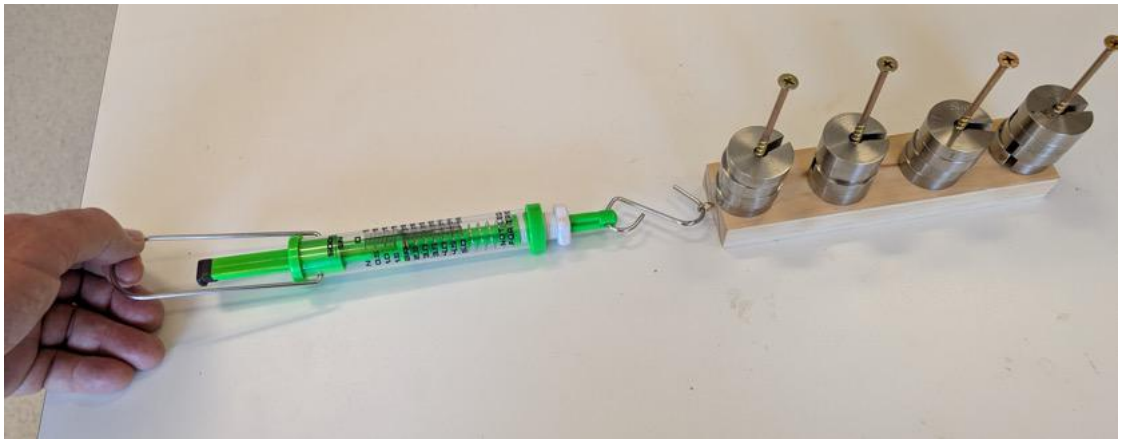
- Identify the dependent and independent variables.
- Make a list of controlled variables.
- Discuss how you will minimise errors and uncertainties in this experiment.
- How does the direction of the applied force matter? Why should it remain parallel to the surface to get accurate friction readings?
- Prepare a table similar to this (below).



Mass (kg)	F_N (newtons)	Kinetic Friction (N)			Average F_f (N)
		Trial 1	Trial 2	Trial 3	

Lab Notes

- Measure and record the mass of the wooden block/tray.
- Using the Newton Meter (or spring balance) gently and steadily drag the block over a horizontal surface and record the force required. This is the kinetic frictional force between the block and the surface. Repeat to obtain 3 sets of results.
- Progressively add mass to the block/tray and repeat until you have recorded at least 6 lines of data in your table.
- Record any observations about any difficulties in keeping the force steady.



Processing of results

- Complete the column for the normal force (F_N) and for the average frictional force in your table of results.
- From your data, plot a graph of the average kinetic friction (vertical axis) versus the normal force and draw a straight line of best fit.
- Calculate the gradient of the line of best fit.

Post-Lab Discussion

- Considering the relationship $\boldsymbol{F_f = \mu_k F_N}$, what does the gradient of your line of best fit represent and what are its units?

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- Does your line of best fit pass through the origin? If not, does this matter? Discuss.

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- Explain how an increase in surface area between the block and the surface would affect the coefficient of kinetic friction, if at all.

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- Imagine this experiment was conducted on an inclined plane instead of a flat surface. How would the process and results differ?

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- In practical terms, why is it important for engineers to understand the coefficient of kinetic friction between different materials? Provide an example where this knowledge is applied.

- If you were to repeat this experiment using different materials for the block or surface, what changes would you expect in the coefficient of kinetic friction, and why?

- Discuss potential sources of error in your experiment and propose improvements to reduce these errors in future trials.

Part B – Static Friction

Aim

To determine and compare the static friction between two surfaces.

Apparatus (per group)

- An adjustable inclined plane with clamp and protractor. (example next page).
- A wooden block to rest on the inclined plane.
- Various objects of different material (say; an eraser, box of tissues, shoe, use your imagination).

Lab Notes

- Place the object on the plane when it is in a horizontal position.
- Slowly, and without shaking or knocking the apparatus, increase the angle of the inclined plane very gradually until the object on the plane slides down.
- Record the angle of the inclined plane when the object begins to slide down.
- Repeat several times – there's a high probability that your results will not be particularly consistent.
- Repeat the above with an object made from different material.

Processing of results

- For each object, calculate the average angle of inclination for the onset of sliding.
- From your data and the relationship $\mu_s = \tan\theta$, determine the coefficient of static friction between your object and the surface.
- Based on your data, estimate the experimental error for the coefficient of static friction for each object you tested.

Post-Lab Discussion

1. Using $F_f = \mu_{s(max)} F_N$, derive the relationship $\mu_{s(max)} = \tan\theta_{max}$.

2. You were not asked to record the mass of the object on the inclined plane. Why not?

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3. Explain why a higher coefficient of static friction is observed than kinetic friction between most surfaces. What does this imply about the initial vs. ongoing forces required for motion?

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4. Consider sources of error in measuring the angle. What specific experimental steps or tools might reduce these errors?

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5. How would using a heavier object affect the angle at which sliding begins? Does it change the coefficient of static friction?

6. If you were to use a smoother or more polished block, how would you expect the coefficient of static friction to change, and why?

7. Imagine you performed this experiment on the Moon, where gravity is weaker. How would this impact the angle at which the block starts to slide, if at all? Explain your reasoning.

8. Propose a practical application where understanding the coefficient of static friction is essential, and explain how this knowledge could be applied.

Experiment 4.3 – 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

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 the space below 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?

4 Experiment 4.4 – Conservation of Momentum in a Collision

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.

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- 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.

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- Prepare a table in the space below 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.

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

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

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4 Problem Set 4.1 – Force & Newton's Laws

1. 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.

2. Use Newton's Law(s) and a free body diagram to explain each of the following.

   (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. 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.

4. 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.

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

6. 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.

7. 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.

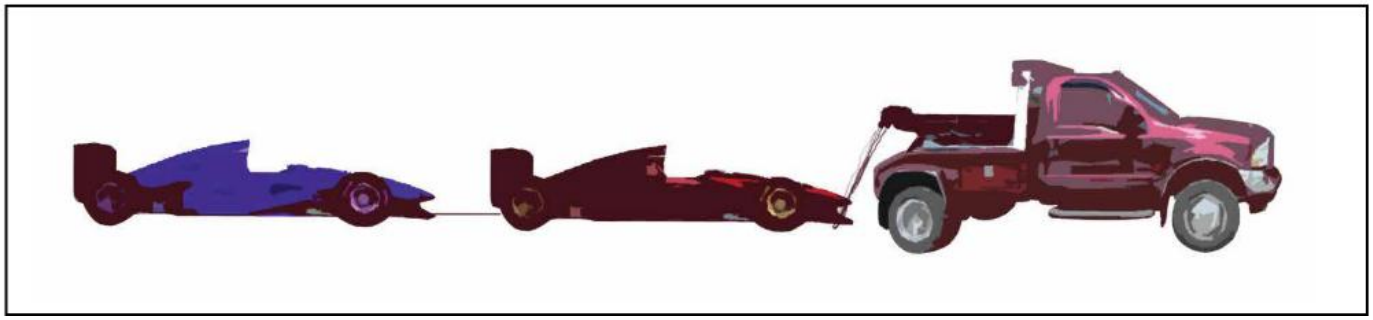
   (b) accelerates the bricks from the ground towards the first floor at a rate of 1.50 m s^{-2}.

   (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}.

8. 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.

9. 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}. The rope between the truck and the first car makes an angle of 60º with the horizontal.



Towing two cars

4 Problem Set 4.2 – Momentum & Impulse

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.

2. 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.

3. 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 0.100 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 104 kg semi-trailer has a 4.25×10^3 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. 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 30.0 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 25.0 m s^{-1}.

5. During a collision between two cars, a passenger's head strikes the unpadded dashboard with an average force of 48.0 N for 2.00 ms. With a suitable air bag, the impact would have lasted a longer time of 80.0 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.

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6. 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.

7. A soldier fired a 10.0 kg shell from a 5.00×10^3 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) momentum 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.

8. 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.

9. In a shunting yard a railway wagon of mass 4.20×10^3 kg rolls along a line at 2.0 m s^{-1} and collides with another wagon, mass 2.50×10^3 kg, moving 1.50 m s^{-1} in the same direction. The impact propels the smaller wagon away at 2.10 m s^{-1}. Calculate the velocity of the larger wagon after the collision?

10. 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 if, after the collision:

    (a) Linda's ball changes direction;

    (b) Walter's ball continues in the same direction.

10. 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?

4 Problem Set 4.3 – Friction

1. When performing an emergency stop while driving a car, you should avoid skidding the tires on the road. Modern cars have an Antiskid Braking System (ABS) installed to prevent a driver locking the wheels when suddenly stopping. In terms of friction, why is it better not to skid when braking?

2. When a 20 kg box is pulled with a force of 100 N, it just starts to move (i.e. the maximum value of static friction is overcome with a force of 100 N). What is the value of the coefficient of static friction?

3. When you learn to drive, you soon learn that you need to ease up slightly on the brake pedal as you come to a stop, or the car will stop with a jerk. Explain this in terms of the relationship between static and kinetic friction.

4. A student is cooking breakfast when he notices that the frictional force between his steel spatula and his Teflon frying pan is only 0.300 N. Knowing that the coefficient of kinetic friction between the two materials is 0.04, he quickly estimates the normal force. What is it?

5. What is the minimum stopping distance for a 1200 kg car travelling at 100 km h^{-1} on a wet road with a friction coefficient of 0.2?

6. A crate of mass 5 kg is being pulled with a force of 20 N and is sliding with an acceleration of 2 m s^{-2}. Find the coefficient of kinetic friction.

7. The static friction for wood on wood is 0.5 and the kinetic friction is 0.3. Assume you have a 150 kg wooden pallet resting on a wood floor.

   (a) What maximum force can you exert horizontally on the pallet without moving it?

   (b) If you continue to exert this force once the pallet starts to slip, what will be the magnitude of its acceleration?

8. In a saloon in the Wild West, the barman pours a glass of cordial and pushes the glass along the bar to the Deputy. The glass is pushed with an initial speed of 1.2 m s^{-1} and stops in front of the Deputy 5 m along the bar. What is the coefficient of friction between the glass and the bar?

9. (a) If half of the weight of a 1400 kg SUV is supported by its two drive wheels, what is the magnitude of the maximum acceleration it can achieve on a wet day if the static friction between rubber and wet road is 0.7?

(b) Will a metal toolbox lying on a wooden board in the back of the SUV slip if it accelerates at this rate? The static coefficient of friction between metal and wood is 0.5.

(c) Solve both problems assuming the truck has four-wheel drive.

10. In an advertisement for a four-wheel-drive vehicle, it is shown simultaneously pulling a number of vehicles out of a deep muddy hole with ease. In terms of friction, explain why this scenario is not realistic. What type of vehicle could do the job?

11. Sam and Theo are experimenting with trolleys on a ramp inclined at 25°. They release a trolley with a mass of 2.0 kg from the top of the ramp. The trolley moves down the ramp, through two light gates. Sam and Theo calculate the acceleration of the trolley to be 3.2 m s^{-2} using the information from the light gates.

    (a) Find the gravitational component of the trolley down the slope.

    (b) Assume that on the ramp there is a constant frictional force acting on the trolley and opposing its motion. Calculate the magnitude of the constant frictional force acting on the trolley.

    (c) Determine the coefficient of friction between the trolley and the ramp.

12. As you take a large bottle of milk from the refrigerator in a supermarket, the ones behind slide forward because the shelf is inclined at 12°. What is the maximum allowable coefficient of static friction that will still allow the remaining bottles behind to slide forward?

4 Comprehension Set 4.1

Read each of the paragraphs below and use the information to answer the questions on the following page.

Example 1

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.

Example 2

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.

Example 3

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'.

Example 4

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.

Example 5

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.

Example 6

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.

Example 7

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.

Questions

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. (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

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(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. 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.

4. (a) Why do swimmers need a force in order to accelerate?

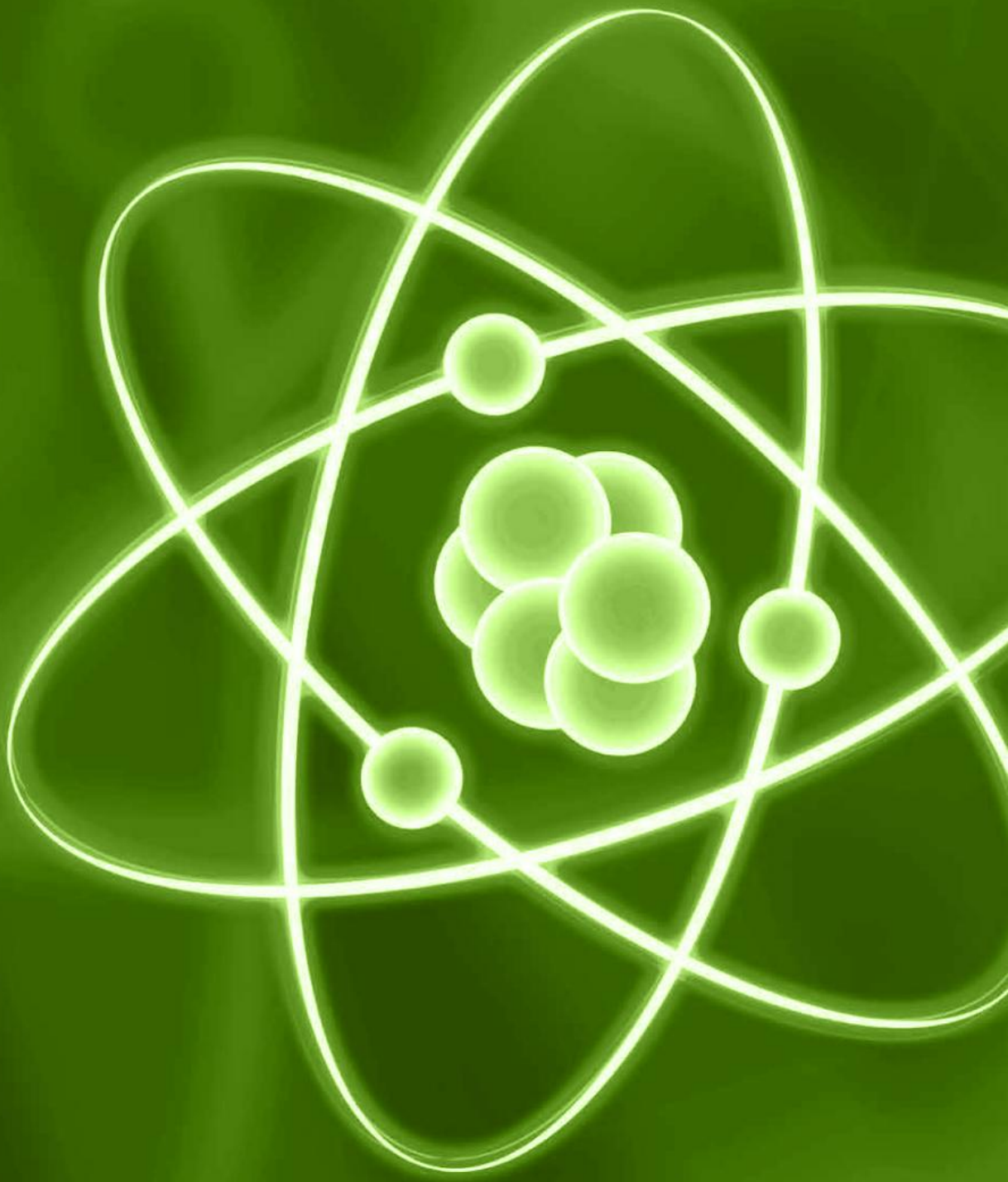
(b) Why do swimmers need a force to maintain their motion?

Unit 1 – Motion, Forces and Energy

Mechanical and Thermal Energy

Chapters 5 – Work, Energy and Power

Chapters 6 – Heating Processes



Chapter 5 – Work, Energy & Power

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:

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

and:

$$E_k = mg\Delta h$$

where:

E_k is kinetic energy in joules (J)

m is mass in kilograms (kg)

v is speed in metres per second (m s^{-1})

E_p is gravitational potential energy in joules (J)

g is acceleration due to gravity, 9.80 m s^{-2} at sea level on Earth.

Δh 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:

$$W = Fs$$

where:

W is the work done, in joules (J)

F is the net force, in newtons (N)

s is the distance moved in the direction of the force, in metres (m)

Thus:

$$W = \Delta E$$

Collisions may be elastic and inelastic; kinetic energy is conserved in elastic collisions, including applying the relationship.

$$\Sigma\frac{1}{2}mv_i^2 = \Sigma\frac{1}{2}mv_f^2$$

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:

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

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

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

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

$$P = \frac{F\Delta s}{\Delta t}$$

$$P = Fv_c$$

where P is the power in watts (W)

W is the work in joules (J)

Δt is the time in seconds (s)

Δs is distance travelled while force is applied

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.

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.

Friction

Friction is a force that we encounter every day. It opposes the relative motion between two surfaces in contact but also enables movement (as you may have noticed if you've ever tried walking on ice). Although friction is a common force, its behaviour is complex and not fully understood. Our current understanding is based largely on observations. However, we can still explore its basic characteristics and learn about the conditions under which it behaves in predictable ways.

Friction is a contact force between two surfaces which opposes motion. Friction is proportional to the normal force (F_N) and the coefficient of friction between the surfaces. Friction can be classified as static or kinetic, depending on the relative motion between surfaces.

$$F_f = \mu F_N$$

Where: F_f is the force of friction in newtons;

μ is the coefficient of friction; and

F_N is the normal force in newtons.

Note that the coefficient of friction is a dimensionless quantity; i.e. it does not have units.

If two surfaces are in contact and moving relative to one another (sliding past each other), then the friction between them is called **kinetic friction**.

When objects are stationary, **static friction** can act between them. The static friction is always greater than the kinetic friction acting between objects.

Static friction is a responsive force that increases to be equal and opposite to whatever force is applied up to a maximum value. Once this maximum value has been met or exceeded, the object will begin to slide over the other surface. At this point, kinetic friction will apply.

Therefore, the magnitude of static friction is given by:

$$F_s \leq \mu_s F_N$$

where μ_s is the coefficient of static friction and F_s is the magnitude of the static friction.

The maximum value of static friction is:

$$F_{s(max)} = \mu_s F_N$$

The magnitude of kinetic friction is given by:

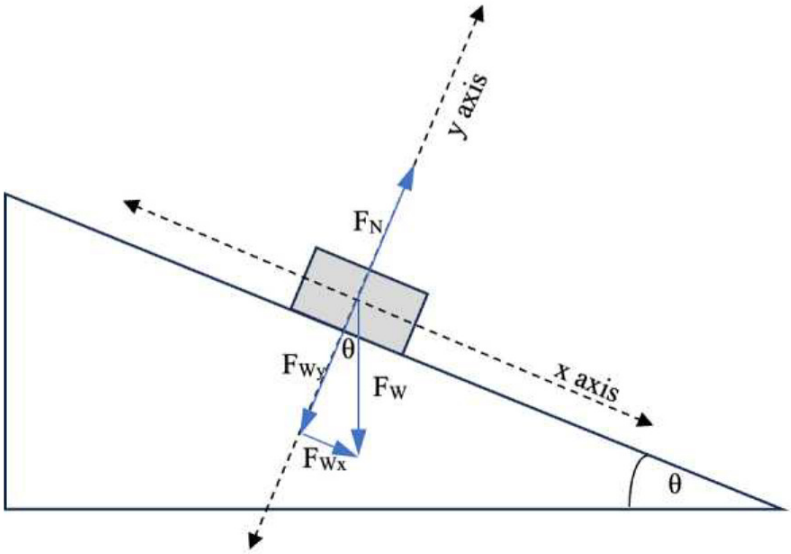
$$F_k = \mu_k F_N$$

where μ_k is the coefficient of kinetic friction.

The direction of friction is always opposite to that of motion, parallel to the surface between objects, and perpendicular to the normal force.

Inclined Planes

Gravitational force on an object (that is, weight) is a vector that can be resolved into components. For inclined planes it is usually easier to solve the problem if you rotate the x and y axis as shown below.



Given that $F_W = mg$, you should be able to work out that $F_{Wy} = mg \cos \theta$ and $F_{Wx} = mg \sin \theta$.

Note that in this drawing, the normal force (F_N) is equal and opposite to F_{Wy}.

5 Experiment 5.1 – Roller Coaster

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 Discussion

- 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.

Post-Lab Discussion

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. Eg. The skier 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.

   For each stage, identify:

   (a) whether work is done, by whom or what, on whom or what, and the result of any work being done

   (b) any changes of energy and where they occur during the journey.

5 Experiment 5.2 – Vehicle Power

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 Discussion

- 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.

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- Design a table in the space below suitable for recording the measurements you will take.

- Discuss how you can minimise errors and uncertainties in the lab.

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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.

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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 about the top speed in the first sentence of this question?

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

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5 Problem Set 5 – Energy, Work & Power

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

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.

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. An ice skater at rest 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.

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

7. 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.

8. 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?

9. A pile driver consists of a large weight that 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.

10. A roller-coaster full of thrill seekers starts at the top of the ride. The 1.80×10^3 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.

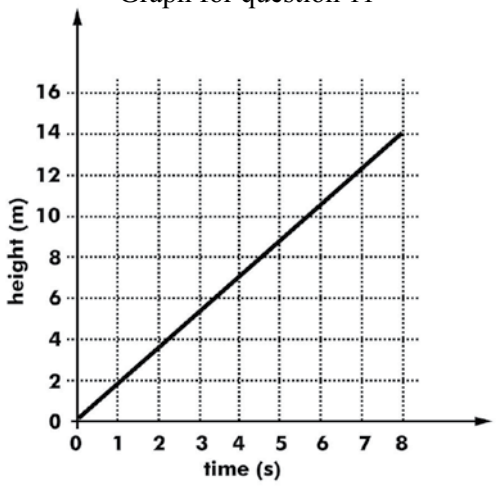
    (a) Calculate the minimum speed that the coaster needs when it is at the bottom of the slope.

    (b) Explain why the coaster must have been travelling faster than this minimum speed.

11. Rob the builder uses a motorised hoist to lift loads a of bricks up the side of a building

(a) The graph shows the time taken for a load 256 kg. Calculate the effective power of the hoist?

Graph for question 11

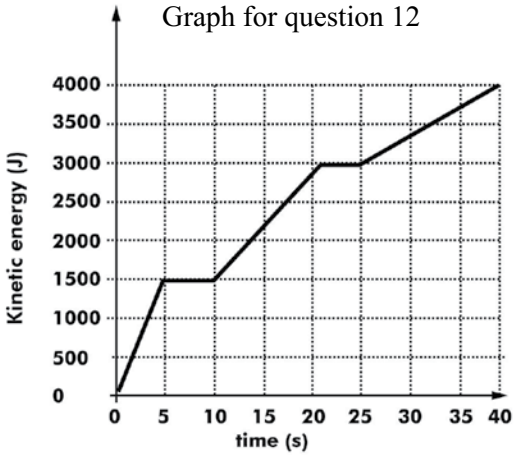


(b) Calculate how fast this hoist could lift a 2750 kg load of bricks and sand.

12. The graph shows Chris' increase in kinetic energy over a 40 s period as he accelerated his three-speed bicycle along a flat, straight road.

(a) Calculate how much power Chris is developing at the 2 s mark.

Graph for question 12



(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.

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13. 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 is 12 m and has a 15º incline to the horizontal. The speed of the carton is 6.0 m s^{-1} at the bottom.

    (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.

Comprehension 5.1

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.

Questions

1. (a) Explain the difference between momentum and impulse.

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(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. 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. (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.

(e) 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. (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 105 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}.

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.

Chapter 6 – Heating Processes

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. At temperatures above absolute zero all atoms and molecules have kinetic energy.

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.

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.

Specific heat capacity

The specific heat capacity of a pure substance is the ratio of the heat energy added to (or removed from) a sample of that substance to the resulting temperature change, per kilogram of the substance.

We express specific heat capacity mathematically as

$$c = \frac{Q}{m\,(T_f - T_i)} \quad \text{or} \quad c = \frac{Q}{m\,c\,\Delta T}$$

where Q is the quantity of energy absorbed or released, in J

m is the mass of substance in kg

$(T_f - T_i)$ or ΔT is the change in temperature in either K or °C.

c is the specific heat capacity of the substance in J kg^{-1} K^{-1} or J kg^{-1} °C^{-1}

The units that we use to measure specific heat capacity in the SI (international system) are joules per kilogram per degree. As long as T_f and T_i are both expressed in the same unit it does not matter whether T is measured in degrees Celsius (°C) or in kelvins (K).

$$Q = mc\,(T_f - T_i) \quad or \quad Q = mc\Delta T$$

For example, if 4.18×10^3 J of energy is added to 1.00 kg of water, the temperature of the water rises by 1.00 °C (or 1.00 K). The specific heat capacity of water is therefore
4.18×10^3 J kg^{-1} K^{-1}, or 4.18×10^3 J kg^{-1} °C^{-1}.

Where appropriate, use the following data in the problems in this chapter:

Density of water = 1.00×10^3 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	cast iron	460
ethelene glycol	2400	stainless steel	445
glass	670	steam (at 110 ºC)	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 result can be predicted by treating the hot water and the cold water as separate items even though they mix completely.

If two substances (or objects) are not in thermal equilibrium and are mixed in an isolated system, then:

$$\Delta Q = 0$$

For the two substances:

$$\Delta Q_1 + \Delta Q_2 = 0$$

$$(mc\Delta T)_1 + (mc\Delta T)_2 = 0$$

$$m_1 c_1 (T_f - T_i)_1 + m_2 c_2 (T_f - T_i)_2 = 0$$

Changes of State and Latent Heat

The specific latent heat capacity of a pure substance is the ratio of the heat energy added to (or removed from) a sample of that substance in order to change its state at constant temperature, per kilogram of the substance.

We express the latent heat capacity mathematically as

$$L = \frac{Q}{m}$$

where ***Q*** is the quantity of energy absorbed or released, in J

m is the mass of substance in kg

L is the specific latent heat capacity of the substance in J kg^{-1}

The units that we use to measure specific latent heat capacity in the SI (international system) are joules per kilogram.

The expression above can also be written as

$$\boldsymbol{Q = m\,L}$$

In general,

- the **latent heat of fusion** (L_f) of a substance is the energy per kilogram that must be added to melt the solid, or removed to freeze the liquid.

  For example, you must remove 3.34×10^5 J of energy from 1.00 kg of water at 0 °C (273 K) to change it to 1.00 kg of ice at 0 °C. The latent heat of fusion of water or ice at 0 °C is therefore 3.34×10^5 J kg^{-1}.

- the **latent heat of vaporisation** (L_v) of a substance is the energy per kilogram that must be added to boil the liquid, or removed to condense the vapour.

  For example, you must add 2.26×10^6 J of energy to 1.00 kg of water at 100°C (373 K) to change it to 1.00 kg of steam at 100 °C. The latent heat of vaporisation of water or steam at 100 °C is therefore 2.26×10^6 J kg^{-1}.

- at constant pressure, the melting point of a pure substance is the same as its freezing point. For water, the freezing/melting point at 100 kPa pressure is 0 °C.
- at constant pressure, the boiling point of a pure substance is the same as its condensation point. For water, the boiling/condensation point at 100 kPa pressure is 100 °C.
- Note that the latent heats of fusion and vaporisation of a single substance are different. We must be careful to use the appropriate value in calculations.

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.

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 6.1 – Thermal Equilibrium

6

Background

When two objects have different temperatures we know that they are not in thermal equilibrium. Thermal energy will flow from the object of high thermal energy to the object of low thermal equilibrium.

Aim

To produce a heating cooling graph for a range of systems as they move from thermal disequilibrium to equilibrium.

Apparatus (per group)

- 2 digital thermometers
- Data logging software
- 2 Insulated cups
- 100 mL measuring cylinder
- Hot water (approx 80 °C)
- Cool water (approx 10 °C)

Pre-Lab Discussion

- What is a heating cooling curve?

_____

_____

_____

- Discuss how you think that the temperature difference between the two initial masses of water will affect the rate at which heat energy will be transferred in the systems.

_____

_____

_____

- Discuss how you think that the mass of water samples will affect to which final temperature the solution, after it has been mixed, will be once it has achieved thermal equilibrium.

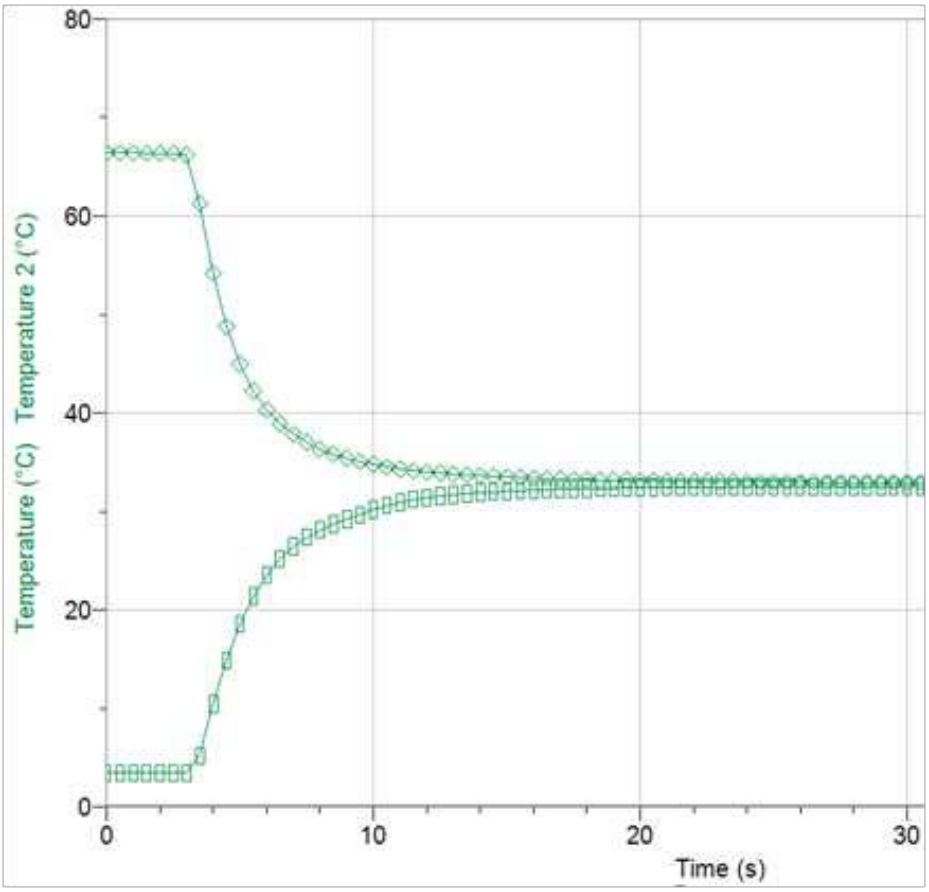
_____

_____

_____

Lab Notes

- Into your two insulated cups place equal masses of hot and cold water. Ideally start with a mass of 100 g (100 mL) in each container.
- Place a temperature probe into each of the cups and allow for the temperature of the probes to settle. This should take no longer than 20 seconds.
- Set your data logging software to record at a rate of 10 samples per second for 60 seconds.
- Press play on the datalogger and then pour one of the water samples into the other. Ensure that both temperature probes are now in the combined mass of water.
- Observe what is happening on both of the temperature *vs* time graphs. Ideally combine the graphs onto one temperature *vs* time axis.
- Repeat the process for a system which has different initial temperatures but the same masses.
- Repeat the process for a system which has different initial temperatures but different masses.
- A sample of an expected graph is shown on page 94.



Post-Lab Discussion

1. Describe what do you notice about the rate of which energy is transferred after the two solutions are mixed immediately after mixing and just before it achieves thermal equilibrium?

2. How do you know that the 'solution' has achieved thermal equilibrium?

3. How can you limit heat loss to the surroundings in this experiment?

4. Why is it wise to ensure that the temperature probes are at thermal equilibrium with the water before it is added to the other mass?

Experiment 6.2 – Specific Heat Capacity of a Metal

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

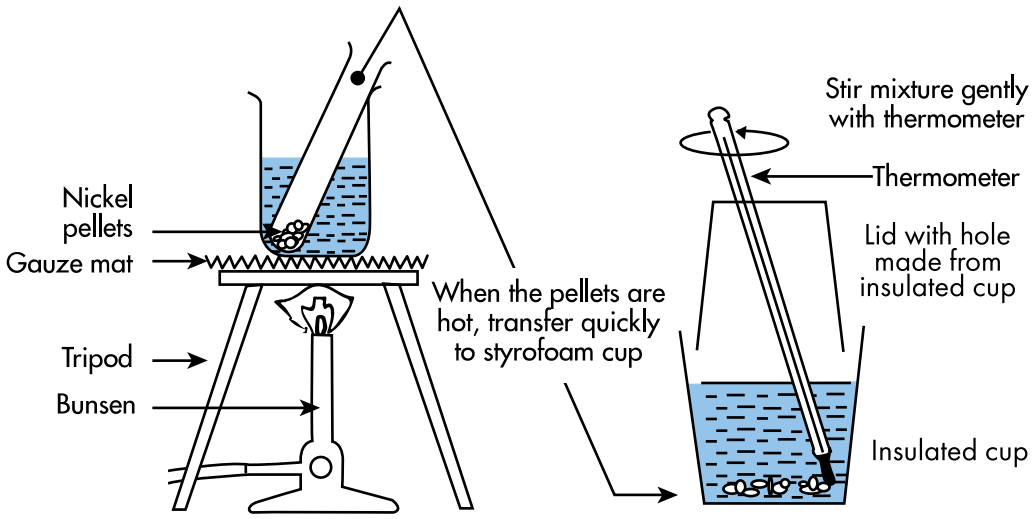
Heat gained by water = $m_{water}\, c_{water}(T_2 - T_1)$

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 6.2

Apparatus (per group)

- Insulated cup with a tight-fitting insulating lid
- two thermometers (if available, one 0 - 100 ºC and one 0 - 50 ºC)
- 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

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 masses and temperatures.

Lab-Notes

- Find and record the mass of the dry cup and lid._____
- Add about 50 mL of cool water to the cup.
- Find and record the mass of the 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 91). 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 ºC.
- Record the temperature of the water in the cup. Use the 0-50 ºC thermometer if you have one. _____
- Record the temperature of the metal pellets. Use the 0-100 ºC thermometer. _____
- Using a test tube holder, quickly transfer the metal pellets to the 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 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 cup.

2. Write a mathematical expression to represent the heat lost by the metal pellets in cooling.

3. Assuming insignificant heat loss to the 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 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.

6 Experiment 6.3 – Melting Ice

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.

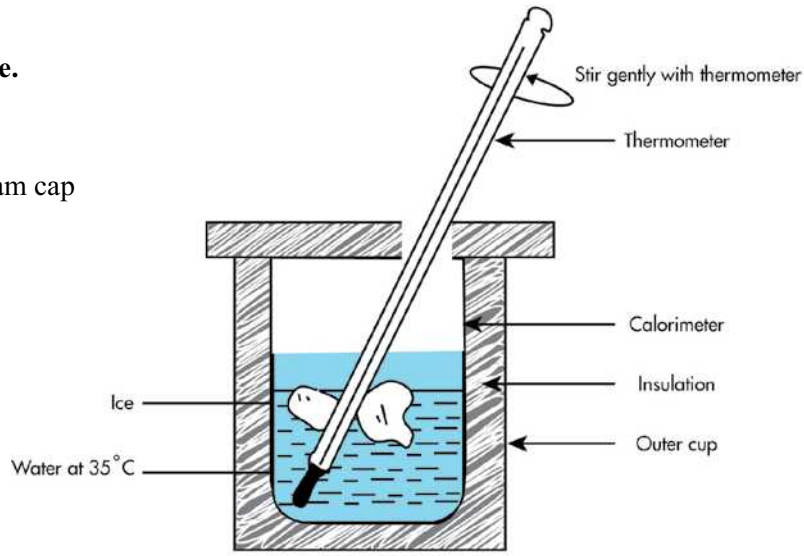
The quantity of heat required to change unit mass of solid to a liquid without a change in temperature is called the 'latent heat of fusion' of that substance.

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



Apparatus for Experiment 6.3

Aim

- 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 = $m_{ice} L_{fusion} + m_{ice\ water} c_{water}(T_2 - T_1)$

Lab Notes

- Measure and record the mass of the empty calorimeter. _____
- Fill the copper calorimeter about two-thirds full of water at about 35 ºC, 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 39. 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 ºC._____
- 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 ºC. 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_f).

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 ºC better for cooling a sprained ankle than similar-sized packs containing water at 0 ºC

Problem Set 6.1 – Specific Heat Capacity

6

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.

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 olive oil into two urns. The urns are the same general size and shape. One is made from cast iron ($c = 460\ J\ kg^{-1}\ K^{-1}$) and the other from brass ($c = 380\ J\ kg^{-1}\ K^{-1}$).

   (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.

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 ºC to 75.0 ºC? Assume that the system converts all the solar energy to thermal energy of the water.

4. 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 ($c_{air} = 1000\ J\ kg^{-1}\ K^{-1}$).

5. A foundry operator finds that it takes 55.3 MJ of heat to heat a 286 kg mass of steel from 22.0 ºC to 452 ºC. Calculate the specific heat capacity of that steel.

6. 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 $4.13 \times 10^3\ J\ kg^{-1}\ K^{-1}$. Determine the final temperature of the soup.

7. Motorists may use ethylene glycol ($c = 2400\ J\ kg^{-1}\ K^{-1}$) instead of water in their cars' cooling systems.

   (a) Compare the time it takes for the coolant to reach 100 ºC 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.

   _____

   _____

   _____

   _____

8. 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 ºC. What is the smallest mass of water the camper can use without the water boiling?

9. A cook pours 800 g of soup at 98.0 ºC 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 ºC to 97.0 ºC. What is the specific heat capacity of the soup?

10. 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 ºC. You decide to cool the tea by adding 35.0 g of water at 18.0 ºC. 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. What can conclude about this party?

11. A mechanic adds 655 g of ethylene glycol antifreeze (c = 2400 J kg^{-1} K^{-1}) at 22.0 ºC to a car's radiator that already contains 6.75 L of water at 92.0 ºC. If the 4.50 kg radiator is made of copper (c = 390 J kg^{-1} K^{-1}), calculate the final temperature of the mixture.

6 Problem Set 6.2 – Change of State - Latent Heat

1. Calculate how much heat:

   (a) 28.6 kg of ice at 0.00 ºC absorbs while it melts completely;

   (b) 423 g of steam at 100.0 ºC releases when it condenses to water at the same temperature;

   (c) 4.58 g of silver absorbs as it boils (L_v (silver) = 2.35 x 10^6 J kg^{-1}).

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 x 10^4 J of heat when it condenses at its boiling point. Calculate the latent heat of vaporisation of cadmium.

3. 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.

4. 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.

5. 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 ºC) is 2.42×10^6 J kg^{-1}.

   (a) If a person evaporates 4.00 L of water through perspiration, calculate how much heat energy the person loses. Assume the evaporating perspiration does not absorb heat from anywhere else.

   (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.

6. A couple of angling brothers, Damien and Adam, decide to make fishing sinkers by pouring molten lead into a mould. Damien melted 55.0 g of lead to cast a sinker. The specific heat of liquid lead is 105 J kg^{-1} °C^{-1} and for solid lead it's 130 J kg^{-1} °C^{-1}. The latent heat of fusion of lead is 2.4×10^4 J kg^{-1}.

   (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) Find the total amount of heat released.

7. An immersion heater can supply heat at the rate of 48.0 J s^{-1}. Calculate:

   (a) How long will it take to heat 12.5 g of water, originally at 26.5 ºC, 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?

8. 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 ºC 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.

9. 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 ºC to 452 ºC.

   (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 ºC, would cool the hot steel down to 100 ºC?

(c) What assumptions have you made in calculating the answer to (b) above?

10. 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 ºC to 185 ºC by spraying water onto the plate.

(a) Calculate the mass of water at 20.0 ºC you will need, assuming all the water evaporates to steam at 100.0 ºC.

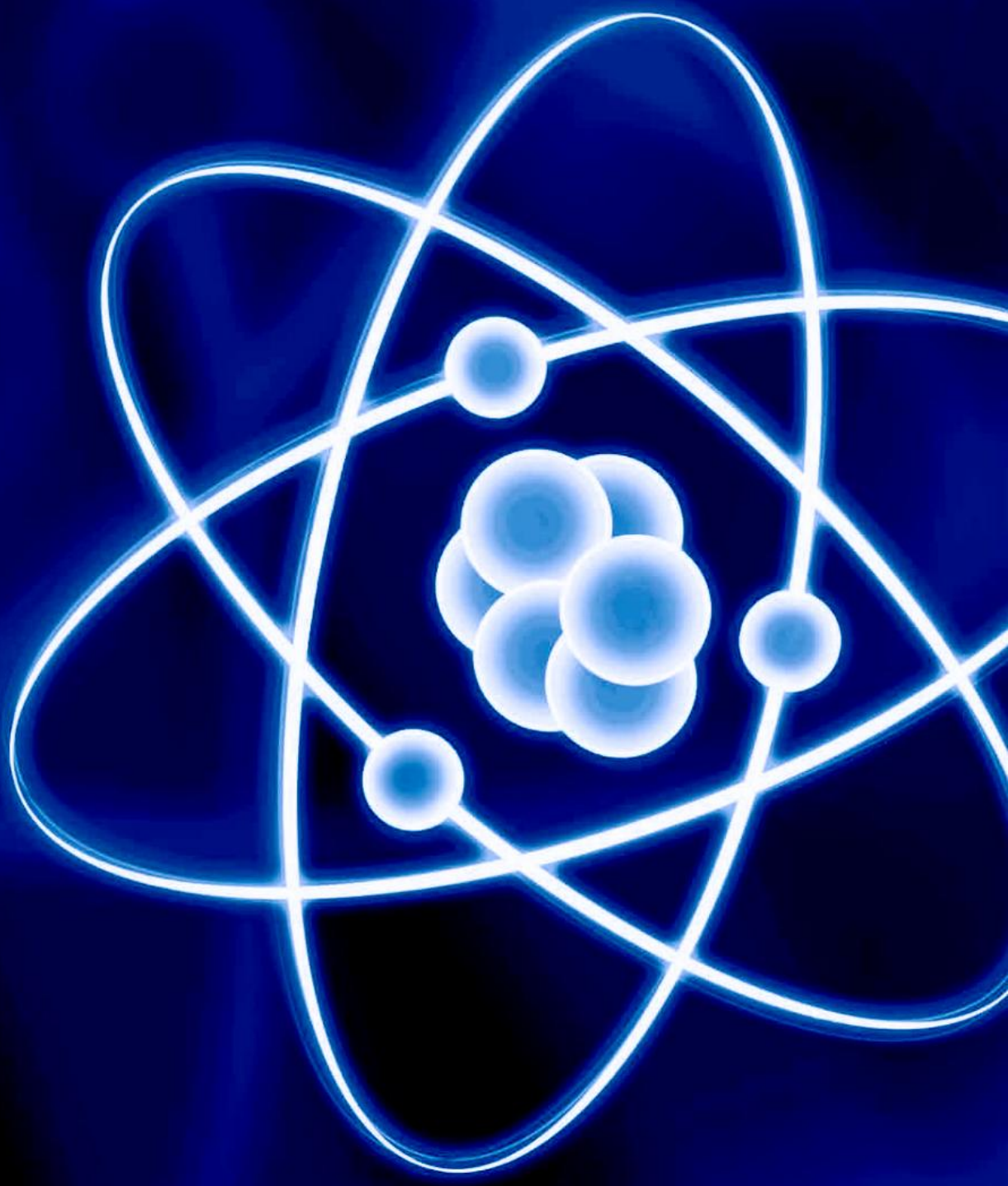
(b) What mass of ice at 0.00 ºC would have the same effect?

11. A maintenance worker uses steam to defrost a small freezer that contains 1.50 kg of ice at 0.00 ºC. Calculate the mass of dry steam at 100 °C he needs to convert all the ice to water at 24.5 ºC. Assume the heat absorbed by the freezer's plastic lining is negligible.

Unit 2 – Waves, Nuclear & Electrical Physics

Waves

Chapters 7 – The Natures of Waves



Chapter 7 – The Nature of Waves

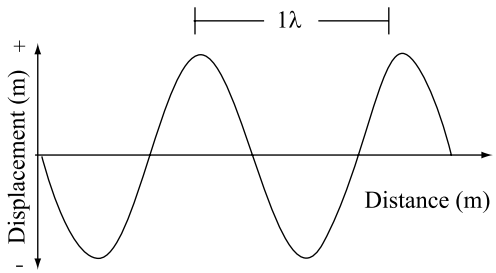
Waves and Wave Behaviour

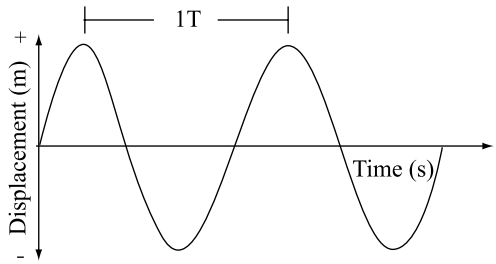
Remember the following important principles

Physicists describe a wave as a disturbance that passes through an elastic medium by means of particles vibrating about their mean position. The wave transfers energy through the medium but does not displace the medium itself. An electromagnetic wave does necessarily need a medium.

You can represent waves by a sine curve on a displacement-distance graph, or, if you study the motion of one point of the wave, on a displacement-time graph.

Graphically, you can show waves as follows:





The properties of waves are related by the following two equations: $v = \lambda f$ and $f = \frac{1}{T}$

where the symbols represent the terms in the following table:

Term	Symbol	Definition	Unit
Phase	φ	Identifies one or more specific points on a harmonic wave train, by reference to the angle in the Sin expression for the wave	–
Wavelength	λ	The distance between two adjacent points in a wave which are in phase	m
Frequency	f	The number of crests or troughs which pass a point or per unit time, or the number of cycles per second	s^{-1} or Hz
Period	T	The time taken for one complete cycle, or the time taken for one complete wave to pass a given point	s
Wave speed	v	The speed at which a crest or a trough moves through the medium	$m\ s^{-1}$
Amplitude	a	The maximum displacement of a particle from its mean position	m

Air columns and strings

Both air columns and strings have nodes and antinodes.

$$\text{Inter-nodal distance} = \frac{\lambda}{2}$$

Reflection, refraction and diffraction

Waves can undergo reflection, refraction or diffraction.

Reflection results when the wave bounces off a surface. The laws of reflection determine the wave's direction after reflection. When a sound wave is reflected, you hear an echo if the reflecting surface is sufficiently far away.

Refraction results when waves bend as they pass from one medium to another. The change in direction is caused by a change in the speed of the wave as it enters a new medium.

Resonance and interference

Interference between waves is common and can cause several different effects. When waves move through the same medium at the same time, constructive and destructive interference may result. This may lead to standing waves or diffraction patterns forming.

Forced vibration occurs when an oscillating energy source forces an object to vibrate in time with the source. This is how loudspeakers work.

Resonance happens when the frequency of forced vibration matches a body's **natural frequency**. The result is a much larger amplitude of vibration than the forced vibration at other frequencies.

7 Experiment 7.1 – Making Waves

Background

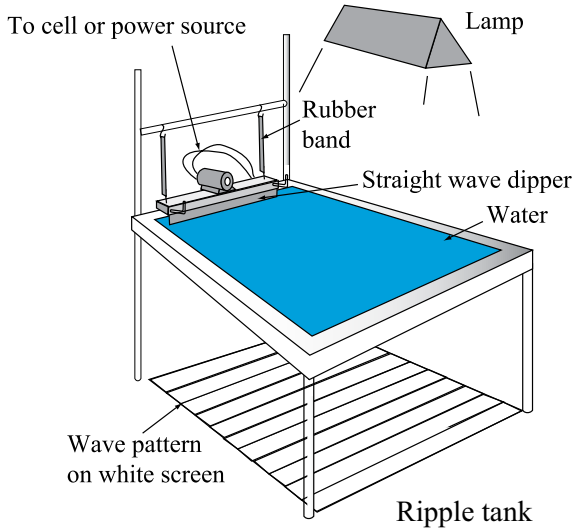
Mechanical waves are affected by various barriers, boundaries, apertures and media. When waves strike barriers they can be reflected. When they pass through apertures or pass edges their direction changes due to diffraction. When they pass from one medium to another, their velocity changes and so may change direction due to refraction. When two different waves collide they interfere. You can observe and study these wave properties using water waves.

Aim

This is a qualitative investigation designed to investigate various wave properties.

Apparatus

- white paper
- stroboscope
- rheostat
- power supply
- leads
- ripple tank kit, including
  - motor
  - vibrator bar
  - dippers
  - reflectors
  - barriers and small Perspex sheet
  - overhead light



Pre-Lab

- Set up the equipment as shown in the diagram.
- Place a lamp 50 cm above the tank.
- Arrange the equipment to show an image of ripple tank on a white backing.
- Add water to 5 mm depth in the tank. Adjust the tank to ensure it is level.

Lab Notes

- Adjust the rheostat and observe the relationship between frequency of the vibrator and wavelength. Draw and describe what you observe.
- Place a flat barrier in the tank and observe "head on" reflection. Draw and describe what you observe.

- The diagram below provides an outline for you to complete.

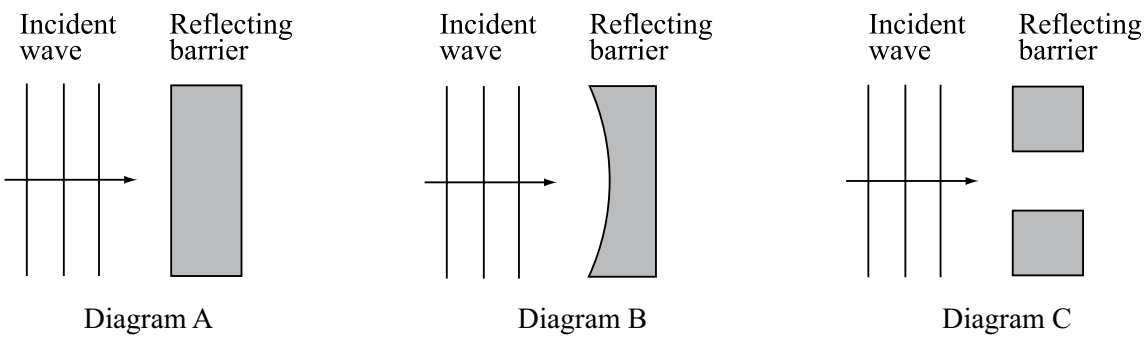


Diagram A Diagram B Diagram C

- Move the barrier so that the waves now strike it at an angle. Again describe and draw what you observe.
- Remove the barrier and replace it with a concave surface. Use the diagram as a guide to describe and draw what you observe.
- Turn the barrier around so that it is now a convex reflector. Describe and draw what you observe.
- Remove the barrier. Place the Perspex sheet into the tank to create a a shallow region. Draw a diagram to show the effect of the shallow water upon waves normal to it.
- Turn the sheet so that the waves are now incident at an acute angle. Draw what you observe.
- Place two barriers in the tank to create a small aperture. Draw what you observe.
- Use the rheostat and increase the wavelength. Again draw what you observe.
- Increase the aperture and repeat the previous two steps. Draw appropriate diagrams to show the observed effects.
- Remove one of the barriers and observe what occurs at the end of the remaining barrier. Describe and draw what you observe.
- Replace the bar with a dipper to create circular waves.
- Repeat all the previous steps using circular waves. Draw your observations.
- Remove the dipper, and replace it with two dippers. Draw what you observe.

Post-Lab Discussion

1. In which of the above experiments did you observe reflection?
2. In which of the above experiments did you observe refraction?
3. In which of the above experiments did you observe diffraction?
4. In which of the above experiments did you observe interference?
6. How does this relationship explain the fact that sound travels around corners? Which wavelengths of sound would you expect to hear most easily around a corner?

   _____

   _____

   _____

7. Under what conditions would you expect sound waves to interfere?

   _____

   _____

   _____

   _____

8. Under what conditions would you expect sound waves to create a stable interference pattern similar to that created in your experiment? Describe what this pattern might sound like to a stationary observer, and to an observer who moves through the pattern.

   _____

   _____

   _____

   _____

7 Experiment 7.2 – Measuring the speed of sound

Background

Sound is a form of wave motion. It is a mechanical wave that involves the longitudinal displacement of particles in a medium. The type of medium will affect the speed at which sound will travel. By accurately measuring the difference between the times that two microphones hear the same sound and knowing their distance apart we can determine the speed in air using

Where: **v** = speed

s = distance between microphones

t = time delay

Aim

To determine the speed of sound in air.

Apparatus

- counter timer
- two microphones
- two or three audio amplifiers (depending upon the ability of the second microphone to pick up the sound)
- electrical leads (two of which are 5 m long)
- tape measure
- thermometer
- a device to make a sharp noise (or you could clap your hands loudly)

Pre-Lab

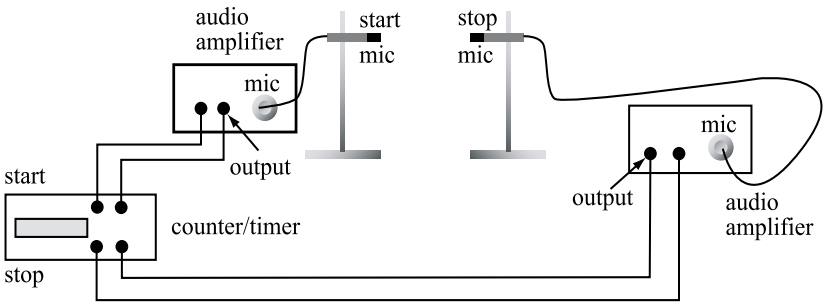
- Use the table on the right to record your data.
- Set the mode select switch of the counter timer to M.
- Use two small wires to connect from the Start sockets of the counter time to the Output sockets of one audio amplifier.
- Connect a microphone to the microphone (Mic) sockets of the audio amplifier.
- Hold the microphone in position using a retort stand and clamp.
- Use the long wires to connect from the Stop sockets of the counter timer to the Output sockets of another audio amplifier placed at the other end of the room. If you do not have a powerful amplifier use two in series.
- Connect the second microphone to the mic socket of this audio amplifier.
- Turn the power to the microphones, audio amplifiers and counter-timer to On.
- A stop watch may also be used, however experimental uncertainties will be high.

Trial	Time (s)
1	
2	
3	
4	
Average	
Uncertainty	

Alternative method of data collection

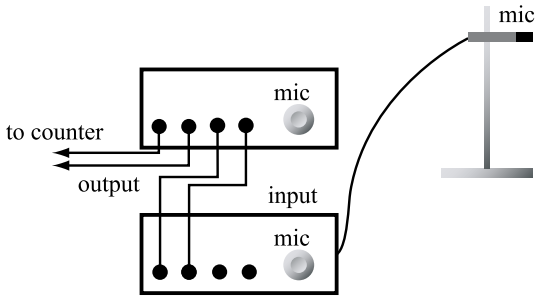
- Use a phone to record the noise from very far away (at least 50 metres)
- Determine the time difference between the video frame showing the noise and the receiving the audio signal.

Quietly reset the counter-timer to show zero on the display.



Make a sharp sound just above the Start microphone. Trials to obtain the correct sound level may be required.

- Adjust the volume control on both audio amplifiers so that a reading is displayed every time a sharp sound is made.
- If the timer does not stop running, the distant microphone is not picking up the sound. This problem may be corrected by connecting the microphone in series with the second audio-amplifier as shown in the diagram.



Lab Notes

- Once the counter timer is working we can take measurements.
- With the counter-timer reset to zero, make a short, sharp sound such as the sound made by clapping two pieces of wood together.
- Record the time shown on the display.
- Reset, and repeat four more times, determine an uncertainty.
- Measure distance between the microphones, included an uncertainty.
- Measure and record the air temperature. _____

Post-Lab Discussion

1. Use your results of distance and time to determine the speed of sound.

2. Look up the average speed of sound at known temperature using a physics reference book.

3. The speed of sound in air increases by 0.61 m s^{-1} per °C increase in temperature. Explain why the speed of sound increases as temperature increases.

4. Determine the speed of sound using the researched values.

5. Propagate your uncertainties in time and distance to estimate an uncertainty in your speed of sound.

6. State the value for the speed of sound in air as determined by you in this experiment and calculate the percentage difference between your value and the accepted value.

7. Give reasons why your answer may not be the same as the theoretical value.

8. What other factors, apart from temperature, affect the speed of sound in air?

Experiment 7.3 – Observing Wave Pulses

7

DEMONSTRATION

Background

In a transverse wave, the particles of the medium move at right angles to the direction of the wave motion. In a longitudinal wave, the particles of the medium move parallel to the direction of the wave motion.

Aim

To examine both transverse and longitudinal waves moving along a stretched spring.

Apparatus

- Long spring
- slinky spring
- string (3 m)
- mass (approximately 100 g)

Part A: Transverse wave pulses

Pre-Lab

- Lay the long spring along the floor. Anchor one end and stretch the spring.

Lab Notes

- Give the spring a sideways flick to produce a single transverse pulse.
- Try producing pulses of different shape and amplitude.

Post-Lab Discussion

1. What happens to the size or amplitude and shape of the pulse as it travels down the spring? Why?

   _____

   _____

2. Can one pulse catch up with another? Explain?

   _____

   _____

3. If the tension in the spring is increased, what happens to the speed of the pulse?

4. What happens to the pulse when it is reflected from the fixed end?

   _____

   _____

5. Observe and describe what happens when two pulses are sent along the spring in opposite directions at the same time. Send one pulse down the spring and as it is reflected from the fixed end, send another pulse.

   _____

   _____

6. By oscillating the spring from side to side at a regular frequency, produce a continuous wave.
7. What happens to the wavelength as the frequency changes?

8. Vary the frequency of the sideways oscillation until the forward and reflected waves combine to form a wave pattern which does not appear to move along the spring. This is called a standing wave. What are the conditions necessary for the production of standing waves?

_____

_____

_____

Part B: Longitudinal waves

Lab Notes

- Try producing pulses of different shape and amplitude.

Post-Lab Discussion

1. What happens to the size or amplitude and shape of the pulse as it travels down the spring? Why?

_____

_____

_____

2. Can one pulse catch up with another?

3. If the tension in the spring is increased, what happens to the speed of the pulse?

4. What happens to the pulse when it is reflected from the fixed end?

_____

_____

_____

5. Observe and describe what happens when two pulses are sent along the spring in opposite directions at the same time. Send one pulse down the spring and as it is reflected from the fixed end, send another pulse.

_____

_____

_____

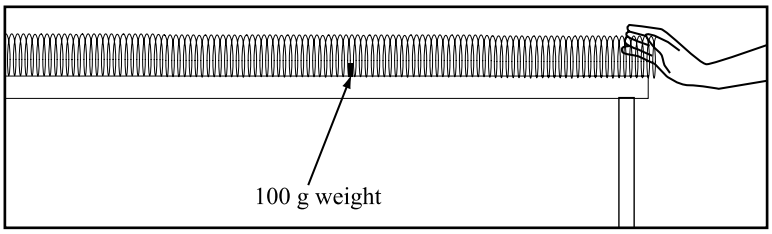
Part C: Waves at a boundary

Lab Notes

- Fasten one end of the long spring to a taut piece of string which is about 3 m long. Send a pulse down from the free end and observe the reflection of a transverse pulse at the end which is connected to the string.
- Repeat, with the spring connected to the string by a runner such as a curtain ring.

Post-Lab Discussion

1. How does the reflection from a fixed and a free end compare?



2. Set up the spring as in Part A and attach a small mass, such as a 100 g piece of lead, to one of the coils of the slinky spring or the long spring. This produces a `discontinuity' in the wave medium by creating one heavy coil surrounded by lighter ones. How is the wave energy reflected and transmitted at the discontinuity?

3. Join the slinky and long springs together. Fix the long spring at the other end and ensure a suitable tension is maintained. Send a transverse wave pulse down the spring. What happens after the pulse reaches the boundary where the two springs join?

4. With the springs still joined, fix the other end of the slinky. Send a pulse down the long spring towards the slinky. What happens after the pulse reaches the boundary?

7 Experiment 7.4 – Resonance in Strings

Background

When a wave pulse travelling along a stretched string reaches the end of the string, the pulse is reflected back along its original path. If the pulse is one of a series of pulses at regular intervals, the incoming pulses will interfere with the reflected pulses. Under certain conditions, this leads to the formation of a standing wave in the string.

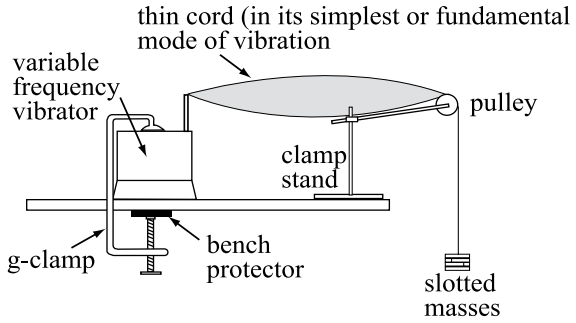
The fixed ends of the string are always displacement nodes, and are separated by one or more displacement antinodes.

Aim

To demonstrate interference and resonance in vibrating stretched strings.

Apparatus

- Variable frequency (wave trough) vibrator
- thin cord
- pulley
- slotted masses
- clamp
- metre rule



Pre-Lab

- Record your measurements in the table below.

- Set up the equipment as shown in the diagram above.
- Suspend a small mass from the end of the cord and set the frequency generator to its minimum setting.
- Gradually increase the frequency until a standing wave is produced which has only one antinode. (If you can only produce a wave that has two or more antinodes, reduce the size of the suspended mass.)

Lab Notes

- Keeping the tension and the length of the cord constant, gradually increase the frequency until a different standing wave pattern is produced. Observe the pattern. Take any measurements that will allow you to calculate the velocity of the wave in the string.

Post-Lab Discussion

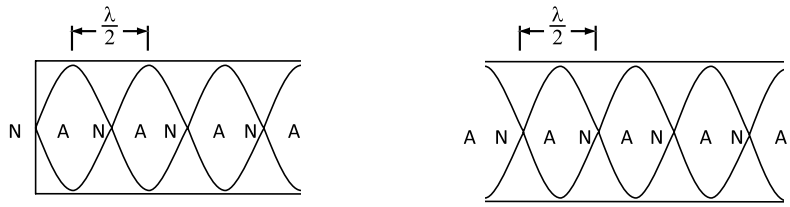
1. Determine the velocity of the wave in the string.

2. If this is a string in a violin, how could it be tuned to produce a note of some desired frequency?

7 Experiment 7.5 – Resonance in Air Columns

Background

Stationary or standing waves can be produced in pipes in much the same way as that in a stretched string. The diagrams below represent standing waves in both closed and open ended pipes.



N - is a node point of zero displacement of air molecules.
A - is an antinode or point of maximum displacement of air molecules.

The internodal distance (distance between two successive nodes) is half a wavelength. If you know the frequency of the sound then you can work out the velocity of sound in the pipe from:

$$v = f\lambda$$

where **v** = velocity of sound in metres per second

f = frequency of the note in hertz

λ = wavelength of the note in metres.

Note that there are two ways to describe nodes and antinodes in air columns. At a pressure node, the pressure remains constant (but the medium undergoes the most vibration). At a displacement node, the medium undergoes zero vibration (but the pressure varies the most). An open end of an air column is a pressure node or a displacement antinode. A closed end of an air column is a pressure antinode or a displacement node.

This experiment can be attempted in two very different ways. In Part 1 you will use an open pipe together with a microphone, an audio amplifier and a cathode ray oscilloscope to detect the position of successive nodes in the open pipe, and hence determine the wavelength of the sound. Part 2 uses a tuning fork and a closed pipe to detect the position of successive harmonics and again determine the wavelength.

Aim

To measure the speed of sound in air using standing waves.

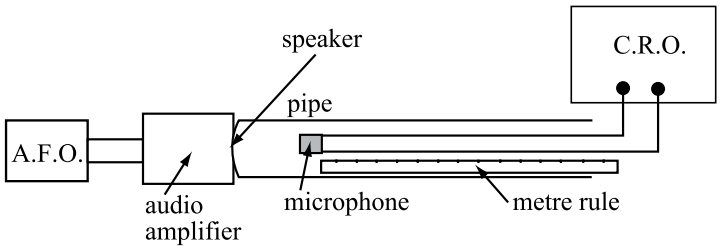
Apparatus

- audio-frequency oscillator (AFO)
- audio amplifier
- cathode ray oscilloscope (CRO)
- small microphone or crystal earpiece
- metre rule
- large measuring cylinder - (1 L or larger)
- thermometer - (0–100 °C)
- glass or plastic tubing - (large diameter, 0.5–1.0 m long)
- selection of tuning forks

Part A: Using an Open Pipe

Pre-Lab

- Draw up a table for recording your results.
- Set up the equipment as shown in the figure below connecting the microphone to the vertical output of the cathode ray oscilloscope (CRO).
- Set the audio frequency oscillator (AFO) to approximately 3000 Hz.
- Adjust the time-base on the CRO to give a fairly crowded pattern on the screen and set the Y -gain to approximately 0.2 V cm^{-1}.
- Slide the metre rule along the pipe until the microphone is about half way along the tube.
- Adjust the frequency of the AFO to give a maximum amplitude. Do not alter frequency as the system has now been adjusted to give a standing wave in the pipe.



Lab Notes

Slowly slide the rule out of the tube while watching the changes on the CRO. As the microphone approaches a node you will notice the amplitude on the CRO will decrease until it reaches a minimum at the node.

- Measure and record the distance between the nodes. It is important to make these measurements as accurate as possible.
- Record your results in a table.
- Repeat the process for various other nodes in the pipe and average the results for at least five measurements.
- Repeat the whole process for frequencies of 1000 Hz, 2000 Hz, 4000 Hz and 5000 Hz.
- Measure and record the temperature of the air in the room.

Post-Lab Discussion

1. Calculate the speed of sound for each set of readings.

2. State the average speed of sound from your readings, and the temperature.

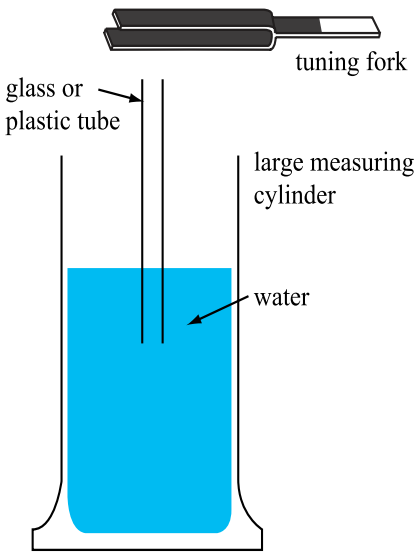
3. Estimate the measurement uncertainties in the experiment. Which measurement introduced the greatest uncertainty? Restate your measured speed of sound, including the uncertainty..

4. Are certain frequencies more suitable for this experiment than others? Explain your answer.

5. What factors affect the speed of sound in the pipe? Describe briefy the effect of each..

Part B: Using a closed pipe

Pre-Lab



- Draw up a table to record your measurements.
- Fill the measuring cylinder to within 10 cm of the top
- Place the glass or plastic tube into the measuring cylinder as shown in the diagram.
- Select a tuning fork and record its frequency.

Lab Notes

- Strike the tuning fork and position it near the open end of the tube.
- Slowly raise the tube until resonance is heard. Carefully adjust the length of the tube until the loudest sound is heard.
- Measure the length of the tube above the water level and record this as (1).
- Record results in a suitable table.
- Raise the tube further and listen for the position of resonance corresponding to the next harmonic. It may be necessary to use a telescopic tube.
- Measure the length of the tube above the water and record this as (2)
- Repeat the Pre-Lab for tuning forks of different frequencies. Hint: Use higher frequencies as these are easier to work with.
- Record the temperature of the air in the room.

Note: You may hear some harmonics of the tuning fork frequency. Ignore these positions.

Post-Lab Discussion

1. Calculate the speed of sound for each set of readings.

2. State the average speed of sound from your readings, and the temperature.

3. Estimate the measurement uncertainties in the experiment. Which measurement introduced the greatest uncertainty? Restate your measured speed of sound, including the uncertainty..

4. Are certain frequencies more suitable for this experiment than others? Explain your answer.

5. What factors affect the speed of sound in the pipe? Describe briefly the effect of each..

7 Problem Set 7.1 – Waves

1. A student sends a longitudinal wave pulse down a slinky spring which is pulled tightly. It takes 0.850 s for the pulse to travel along the 12.5 m slinky spring. Determine the velocity of sound in the slinky.

2. A second student sends a transverse wave down a stretched rope. The student measures the wavelength of the transverse wave and finds it to be 0.662 m. If the student is producing four waves per second, determine the velocity of sound in the rope.

3. A tuning fork is producing a frequency of 120 Hz. The speed of sound in the air around the tuning fork is measured to be 346 ms^{-1}. Determine the period and the wavelength of the sound signal.

4. Transverse water waves pass the end of a pier at the rate of four crests every 6.45 s. Determine the velocity of the waves if the distance between crests is measured to be 8.00 m.

5. A fisherperson has a small float that is moving up and down with the motion of the sea. He is curious as to why the float does not appear to move along with the waves as they move past his float. Explain this observation.

   _____

   _____

   _____

6. Seismic waves can be both transverse and longitudinal at the same time. The Earth after a large seismic event can do the same. Identify which type of wave usually does the most damage to structures and explain why.

   _____

   _____

   _____

   _____

   _____

7. The speed of sound varies with temperature according to the equation $v = 331 + 0.6T$, where v is the speed and T is the temperature in °C. A sound technician finds the speed of sound is 340 m s^{-1} one day and 343 m s^{-1} the following day. If the difference is due to temperature difference only, determine the temperature difference

8. A park has a circular fence around it. The top rail of the fence is a metal pipe. A physics teacher sets a group of students the task of finding the radius of the fence by using their knowledge of sound. One member of the group hits the pipe with a hammer giving a sound of 350 Hz; a second student, standing directly opposite on the other side of the park, detects two sounds, 0.300 s apart. If the speed of sound is 330 m s^{-1} in air and 1310 m s^{-1} in this metal pipe, calculate the radius of the fence.

9. If you throw a stone into a still pond, ripples radiate out from where the stone enters the water. A group decides to take some measurements and record the following data to calculate the wavelength, speed and frequency of the ripples. Some five seconds after a stone entered the water, they noted that 42 ripples covered a distance of 2.00 m from where the stone entered the water. Calculate the: (a) wavelength (b) speed (c) frequency, of the ripples or waves.

10. While sitting on the beach you notice water waves hitting the shore at the rate of one wave every 2.00 s. Calculate: (a) the period of the waves (b) the frequency of the waves.

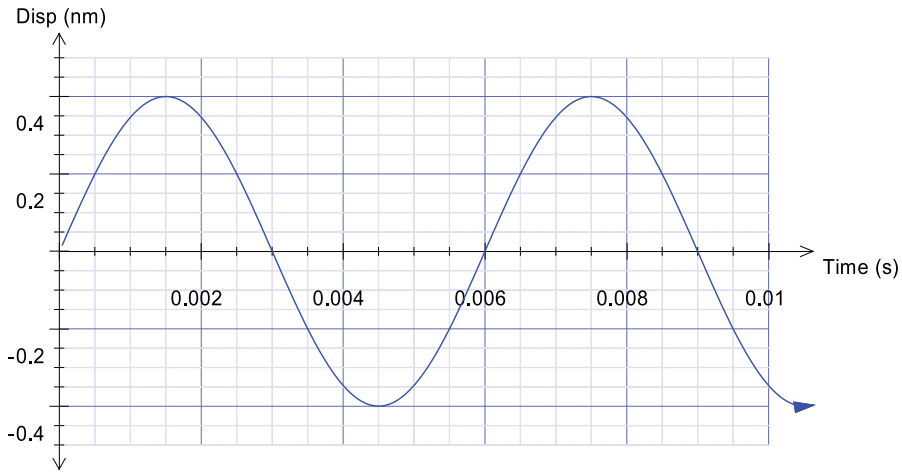
11. Draw the displacement vs time graphs for the following sound signals in air. Ensure that you identify the amplitude and the period clearly by selecting an appropriate scale.

    (a) A 2.00 Hz sound signal in which the molecules move a maximum of 1.00 mm from their rest positions

    (b) A 5.00 Hz sound signal in which the molecules move a maximum of 2.00 nm from their rest position.

(c) A 0.500 Hz sound signal in which the molecules move a maximum of 5.00 nm from their rest position.

12. You are given the following displacement vs time graphs. Determine the period, frequency and amplitude (in nm or mm) for the sound signals, and calculate the wavelength given that the velocity of sound is 339 m s^{-1}

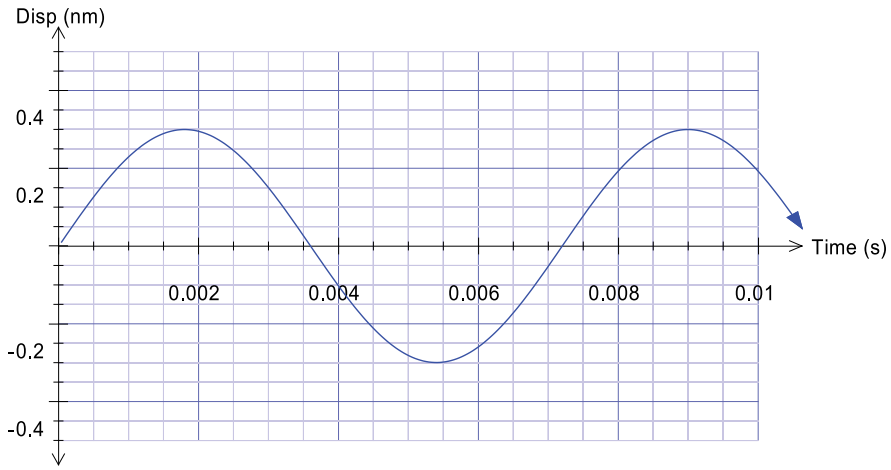


T = _____

f = _____

A = _____

λ = _____

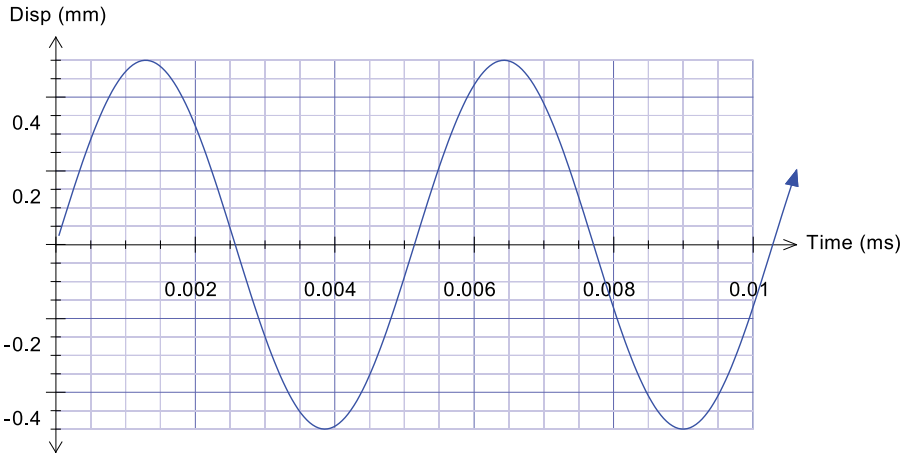


T = _____

f = _____

A = _____

λ = _____



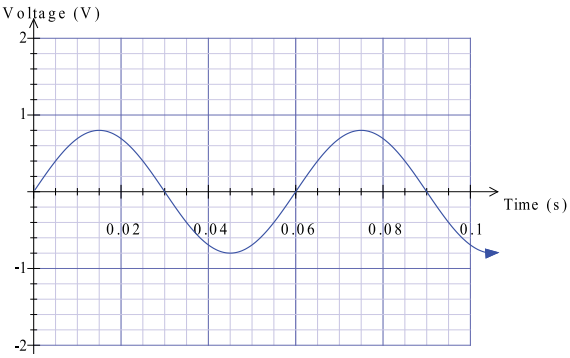
T = _____

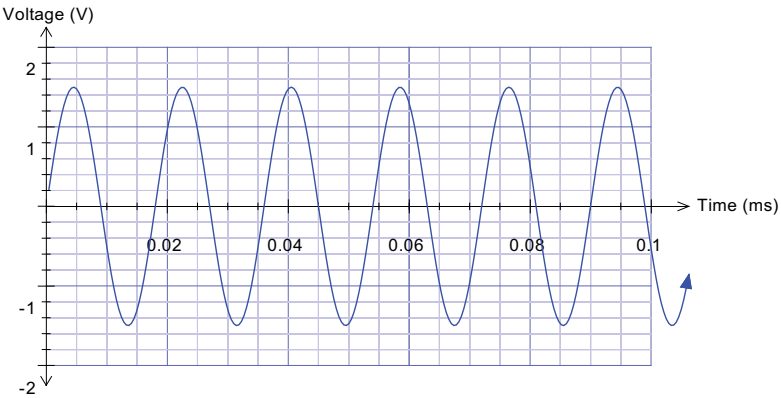
f = _____

A = _____

λ = _____

13. You are given the following voltage vs time graphs for a simple microphone connected to computer running analysis software. Determine the period and frequency of the sound waves, and calculate the wavelength given that the velocity of sound is 349 m s^{-1}.





T = _____

f = _____

A = _____

λ = _____

T = _____

f = _____

A = _____

λ = _____

14. Jane whistles into a microphone connected to a cathode ray oscilloscope. Figure 1 (left)shows the trace on the oscilloscope. George then whistles into the same microphone from the same distance. Figure 2 shows his whistle's oscilloscope trace. During the experiment the controls on the cathode ray oscilloscope are unaltered.

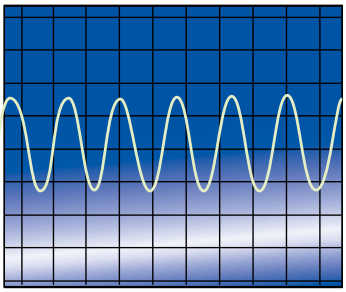


Figure 1

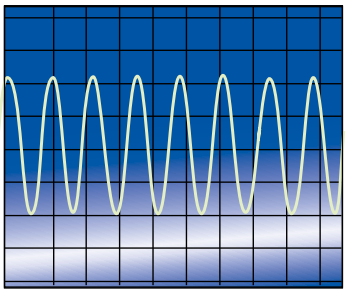


Figure 2

(a) Who whistles louder?

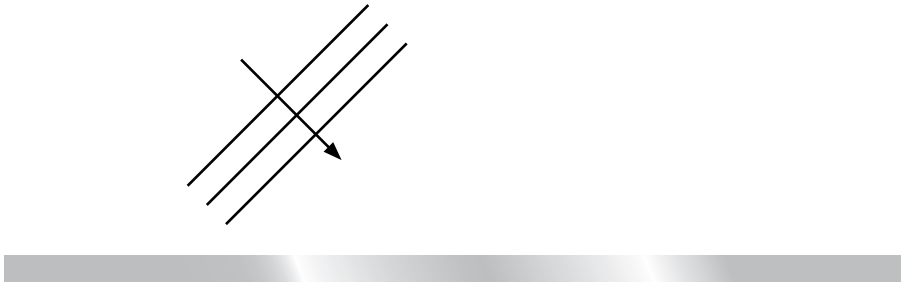
(b) Whose note has the greater wavelength?

(c) Whose note has the greater frequency?

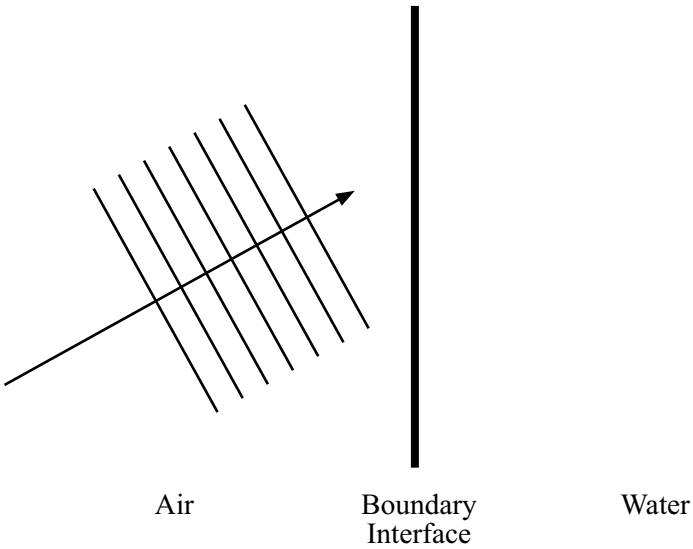
Problem Set 7.2 – Wave Behaviour

7

1. You are trying to explain how sound waves reflect to a new physics student. Finish the following diagram showing sound reflecting from a surface. Include rays, wavefronts, angle of incidence, normal and all labels.



2. Finish the following diagram showing sound refracting as it passes from air to water. Include rays, wavefronts, angle of incidence, normal and all labels.



3. When a sound wave meets your ear, your ear may absorb, transmit, or reflect some of the wave's energy.

   (a) What happens to the wavelength of a reflected wave?

   (b) What happens to the frequency of a transmitted wave?

   (c) Your ear responds to sound waves of wavelengths between $\lambda = 0.02$ m and $\lambda = 10$ m. If the speed of sound in air is 335 m s^{-1}, calculate the range of frequencies that your ear can detect.

4. Sound researchers have noticed the way completely blind people can walk down busy streets without bumping into things. When researchers block such a blind person's ears, the blind person tends to bump into more objects. Explain why this happens?

_____

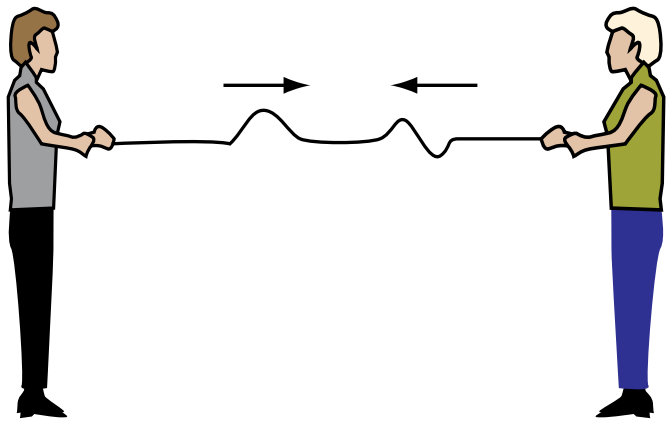
_____

_____

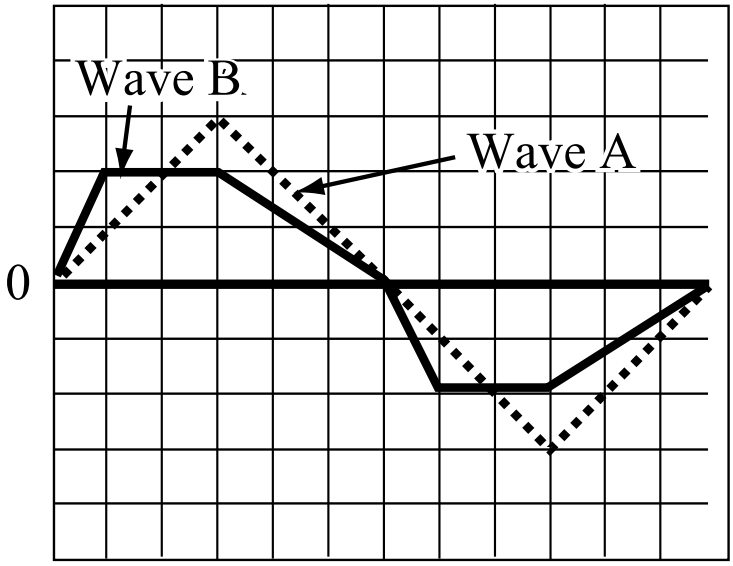
_____

5. A marine biologist uses an echo-sounder to find schools of fish. The echo-sounder uses ultrasound pulses. An echo-sounder sends a pulse to the sea bottom and it returns to the instrument 0.100 s later. If the speed of sound in water is 1456 m s^{-1}, what is the water depth recorded by that echo-sounder?

6. During an experiment you and your partner hold onto opposite ends of a rope. You each jerk the rope to send a pulse along the rope from each end, as shown in the diagram. On the diagram show what the resultant pulse looks like when the two pulses are exactly superimposed.



7. The diagram right shows a CRO trace of two superimposed waves. Use the superposition principle to draw a resultant displacement wave.



8. A child's whistle has a distance of 120 mm between the open and closed ends. Determine the lowest frequency note that the child can make on that whistle, given the velocity of sound is 340 m s^{-1}.

9. A musical ensemble includes a violin, a guitar and a double bass.

   (a) The violinist produces a fundamental note of frequency 512 Hz. If the string producing the note is 500 mm long, calculate the speed of the waves along the string.

   (b) The guitarist produces different notes by plucking a string with one hand while sliding a finger of the other hand down the string. Describe what happens to the note the guitar produces when the finger slides down the string, and explain why the note changes.

   (c) The double bass has strings 1.25 m long. When the musician plucks one of the strings the speed of the waves in the string is 210 m s^{-1}. Determine the frequencies of the first three harmonics (fundamental and first two overtones) of this string.

10. An organ repairer noticed that dust seemed to collect in certain regions inside organ pipes. She suspected that the way the sound waves behaved inside the pipe determined the dust collection points. Draw the standing wave diagrams to represent the first three harmonics as displacement waves in an organ pipe:

(a) Open at both ends – Draw the pressure waveforms.

(b) Open at one end only – Draw the displacement waveforms.

11. On the right is a table of frequency ranges for instruments and voices.

(a) Which instrument has the greatest frequency range?

(b) Which singer can produce the lowest pitched note?

(c) Which instrument can produce the highest pitched note?

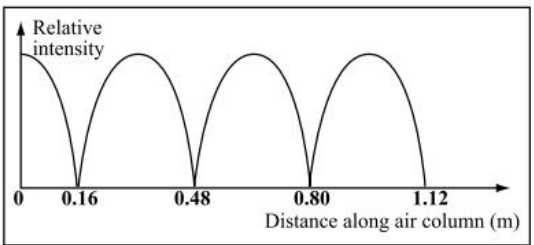
(d) Which singer has the most restricted frequency range?

Frequency Table

Instrument	*Frequency range (Hz)*
Piano	27-3900
Trombone	80-500
Clarinet	150-1400
Flute	256-2100
Piccolo	512-3600
Voice	*Approximate range (Hz)*
Bass	80-<400
Baritone	100->400
Tenor	170-500
Alto	200-650
Soprano	230-1350

12. During a laboratory session a group of students measure the intensity of sound along a resonating air column. They used a tuning fork with a frequency of 512 Hz to set the air column resonating. They then plotted their results on a graph shown below.

(a) Calculate the wavelength and speed of the sound.



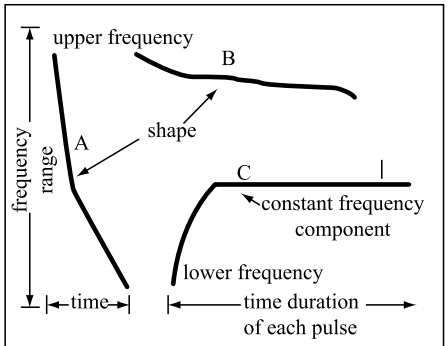
Resonating air column results

(b) If the air column is 1.12m long, is it an open or closed pipe? Explain.

13. When you set a tuning fork vibrating you can hear the note better if you hold the stem in contact with a solid surface such as a bench-top. Explain?

14. A singer was supposed to be able to smash a wine glass simply by singing a certain note close to the glass. Explain the physical principle that could account for this.

15. A bat researcher gathered some data in the field and produced a graph showing the frequency over time of single bat calls from three different species, A, B, and C).



Basic call types:
FM = Frequency Modulated Calls (Common or ordinary bats)
Sh -FM = Shallow Frequency Modulated Calls (Sheath-tail and Free-tail bats)
CF = Constant Frequency (Horseshoe and leaf-nosed bats)

Field information from bat calls

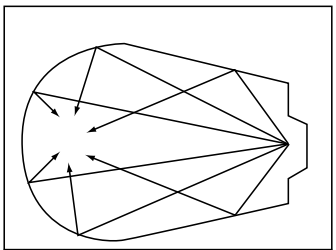
(a) Which call would be from the Sheath-tail and Free-tail bats?

(b) Which call would be from bats that use a large range of frequencies in their call?

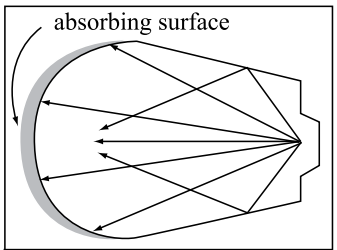
(c) Which type of bat produces the longest pulse call?

16. When designing concert halls, acoustic engineers avoid 'dead spots' (places where you can hardly hear sounds from the stage that are audible in most other places in the hall).

(a) What could cause 'dead spots'?



Concert Hall 1



Concert Hall 2

(b) The diagrams show how two differently designed concert halls reflect sound. Which is the better design? Explain.

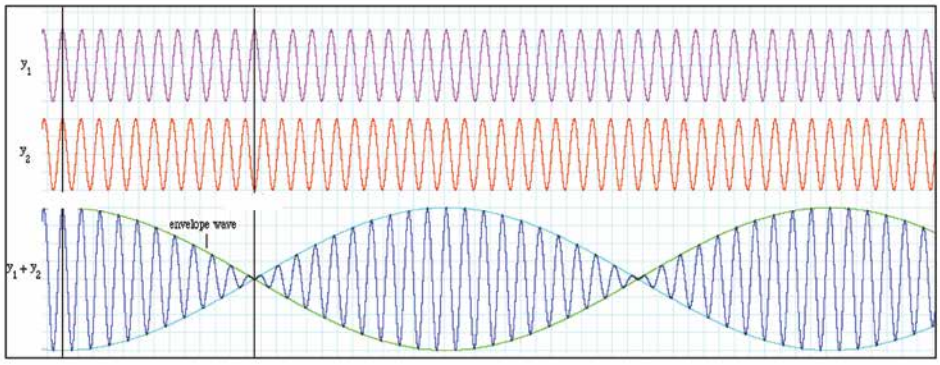
17. When a sound wave passes (refracts) from one medium into another, the frequency remains unchanged. If the wavelength of a sound in air is 1.40 m and the speed of sound in air is 346 m s^{-1}, calculate the wavelength of this sound after it passes into water in which its speed is 1450 m s^{-1}.

18. Two speakers in a room are 1.10 m apart and produce the same sounds, at the same time, in phase. Tom is 3.60 m directly in front of one of the speakers and notices that certain notes produce distinctly louder sounds

    (a) Determine the two longest wavelengths that could cause this phenomenon.

    (b) Determine the lowest frequency that could cause this phenomenon, if the speed of sound is 346 m s^{-1}.

19. (a) Two sounds are played and their waveforms displayed on a computer as y_1 and y_2. The third waveform shows the resultant waveform, $y_1 + y_2$



Explain the shape of the resultant waveform in terms of constructive and destructive interference.

(b) Using your answer to (a) as a guide, explain how the following could occur: A 2.5 m long open glass pipe is struck simultaneously at both ends by soft rubber gloves. The pipe then shatters at the middle, 1.25 m from either end.

Comprehension 7.1

Noise generally has many unrelated frequencies with no recognisable sequences. In general, music involves single frequencies or groups of related frequencies played in recognisable sequences (which we call tunes).

Musical instruments produce sounds through the vibration in regular waveforms of either air columns, strings or membranes. We group musical instruments into groups such as wind, percussion or strings.

The musical note a wind instrument produces depends on the air column's length and temperature, and whether the air column is open at both ends, or closed at one end. The energy input into most wind instruments involves blowing air across an opening (e.g. the flute); blowing air over a reed to make it vibrate (e.g. the clarinet); or blowing into the instrument (e.g. the trumpet).

The musical note a stringed instrument produces depends on the length, mass per unit length, and tension of the string.

The energy input into a stringed instrument may involve striking the string with a hammer (e.g. the piano); plucking the string (e.g. the harpsichord); or bowing (e.g. the violin).

Mechanical waves such as sound, water waves and earthquake waves may be longitudinal or transverse.

The reason why a wave is longitudinal or transverse is because of the way the energy source vibrates.

While longitudinal waves can travel through either solids or fluids, transverse waves can only travel through matter whose particles are strongly bound together, such as solids.

Waves are important in human communications. We use longitudinal sound waves when we speak and listen.

Many other animals use sound waves to communicate, sometimes over long distances.

Bats, whales, dolphins and birds can communicate by varying the frequency and amplitude of waves.

Waves are important in communications. We use longitudinal sound waves when we speak and listen. Many other animals use sound waves to communicate, sometimes over long distances. Bats, whales, dolphins and birds can communicate by varying the frequency and amplitude of waves.

Comprehension Questions

1. How does a vibrating string produce sound waves that a listener can hear?

2. Explain why a musical instrument requires an energy input before it can produce a sound.

3. Stringed instruments can be tuned by adjusting the tension of each string. This changes the speed of the wave that can pass through the string. Explain why this changes the note produced.

4. Explain the major differences between longitudinal and transverse waves.

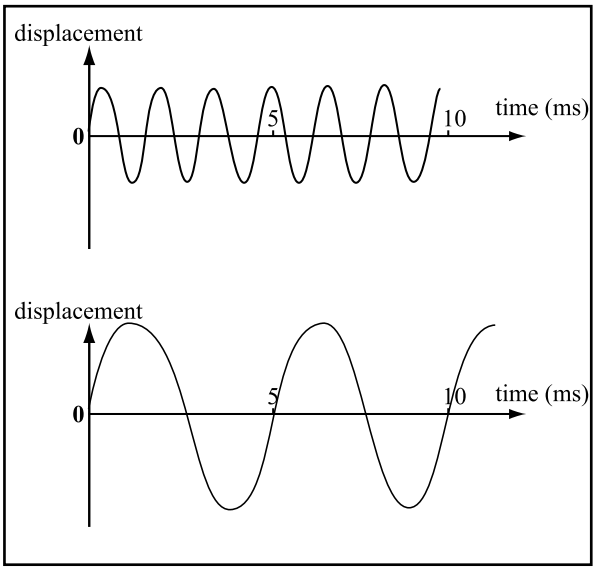
5. Earthquakes are waves that travel through rock. Some earthquake waves are longitudinal, others are transverse. One type of earthquake wave cannot pass through the Earth's liquid outer core. Is this likely to be a longitudinal or a transverse wave? Explain.

6. The graphs below represent sounds produced by a musical instrument. Assume the speed of sound was 340 m s^{-1} in each case.

   (a) Which of the graphs shows the louder sound?

   (b) Which of the graphs shows the higher-frequency sound? Determine the frequency of this sound.

   (c) Which of the graphs shows the longer wavelength sound? Determine the wavelength of this sound.

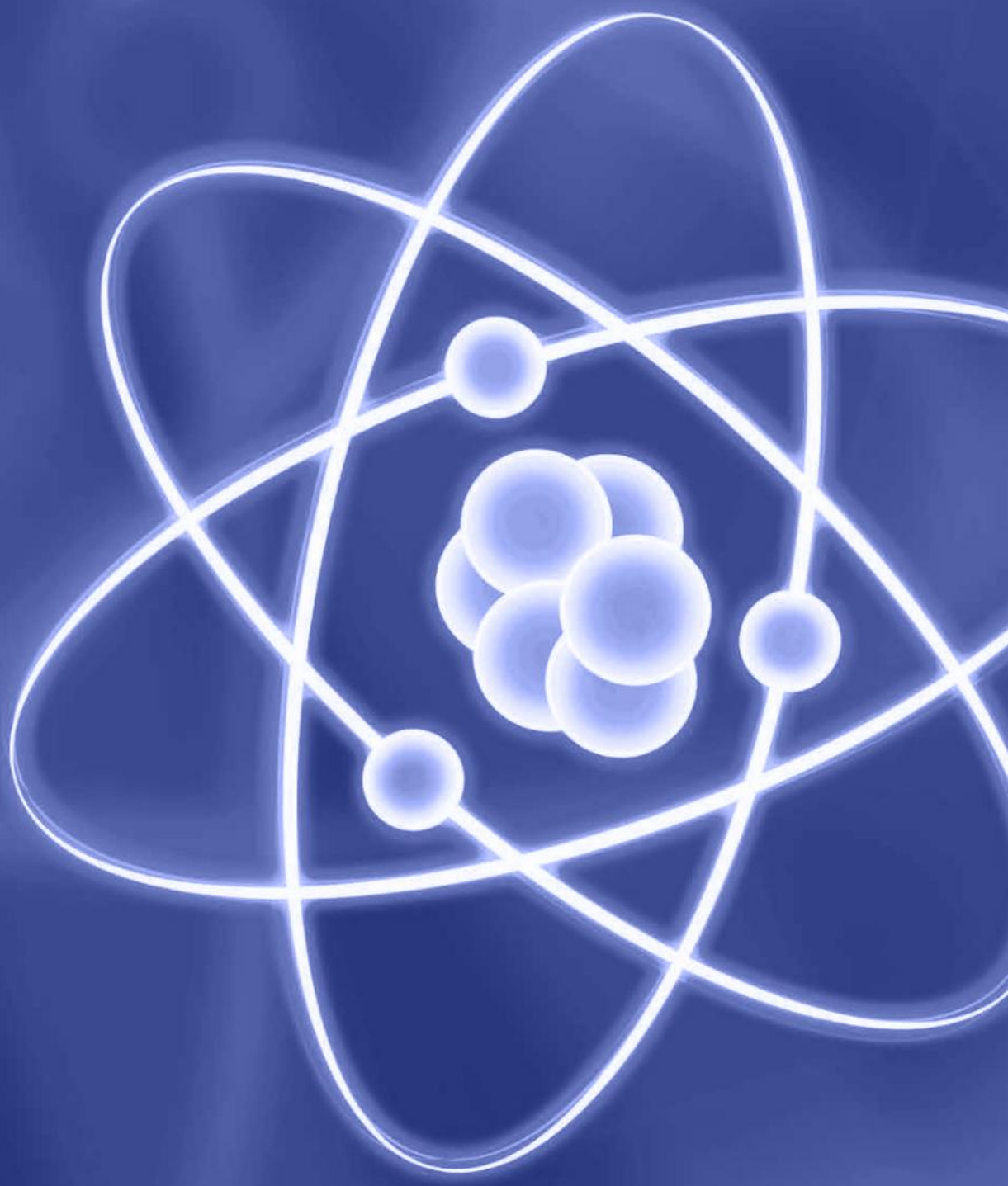


Unit 2 – Waves, Nuclear & Electrical Physics

Ionising Radiation and Nuclear Reactions

Chapter 8 – Particles in the Nucleus

Chapter 9 – Fission and Fusion



Chapter 8 – Particles in the Nucleus

The **strong nuclear force**, sometimes named the strong force, is one of the four basic forces in nature – the others being gravity, the electromagnetic force, and the weak nuclear force. It is a very short range force and is responsible for holding the protons and neutrons together in the nucleus. As its name implies it is the strongest of these four forces.

Based on 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 nucleon 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: ${}^{7}_{3}Li$

The element is lithium. The nucleus has three protons and four neutrons. We call it lithium-7. Another isotope of lithium, ${}^{7}_{3}Li$, has a different number of neutrons.

The following table shows the symbols and common names for a number of particles.

alpha particle ${}^{4}_{2}He$	beta particle ${}^{0}_{-1}e$	gamma ray ${}^{0}_{0}\gamma$	neutron ${}^{1}_{0}n$
α	ß	γ	n
positron ${}^{0}_{+1}e$	proton ${}^{1}_{1}H$	deuterium ${}^{2}_{1}H$	tritium ${}^{3}_{1}H$
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: ${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$
   In this example, we see that:
   mass is conserved because (14 + 4) = (17 + 1)
   charge is conserved because (7 + 2) = (8 + 1)

Background Radiation

This is naturally occurring radiation from the environment and will differ from place to place. It comes from such sources as cosmic radiation and terrestrial radiation (e.g. the materials in particular place and/or the geology of a particular region).

Absorbed dose

This is the physical dose quantity absorbed by a target material when irradiated with some form of nuclear radiation. When living tissue is exposed to a radiation dose it is important for radiological protection to know what this dose is as an excessive amount of radiation may cause ionisation of atoms and/or changes in DNA and permanent cell damage. How severe this damage is depends on how much radiation the individual has absorbed.

The absorbed dose is calculated by dividing the energy absorbed by the material by the total mass of tissue irradiated.

The units are therefore joules per kilogram and in this case they are defined as grays (Gy).

Dose Equivalent

This is a quantity which takes into account the type of radiation the tissue is exposed to as not all forms of radiation are equivalent in their potential to do damage to living tissue. Each form of radiation has a weighting factor that the absorbed dose is multiplied by in order that the biological effects of each form of radiation are considered equal. These weighting factors are based on gamma rays having a weighting factor of one.

The unit for dose equivalent is the seivert (Sv) and it is calculated by multiplying the absorbed dose by the weighting factor for that form of radiation.

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. Symptoms of early radiation sickness syndrome are described in the table below.

Table of weighting factors

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

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

A More Fundamental Look at Matter

It has been a fundamental pursuit of science (even before it was called science) to try to find out what things are made of, often in order to be able to use the building blocks discovered to make new materials. It was discovered that some pure substances can be broken up, or divided, but this just leads to smaller amounts of the same pure substance i.e. they do not appear to be made up of anything else. The concept of the atom comes to us from the ancient Greeks who hypothesised that there must be some smallest particle which was uncuttable (atomos) of such a pure substance, and which was different for different pure substances. While the idea of the atom was a potentially powerful one, there was no consensus that such things existed, and for most of scientific history, there was no hard evidence to support the hypothesis.

John Dalton's atomic theory (1803) that compounds produced in chemical reaction were best explained by the rearrangement of whole number ratios of atoms of elements, provided the best argument at the time for this model of matter. Dalton also proposed the relative atomic weights for a small number of atoms. It was not until 1905, however, that Einstein provided the experimental evidence for the existence of atoms, by which time the electron had already been discovered by Kelvin, and followed some years later by the discovery of the atomic nucleus by Rutherford, and the proton and neutron.

For a time it appeared that all matter was made up of these three 'fundamental' particles. Research into radioactive decay, particularly beta decay, revealed an anomaly which suggested a violation of the conservation laws of momentum and energy. The importance of the various laws of conservation to physics cannot be underestimated, and in order to maintain conservation, Fermi proposed the existence of a fourth fundamental particle, later called the neutrino. This particle was characterised as having no charge, and as being essentially massless, certainly compared to the other sub-atomic particles. In a beta minus (β-) decay event, an antimatter version of the neutrino (an antineutrino, represented by a bar over the species) is co-emitted with the β- particle (an electron) as per the following equation:

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\upsilon}$$

In this reaction, a neutron in the nucleus is changed into a proton.

Similarly in a beta plus (β+) decay, a neutrino is co-emitted with a positron as per the following reaction, where a proton in the nucleus is converted into a neutron:

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}\beta + {}^{0}_{0}\upsilon$$

The fact that protons and neutrons could be converted into one another, raised questions about how 'fundamental' they were. E xperiments with high energy particle colliders revealed that they were, in turn, composed of particles called quarks which are now considered, along with electrons, positrons, and neutrinos, to be the fundamental particles that make up all the matter around us.

The two quarks which make up protons and neutrons are the up quark (u) and the down quark (d). The proton is composed of two up quarks and one down quark (uud), and the neutron is composed of one up quark and two down quarks (udd). Thus, in order for a proton to be converted into a neutron, one of the up quarks has to be converted into a down quark, and vice versa in order for a neutron to be converted into a proton.

Our best understanding of how the matter in the modern universe came to be, is provided by the Big Bang theory, first proposed in 1927 by Georges Lemaître. In the early universe up and down quarks came together to form protons and neutrons, followed by electrons which then lead to the formation of hydrogen isotopes. Nuclear fusion of hydrogen isotopes then produced helium, but not much more, and even today the universe is dominated by these 'light' elements. The nuclear fusion processes that occur in stars will produce a small number of the other elements, but it is the tremendous extremes of temperature and pressure that occur when a star 'dies', collapsing under its own weight to form a supernova explosion, that produces, again by nuclear fusion, all the remaining elements on the periodic table.

Half Life

Activity

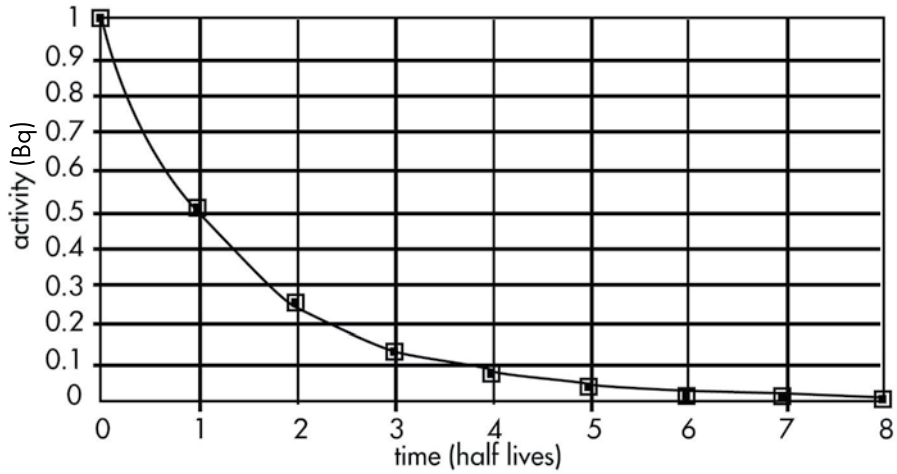
A radioactive sample emits radiation every time a nucleus decays. Scientists call the number of decays that happen every second in an amount of radioactive material its 'activity'. The SI unit for activity is the becquerel (Bq).

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	$\frac{N}{2}$	$\frac{N}{4}$	$\frac{N}{8}$	$\frac{N}{16}$	$\frac{N}{32}$	$\cdots \frac{N}{2^n}$

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.
The number of nuclides remaining after a radio isotope has been decaying for a given period of time is given by

$$N = N_0 (½)^n$$

Where N = number of nuclides remaining
N_0 = original number of nuclides at time t_0
n = number of half lives that have passed since t_0

8 Experiment 8.1 – Simulated Radioactive Decay

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)

- 40 die
- A small box with a lid (photocopy paper box works well)

Pre-Lab

- In this simulation you will use die to represent radioactive nuclei
- A ‘decayed’ dice is one which falls with the number ‘6’ facing up.
- Each throw represents an equal unit of time.

Lab Notes

- Count out 40 die and place them inside the box and put the lid on.
- Shake the die inside the box, remove the lid and examine the die.
- Any dice which is showing the number ‘6’ uppermost represents a radionuclide which has decayed.
- Removed the ‘decayed’ die and record the number of these in the table below.
- For each round, calculate the number of ‘undecayed’ die remaining and add this to the table below
- Repeat steps 2-4 until 15 throws have been completed (or all die have decayed).
- Conduct another two repeat trials and add these to the table
- Calculate the averages for the number of ‘decayed’ and ‘undecayed’ for each throw in your table.
- Transfer your average undecayed die results to a class table.
- Calculate the class average undecayed die per throw, and add this to the table on the following page.

Throw	Decays (number of die showing a ‘6’)				Undecayed (die remaining)				Class results average
	Trial 1	Trial 2	Trial 3	Average	Trial 1	Trial 2	Trial 3	Average	Total
0	0	0	0	0	40	40	40	40	40
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

Post-Lab Discussion

1. Use Excel or a separate sheet of graph paper to plot the data from your table of the average number of nuclei remaining against 'time-units' (throws) for your group on the first grid below. Include a curve of best fit.
2. Use Excel or a separate sheet of graph paper to plot the class average and include a curve of best fit.
3. Explain why the points plotted for your group data do not fall exactly on the curve.

4. What difference can be seen between the curves based on your group data, and the curve based on the class data? Explain this difference.

5. Use the line of best fit for the class data to determine the time it takes (in units of number of throws) for 40 die to 'decay' to 20 die and for 20 die to 'decay' to 10 die. This is called the half-life.

6. Would the half-life of the radioactive decay simulation be shorter or longer if eight-sided die, instead of six-sided die, were used? Explain briefly.

7. Why is it not possible to predict when any particular single radioactive nucleus will decay?

8. Write a concluding statement, based on your results, that relates to the purpose of the experiment. Did you achieve your aim?

Experiment 8.2 – Range of Alpha & Beta Particles in Air

8

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?

Note: Your teacher may decide to perform this experiment as a demonstration. If so, you should still ensure that you are familiar with the apparatus and the procedure.

Aim

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

Apparatus

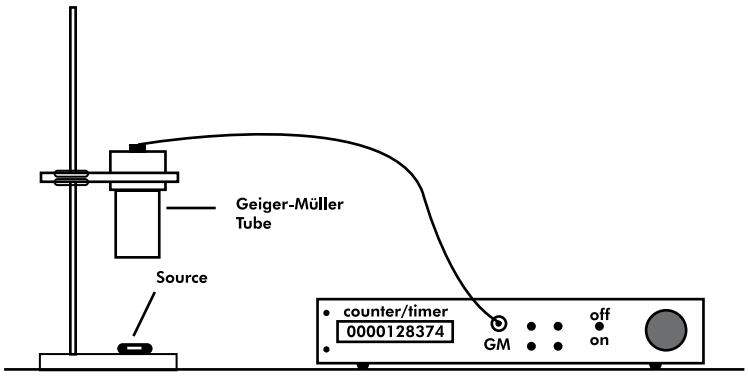
- Geiger-Muller tube and counter
- Electronic timer or stopclock
- Retort stand and clamp
- Alpha source (americium-241) and beta source (strontium-90)
- Metre ruler
- Tongs and gloves

Pre-Lab

- Find out how to use the Geiger counter.
- 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 in the table on the following page.
- Repeat the exercise using the strontium-90 source, over a distance of 24 cm. Record your observations in the table on the following page.



Apparatus for Experiment 8.2

Distance from Source (cm)	Counts per minute (cpm)		True count (cpm)		Distance from Source (cm)	Counts per minute (cpm)	True Count (cpm)
	α-source	β-source	α-source	β-source			
1					13		
2					14		
3					15		
4					16		
5					17		
6					18		
7					19		
8					20		
9					21		
10					22		
11					23		
12					24		

Post-Lab Discussion

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. Use Excel or a separate sheet of graph paper show distance from the source *vs* true counts per minute for each source on the table provided.
4. Write a brief paragraph describing what you have found out from the results.

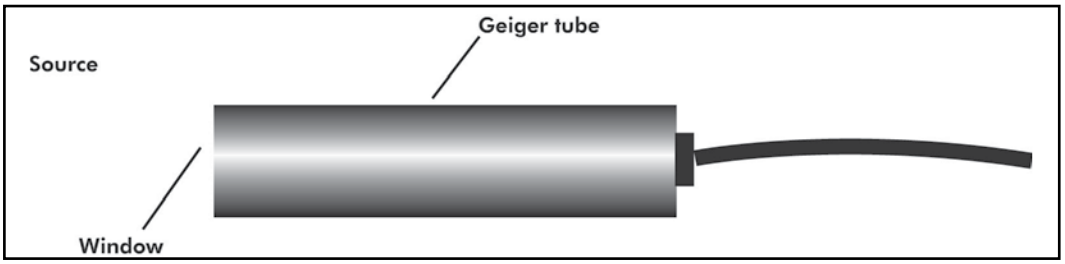
5. Use a reference book if necessary to find answers to the following:

   (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 8.4 – Penetration Power of Radiation

8

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.

Note: Your teacher may decide to perform this experiment as a demonstration. If so, you should still ensure that you are familiar with the apparatus and procedure.

Aim

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

Apparatus

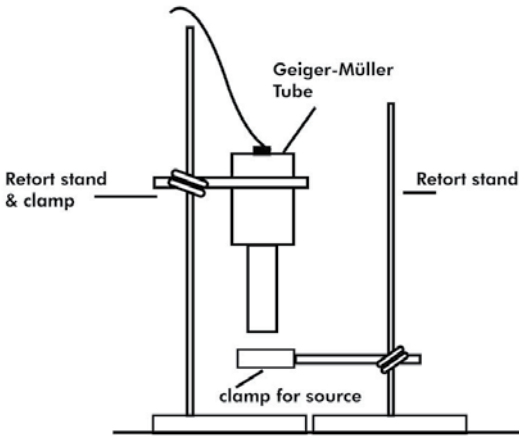
- Stopclock, stopwatch or electronic timer
- Geiger tube and counter
- Radioactive sources: americium-241 (alpha); strontium-90 (beta); cobalt-60 (gamma)
- Sheets of paper, aluminium and lead
- Two retort stands, boss heads and clamps
- Tongs and gloves
- Metre rule

Pre-Lab

- Find out how to use the Geiger counter.
- 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 (right) 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. Add this to the table on the following page.
- Place a sheet of paper between the source and Geiger tube and record the count rate in counts per minute Add this to the table below.
- Without moving anything but the paper, repeat the procedure for aluminium and lead.
- Repeat these steps for the other two radioactive sources.



Apparatus for Experiment 8.4

Test Sample	Counts per Minute by Source (cpm)			True Count by Source (cpm)		
	Alpha	Beta	Gamma	Alpha	Beta	Gamma
None						
Paper						
Aluminium						
Lead						

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.

_____

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3. Summarise the characteristics (mass, charge and speed) of alpha, beta and gamma radiation by completing the table below.

	Mass	Charge	Speed
Alpha			
Beta			
Gamma			

4. Account for the different penetrating abilities of each type of radiation in terms of their characteristics.

_____

_____

_____

_____

5. Americium-241 also emits gamma radiation. How has this affected your results?

6. How far through human tissue does each type of radiation penetrate?

7. People working with radiation sources often wear or use different types of shielding materials for protection. Find out about these materials and write a summary.

8. 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.

8 Experiment 8.5 – Deflecting Alpha & Beta Radiation

Background

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.

Note: Your teacher may decide to perform this experiment as a demonstration. If so, you should still ensure that you are familiar with the apparatus and procedure.

Aim

To separate and identify alpha, beta and gamma rays.

Apparatus

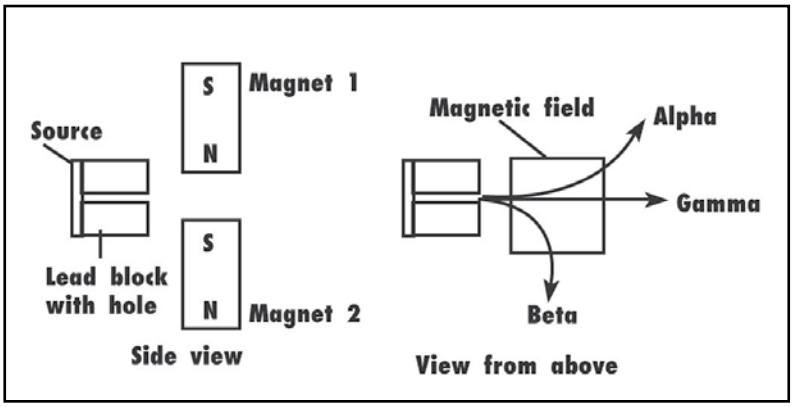
- a source of mixed radiation, such as alpha and gamma (americium-241) or any of the beta and gamma sources mentioned in Experiment 8.4;
- two strong magnets;
- a lead block with a hole drilled through it;
- a Geiger tube and counter.

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 in the space provided.

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.

   Discuss how you could make your experimental set-up more effective to avoid this?

   _____

   _____

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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.

   _____

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8 Experiment 8.6 – Radiation & Distance

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.

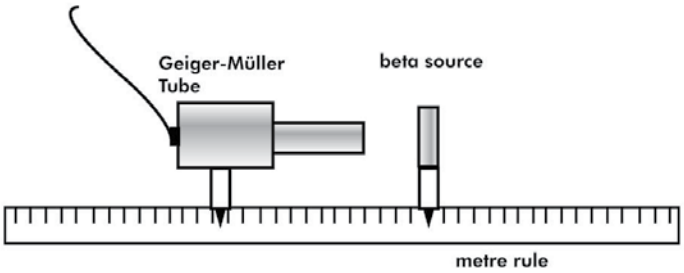
Radiation travels in every direction in straight lines from the centre of the source. A well-known example is light rays from the Sun. As the radiation moves farther from the source, it becomes less intense. With this information, we are going to investigate this effect to determine any mathematical 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



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 the true counts per minute (c min^{-1}) the table (below).
- 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.
- Conduct two repeat trials for each distance, add these to the table, and calculate the average corrected counts per minute for each distance.
- Indicate the absolute and percentage 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					

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* $1/r^2$

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 law? 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 Set 8.1 – Nuclei & Radiation

8

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

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

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

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

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

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

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

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

   c $^{22}_{11}Na \rightarrow ^{22}_{10}Ne + § + ^{0}_{0}\nu$

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

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

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.

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

5. Radioactive potassium-42 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. 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, decays to form caesium-141. What else is produced in this decay?

7. Iodine-131 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.

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 from molybdenum-99. Write down the decay equation for this.

9. Radon-222 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.

10. One reaction that interests nuclear fusion researchers involves the fusion of deuterium and tritium to form alpha particles.

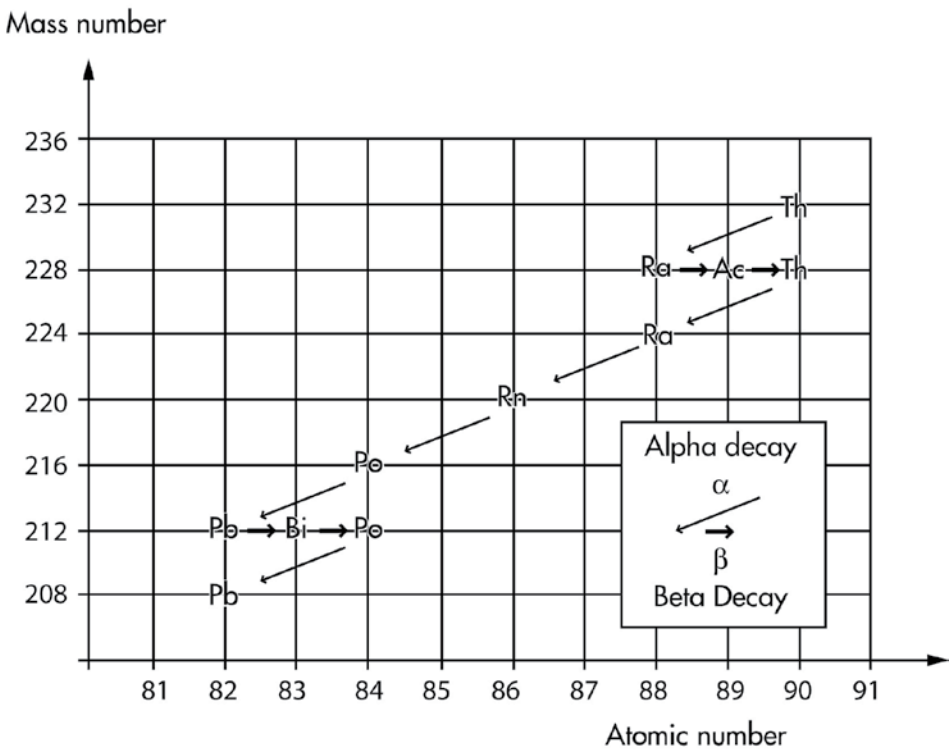
    (a) Write the nuclear equation for this reaction.

    (b) Name any other particle the reaction produces.

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?

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.

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 13

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.

15 In a nuclear fission reaction, uranium-235 plus a neutron yields antimony-134 and yttrium-95, three neutrons and another particle.

(a) Write an equation for this nuclear reaction.

(b) What other particle is produced?

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.

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.

18. Charge is a conserved quantity, and protons have a relative charge of +1 (once considered to be the smallest possible unit of charge). Up quarks have a charge of +2/3. If a proton's quark composition is uud, what must be the charge on a down quark?

19. Show how the quark composition of a neutron must therefore result in a neutron having a charge of zero.

20. Electrons are still considered to be fundamental particles. What does this mean that they are made up of?

21. Electrons and positrons are antimatter versions of each other i.e. they have all the same properties except that they are opposite in electric charge. With this in mind:

    (a) What is the mass of a positron in kg?

    (b) What is the absolute charge of a positron?

22. The antimatter version of a particle is written with a bar over the symbol e.g. a neutrino is written using the Greek letter 'nu' υ, and an antineutrino is written using $\bar{\upsilon}$. Protons and neutrons also have their anti-matter versions. Write the symbols for an anti-proton and anti-neutron.

23. An anti-proton is made up of two anti-up quarks and one anti-down quark.
    Write the quark formula for an anti-proton.

24. Anti-protons and anti-quarks are also opposite in electric charge to their matter versions. Show that the charges on the anti-ups and anti-down quarks that make up an anti-proton give it a charge of -1.

8 Problem Set 8.2 – Half Life

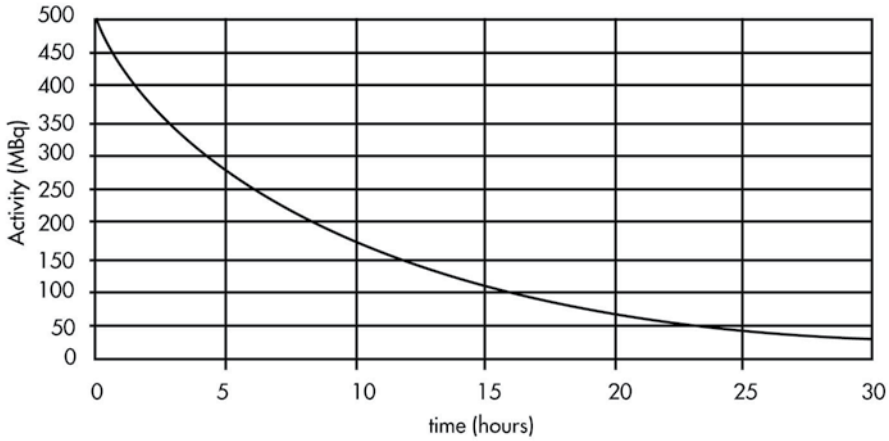
1. A radioactive counter shows that the rate of emission of beta particles from a radioactive source decreased to half the initial rate in 22.0 hours.

   (a) Calculate the half-life of the element.

   (b) Calculate the fraction of the original number of radioactive atoms that is still unchanged in that time.

   (c) Determine the fraction of the original number of atoms that will have disintegrated in 44.0 hours.

2. Technetium-99m is the most common radioisotope that doctors use in nuclear medicine. The following graph shows the activity of a normal 5.00×10^2 MBq dose of technetium-99m over 30.0 hours.



Decay graph of a 5.00×10^2 MBq sample of technetium-99m

   (a) Determine from the graph, the half-life of technetium-99m.

   (b) Estimate how long it would take before the activity of the dose drops to about 2 MBq.

3. One product of nuclear power plants is the isotope cæsium-137, which has a half-life of 30.0 years. How many years will it take for the activity of a sample of Cs-137 to reduce to $^1/_{16}$ of its original value?

4. The radioactive isotope phosphorus-32 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 2.40 MBq. What was the activity of the sample 42.9 days later?

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.

   _____

   _____

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   _____

6. Urologists use radioactive iodine in their diagnosis of kidney problems. The isotope they use has a half-life of 12.0 hours, and the doctors need samples that have an activity of 8.00×10^5 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 24.0 hours before use;

   (b) 24.0 hours after the doctor injects it in a patient.

7. A sample of processed waste from a nuclear reactor contains 1.00×10^{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.

8. The half life of a radioactive cobalt-60 source radiographers use for medical irradiation is 5.30 years.

   (a) If the activity of a new source is 800 GBq, what is its activity after 26.0 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.

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.

   _____

   _____

   _____

10. The gold isotope, gold-198, that engineers use to track sewage, is a beta-emitter with a half-life of 2.70 days.

    (a) If the original activity of a particular sample is 8.00 MBq, what is the approximate activity after 7.00 days?

    (b) What is the equation for its decay?

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. Explain why is there less carbon-14 in old animal bone compared with the same mass of new bone.

12. An archæologist finds a fragment of a wooden artefact from the site of an ancient human settlement in Australia. They measure the ratio of carbon-14 to carbon-12 in the wood and find 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.

13. Magnesium-24 is a stable nuclide. It can be transformed into sodium-24 by neutron bombardment. Sodium-24 is radioactive, being a beta and gamma emitter with a half-life of 15.0 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 1.00 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?

14. 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?

15. 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.

16. 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?

17. (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?

Problem Set 8.3 – Radiation & the Environment

8

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.

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?

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.

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?

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

6. Jamie is a radiologist with the local hospital. While working on one particular machine, they were 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.

7. Explain exactly what the following expressions mean:

   (a) LD-50/50 = 4.5 Sv

   (b) LD-100/20 = 9.5 Sv

8. A miner who is employed at a radioactive mine, has a body of mass 78.5 kg. They 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 them 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 their lungs, how would that alter your answers to (a), (b) and (c) above?

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). Estimate how much energy this internal radioactivity releases in an average 50 kg child in one year. Assume the quality factor is 1.

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?

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?

    _____

    _____

    _____

    _____

12. In a radiation accident a worker absorbs 28.7 J of radioactive energy from gamma rays. If they have a body mass of 64.2 kg:

    (a) What is their absorbed dose?

    (b) What is the dose equivalent?

    (c) Is this dose enough to cause serious immediate damage? Explain.

    _____

    _____

    _____

    _____

    _____

    (d) If they had instead absorbed the energy from alpha radiation, how different would their situation be? Qualify your answer.

13. 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.

    (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 an accumulated 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?

14. 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?

15. 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?

16. 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)?

8 Comprehension 8.1

‘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 radiotherapy 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.

Questions

1. (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. Write balanced equations showing:

   (a) the alpha decay of thorium-229

   (b) the beta decay of iodine-131

   (c) the gamma decay of excited barium-137

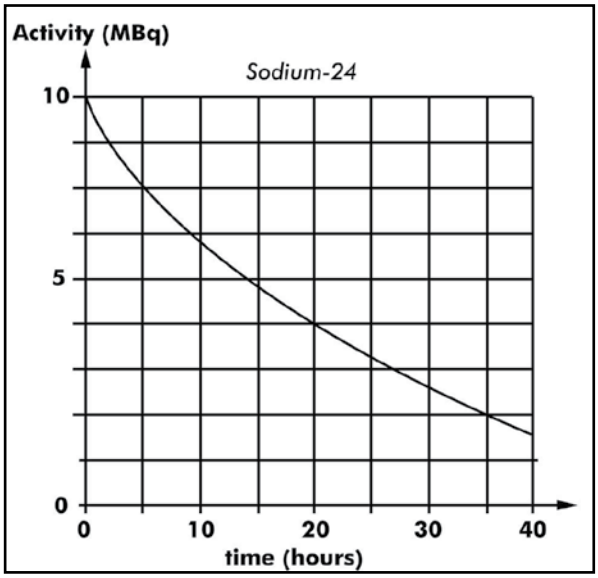
   (d) the positron (positive beta) decay of carbon-11

   (e) the transmutation of beryllium-9 into carbon-12 through the absorption of an alpha particle.

3. (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. 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?

_____

_____

_____

_____

_____

Chapter 9 – Fission & Fusion

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:

$$\Delta E = \Delta mc^2$$

where: **ΔE** is the binding energy in **J**

Δm is the mass difference 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

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:

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

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

Other data:

$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

$1\ \text{MeV} = 1.60 \times 10^{-13}\ \text{J}$

Energy equivalent of 1 u = 931 MeV

Mass of proton $= 1.67262 \times 10^{-27}$ kg $= 1.00727$ **u**

Mass of neutron $= 1.67493 \times 10^{-27}$ kg $= 1.00867$ **u**

Mass of electron $= 9.11 \times 10^{-31}$ kg $= 5.49 \times 10^{-4}$ **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.

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 9.1 – Simulating a Chain Reaction

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.

Background

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

- Three 30 cm by 30 cm squares of newspaper per student
- Camera or timer
- Safety glasses to be worn to avoid being hit in the eye by a projectile

Lab Notes

- Each student takes their three pieces of newspaper and screws them up tightly into balls.
- Students arrange themselves in an array with up to a couple of metres between each student. This may be done sitting in a classroom, or standing in a suitable indoors space such as a gym.
- Each student represents a U-235 nucleus, and the paper balls represent neutrons.
- The teacher will initiate the chain reaction by tossing a 'neutron' into the 'uranium mass'.
- If the criterion for a fission reaction is met, the affected 'nucleus' will instantly and randomly 'emit' (throw) the amount of 'neutrons' specified for each of the scenarios below.
- Make a photographic record of the different scenarios, or time how long they take until completion, to enable you to compare them after the events.
- It is important to emphasise that uranium nuclei release neutrons instantly and randomly when they undergo fission. They do not deliberately target any other nucleus, and they do not pause to think about whether or not they will undergo fission after bombardment. Any student who does not follow the instructions will be considered to have undergone alpha decay, followed a decay series which turns them into lead, and they will be removed from the reactor core.

Scenario 1: Unsustainable Chain Reaction:

- A fission event only occurs if a student is directly hit by a neutron. When this occurs, they immediately throw ONE neutron only, in a random direction.

Scenario 2: Sustainable Chain Reaction:

- A fission event occurs if a bombarding neutron lands anywhere within a metre of a student. When this occurs, they immediately throw ONE neutron only, in a random direction.

Scenario 3: Uncontrolled Chain Reaction:

- A fission event occurs if a bombarding neutron lands anywhere within a metre of a student. When this occurs, they immediately throw THREE neutrons, in random directions.

Post-Lab Discussion

1. Describe what happened in your simulated chain reactions.

2. How would the simulation change if instead of having a 2D array of students with gravity influencing the motion of the 'neutrons', there was instead a 3D array in space where gravity was not a significant influence?

3. 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.

9 Problem Set 9.1 – Binding Energy

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.

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.

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

4. The binding energy per nucleon values for two nuclei are:

   Nucleus A: 6.90 MeV nucleon^{-1} Nucleus B: 8.80 MeV nucleon^{-1}

   Which of these is the more stable nucleus? Explain.

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, $^{131}_{53}\mathrm{I}$.

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 = $^{3}_{1}\mathrm{H}$

7. A small proportion of all the carbon in living organisms is the radioactive isotope carbon-14. $^{12}_{6}\mathrm{C}$

   Calculate the binding energy per nucleon of both the carbon-12 and carbon-14 nuclei and hence state which is more stable.

   _____

   _____

   _____

   _____

8. One of the simplest fusion reactions is:

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

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

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

(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.

10. Uranium-238 undergoes a series of radioactive decays, the first of which is: $^{238}_{92}U \rightarrow ^{4}_{2}He + ^{234}_{90}Th$
Calculate how much energy one such uranium-238 decay releases.

11. In a fission reactor, a nucleus of uranium-235 may capture one neutron. The products of this fission are xenon-142, strontium-90 and neutrons. Write the nuclear equation for this fission. Indicate the number of neutrons that are released in this reaction.

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?

    _____

    _____

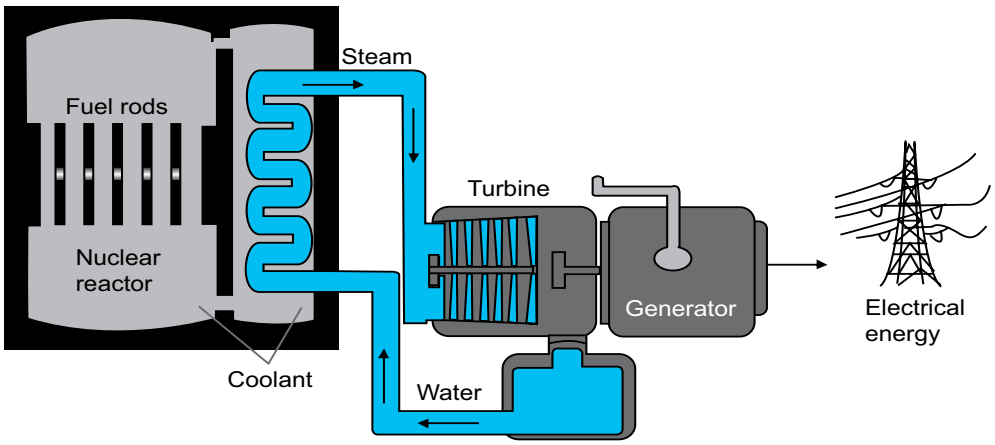
    (b) Why can't this thermal energy be used to generate electricity?

    _____

    _____

    _____

    _____



13. After absorbing a neutron, a uranium-235 nucleus can fission to produce barium-141 and krypton-92.

    (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.

14. Hydrogen and deuterium fuse to give helium-3

(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?

15. When alpha particles , having kinetic energy 3.0000 MeV bombard nitrogen-14 nuclei, oxygen-17 forms and the reaction releases a proton. Calculate the kinetic energy shared by the reaction products.

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?

17. The proton bombardment of a Li-7 nucleus results in the formation of two alpha particles. (a) Write the equation for this reaction.

(b) If all of the energy released in this reaction is equally divided between the alpha particles as kinetic energy, what kinetic energy would each alpha particle have? Give your answer in both electron volts and joules.

18. When a particle and its anti-particle collide they annihilate each other and all of their mass is converted to gamma ray photons. How much gamma ray energy was released in one such collision between a proton and an anti-proton as the Universe was forming?

19. A radon-222 nucleus undergoes radioactive decay emitting an alpha particle and energy.
    (a) Write the equation for this decay process.

    (b) Apart from an alpha particle, what other radiation may also be emitted?

20. Engineers use the radioisotope gold-198, a beta emitter, to track sewage.
    (a) Gold-198 decays to mercury-198. 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 Comprehension 9.1 – Nuclear Energy

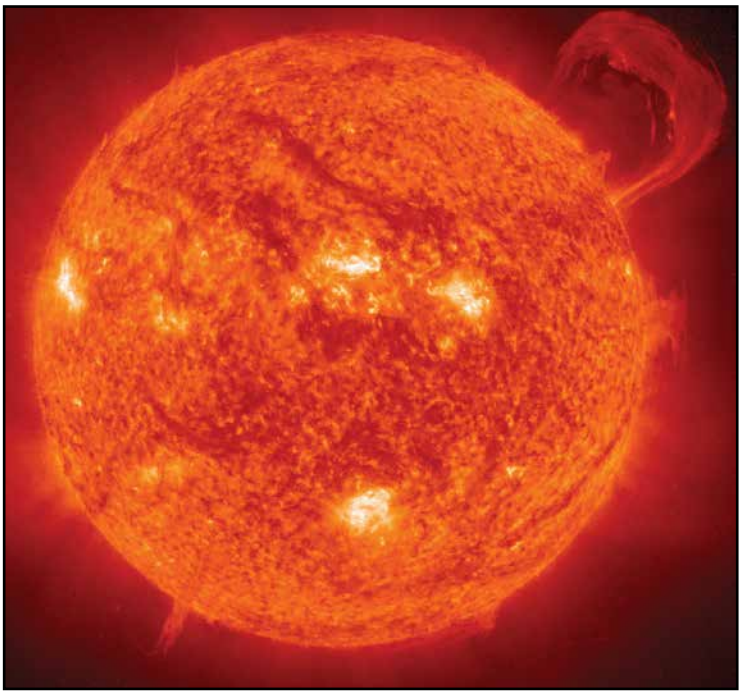
We use nuclear energy all the time. The Sun produces solar energy when small, light nuclei combine to produce larger nuclei and lots of energy. This process is called 'fusion'. Nuclear power plants use large, heavy nuclei. When these break apart, they produce smaller nuclei, radiation and energy. This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

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.

At Fukushima in 2011, the cooling systems of three nuclear reactors were turned off when a tsunami flooded the power supply. All three reactors cores eventually melted. While no deaths or injuries have been attributed to the radiation released in this incident, more than 100 000 residents of the surrounding area were evacuated and cannot return to their homes or businesses. 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.



An unusual view of the Sun taken through a filter.

Nuclear explosion

Questions

1. (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. 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 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. 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, cerium-146, and some neutrons and beta particles.

(c) Write a balanced equation for this process.

(d) The atomic mass of yttrium-88 is 87.90950 u and the atomic mass of cerium-146 is 145.91877 u. Calculate the mass difference, and hence the energy released by this reaction.

4. (a) List and explain three characteristics that determine whether a particular isotope is suitable for radiotherapy.

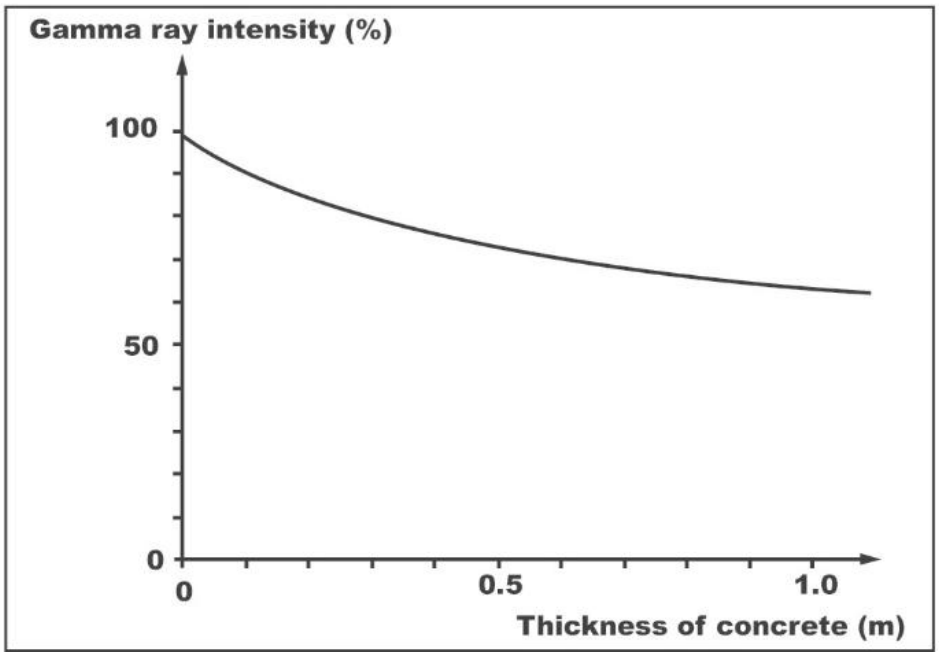
(b) Explain why does radiotherapy has side effects?

5. (a) Explain the relationship between the units of 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.

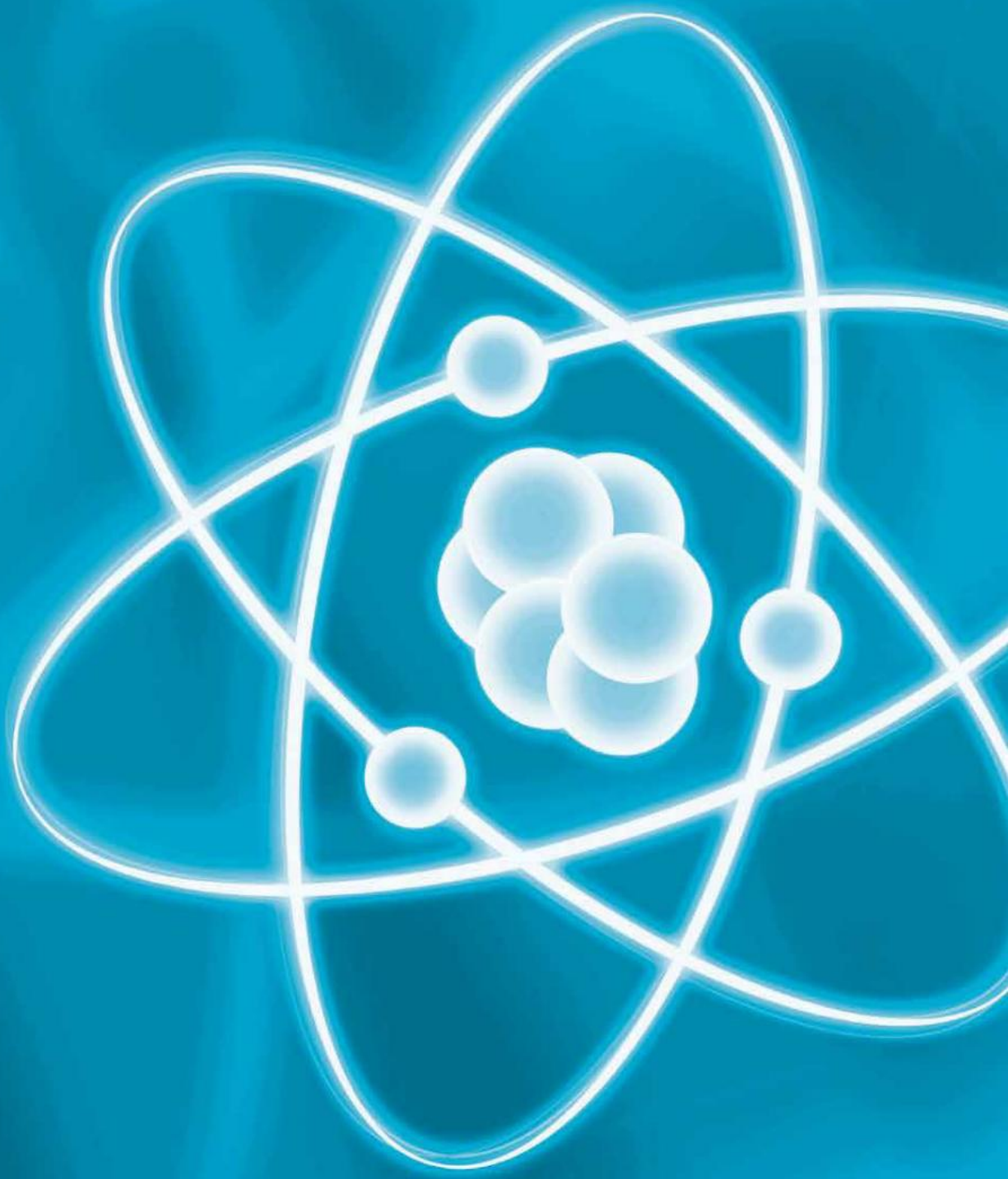
The containment shell of a nuclear reactor typically consists of a thick layer of steel surrounded by several metres of concrete. Explain why the designers feel this is necessary.



Unit 2 – Waves, Nuclear and Electrical Physics

Electrical Forces and Energy

Chapter 10 – Electrical Physics



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.

$$\mathbf{I = \frac{q}{\Delta t}}$$

where: **I** is the current in amperes (A)

q is the charge in coulombs (C) passing any point

Δt 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.

$$\mathbf{\Delta V = \frac{W}{q}}$$

where: **ΔV** is the potential difference, in volts (V)

q is the charge passing any point, in coulombs (C)

W is the potential energy change of the charge, in joules (J)

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 × Time:

$$E = P\Delta t = VI\Delta t$$

Mathematically:

$$E = IV\Delta t \quad \text{or} \quad E = \frac{V^2\Delta t}{R} \quad \text{or} \quad E = I^2R\Delta t$$

where: Δt 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 3.60 MJ (3.60×10^6 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 2024, domestic users paid about 29 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 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 syllabus, and for such questions you should assume that the mains potential is 240 V, and that Ohm's Law is valid.

Circuits and Ohm's Law

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.

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

where: **R** is the resistance in ohms (Ω)

V is the potential difference in volts (V)

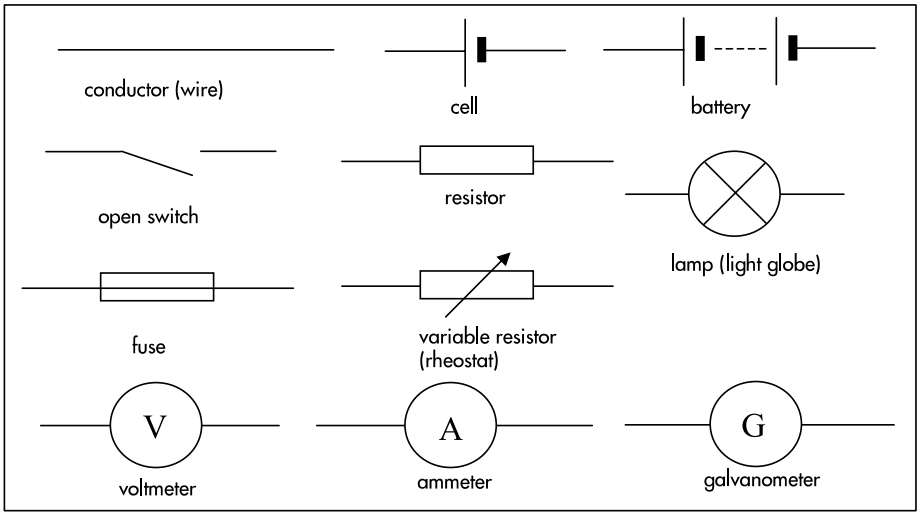
I is the current in amperes (A)

$$\mathbf{V = IR}$$

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.



Standard symbols used in circuit diagrams

Circuits and Safety

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 on the following page support the view that Residual Current Devices, known as RCDs, should help to reduce electrical fatalities.

Examples of Electrical fatality distribution – Australia and Papua New Guinea

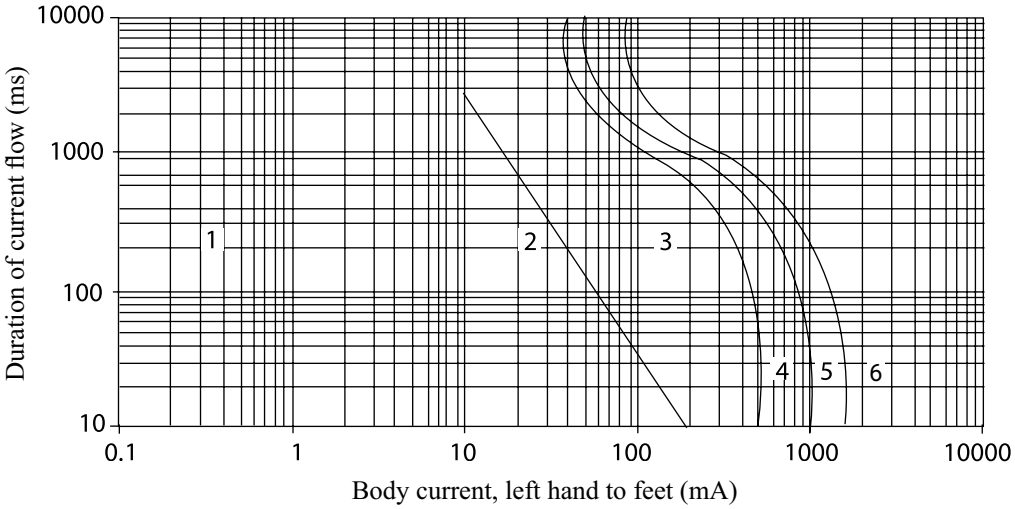
Type	Reported Accidents	RCD Preventable
Domestic 240/415v	150	134
Other 240/415v	123	49
High Voltage	76	0
Total	349	183

Circuit Type	Reported Accidents	RCD Preventable
Mains & Submains	12	6
Powerpoint	19	16
Lighting	13	11
Permanently wired equipment	4	4
Equipment connect to a powerpoint	102	97
Total	150	134

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 physiological 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.

Parallel and Series Circuits

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:

$$\mathbf{R_t = R_1 + R_2 + \cdots}$$

- 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.

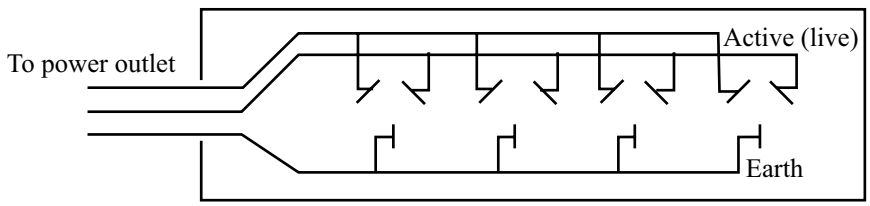
In a **parallel circuit** the current has a separate path through each component. An example of a parallel circuit is a power board. Each component in a parallel circuit receives the same potential difference (PD or voltage).

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:

$$\mathbf{\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots}$$



Circuit diagram

Experiment 10.1 – Measuring Electrical Energy

Background

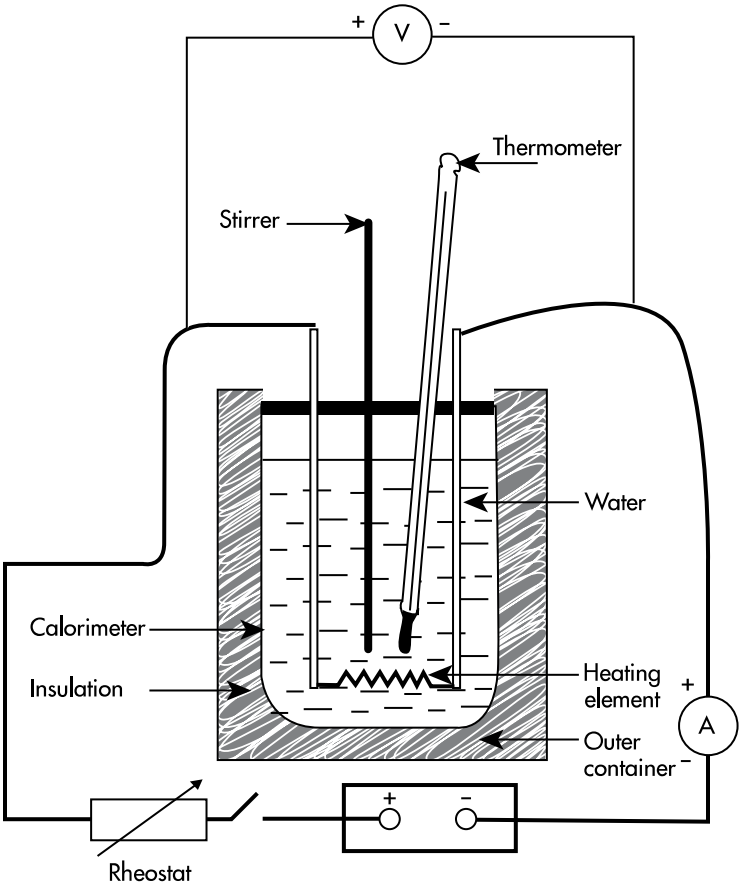
Electrical energy can be converted into other forms of energy. A common conversion is the heat produced when an electric current flows through a resistor. Electric kettles, electric hot water systems and bar heaters all depend on this energy conversion.

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



Apparatus for Experiment 10.1

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.

Lab Notes

- Determine and record in the table provided 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. Record this in the table.
- 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 in the table.
- 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

Mass of empty calorimeter + accessories (g)	
Mass of calorimeter plus water (g)	
Potential difference (V)	
Current (A)	
Initial temperature (°C)	

Time (min)	**Temperature (°C)**
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Continue data collection until either 10 mins has passed, or the temperature has risen by 30 °C.

Post-Lab Discussion

1. What was your experimental hypothesis?

2. Identify the following variables:
   (a) Independent variable

   (b) Dependent variable

   (c) Control variables

3. Calculate the electrical energy supplied to the water and calorimeter.

4. Calculate the energy absorbed by the calorimeter and the water, using their masses and increases in temperature

5. Compare the two energy amounts. Account for any discrepancies.

6. Analyse and discuss the major sources of error and uncertainty in this experiment, and some possible ways to reduce them.

7. Calculate the overall efficiency of the heater in warming the water.

Experiment 10.2 – Potential Difference, Current & Resistance

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 that will 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)

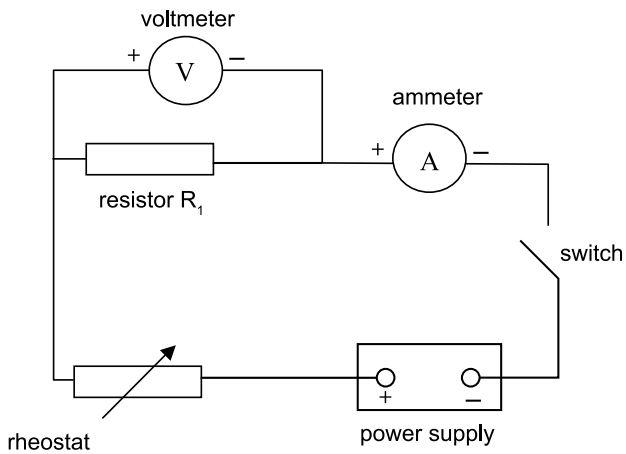
- power supply
- switch
- seven electrical leads
- voltmeter or multimeter
- ammeter or multimeter
- three different resistors (you can also use diodes and LEDs)
- variable resistor (rheostat)

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.

Lab Notes

- Connect the equipment as shown in the circuit diagram (*right*). 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 the table on the following page.



Apparatus for Experiment 10.3

- 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.

Resistor	Trial	Current (A)	Voltage (V)	Resistance (Ω)
R1	1			
	2			
	3			
	4			
	5			
R2	1			
	2			
	3			
	4			
	5			
R3	1			
	2			
	3			
	4			
	5			

1. Calculate and record the resistance values, using:

   $\mathbf{R = \frac{V}{I}}$ for each set of readings.

2. Plot a graph of current against potential difference for each resistor on a separate sheet of graph paper.
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?

Experiment 10.3 – Resistors in Series

10

Background

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 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.

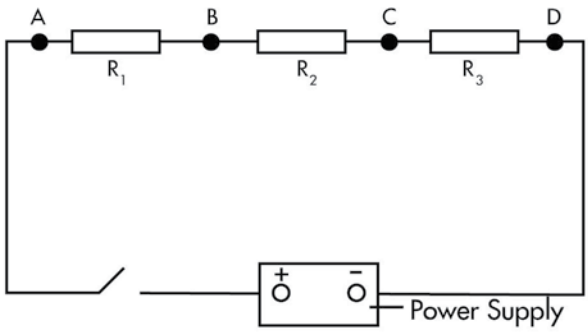
- In your group, plan the type of table that you will use to record your data.

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.

Post-Lab Discussion

1. What is the relationship between current and resistance in a series circuit?



Apparatus for Experiment 10.3

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 10.4 – Resistors in Parallel

10

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

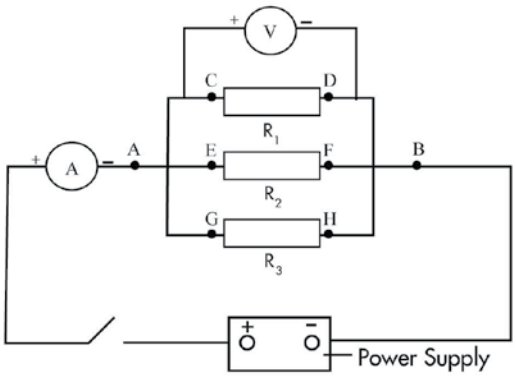
Pre-Lab

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 (*below*).
- 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 10.4

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 $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ 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?

Problem Set 10.1 – Electrical Energy & Power

10

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.

Car window demister

2. A 6.00 W globe draws a current of 5.00×10^2 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.

3. 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?

4. 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) Calculate the operating resistance of the motor.

5. A typical headlight globe in a car operates at 12.0 V and dissipates 55.0 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.

6. 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 29c per kW h. Calculate how much it costs to operate the following devices at home:

(a) A 60 W desk lamp for 3.00 hours per day, 5.00 days per week, for 9.00 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.

7. Calculate the cost of running each of the following from the 240 V mains:

   (a) an electric fan heater rated at 2.00 kW, for 3.00 hours;

   (b) an electric water heater whose element has a resistance of 26.0 W, for 4.00 hours;

   (c) an electric drill rated at 8.00 A, which is run for 30.0 minutes.

8. 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 10.0 amp-hours. This means that it can deliver 2.00 A for 5.00 hours, or 1.00 A for 10.0 hours, before its emf drops to a useless level.

   (a) A standard 12.0 V car battery is rated at 40.0 amp-hour. How much energy, in joules, can it provide before it is 'flat'?

   (b) A more expensive 12.0 V battery is rated at 75.0 amp-hour. For how long can it be used for emergency lighting comprising of two 55.0 W headlight globes?

9. A nickel metal hydride rechargeable AA cell is rated at 2.30 amp-hour and has an emf of approximately 1.40 V when fully charged. Suppose one such cell is used in a small 3.00 W 'key light'. How long will the cell last until it needs to be recharged?

10 Problem Set 10.2 – Circuits & Ohm's Law

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 kW and has 3.42 V across it. Calculate the current through this resistor.

   (c) A 2.00 kW resistor has a power rating of 1.60 W. Calculate the maximum current it will tolerate.

2. A telephone receiver has a resistance of 8.00×10^3 W, and it uses a current of 7.00 mA. What potential difference must the exchange supply to make the receiver work properly?

3. A technician has to replace the indicator lamps in a stereo amplifier. Each lamp operates on 14.0 V and draws a current of 5.00×10^2 mA. Calculate the operating resistance of such a lamp.

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 4.70 W. What potential difference battery would you advise Tom to use in his car?

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.

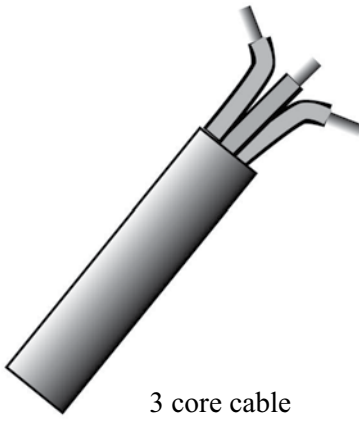
   (b) What happens inside the heating element that causes the resistance to increase as its temperature rises?

   (c) Calculate the resistance of a 240 V bar heater that passes 10.0 A once it is at its normal operating temperature.

   (d) Calculate the power consumption of a 240 V heater that passes 10.0 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?

6. The figure (*right*) 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 ºC.

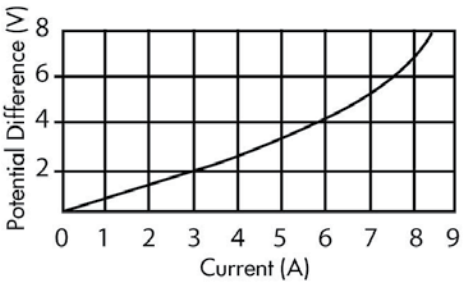


3 core cable

(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.

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?

8. Why is it that the electricity does not kill birds when they perch on high voltage transmission lines?

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?

Problem Set 10.3 – Parallel & Series Circuits

1. Are the appliances in your home connected to the electricity supply in series or in parallel? Give evidence to support your answer.

2. Calculate the total resistance of a string of twelve fairy lights connected in series, if the resistance of each lamp is 30.0 Ω.

3. An auto electrician connects two 12.0 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 20.0 Ω. 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.

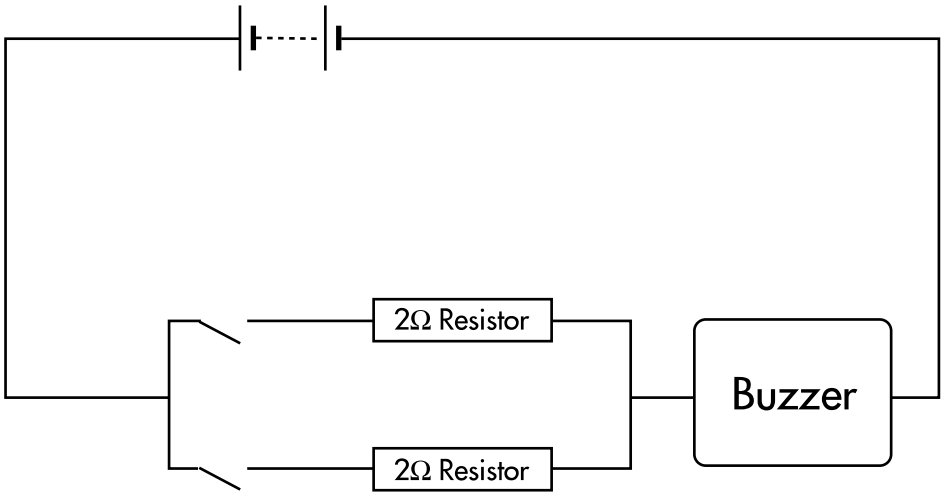
   (d) How does the intensity of light in (c) compare with (b)? Explain.

4. A farmer wants to run a 12.0 V car radio on the 32.0 V farm electricity supply. The radio uses 4.00 A.

   (a) What resistance must the farmer use in series with her radio?

   (b) Calculate the power rating of the resister needed.

5. Claire has a personal alarm with her for safety. It consists of two 9.00 V batteries, two switches each connected to a 2.00 Ω resistor and a buzzer of resistance 3.00 Ω. The circuit diagram is shown below:

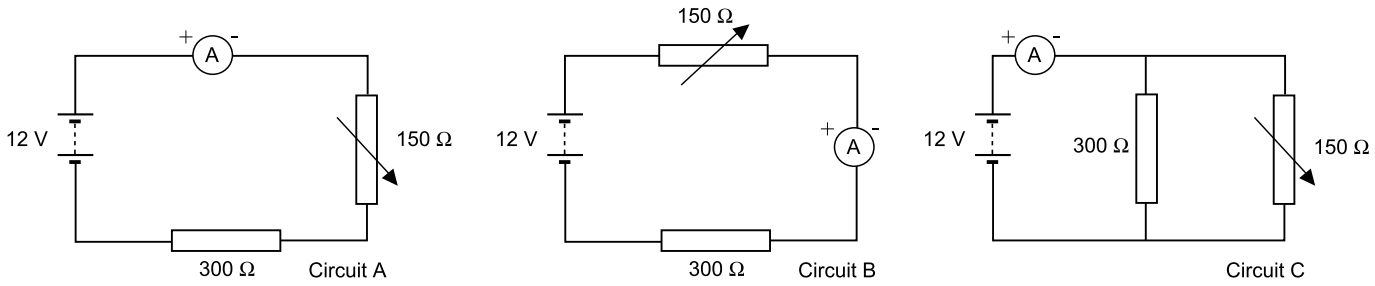


(a) Calculate the total resistance of the personal alarm circuit when both of the switches are closed.

(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 3.00 minutes at the softest setting.



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?

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?

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.

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?

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 Ω microwave oven, a 450 Ω toaster and a 1000 Ω electric kettle.

(b) Will the total current increase, decrease or remain the same if a 150 Ω coffee grinder is also switched on? Explain.

11. You are designing a new type of kettle. The kettle has two identical heating elements, each of 100 Ω resistance.

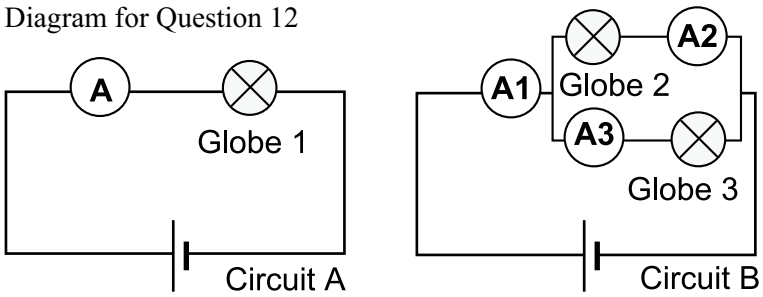
(a) What is the resistance of the kettle if the heating elements are connected in series?

(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.

12. A student sets up circuit A as shown in the diagram (below) 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.

Diagram for Question 12



(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 A?

13. 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 12.0 V globes. A car has two 60.0 W headlights and two 10.0 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 60.0 W lamps.

(d) Calculate the individual resistances of the 10.0 W lamps.

(e) Calculate the current supplied by the car battery when the car is parked but the lights are left on.

Optional Question:

14. 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 12.0 V, and must provide a current of 80.0 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 0.0500 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.

10 Problem Set 10.4 – Circuits & Safety

1. Name and describe the function of each conductor in a three-wire domestic general power outlet (three-pin socket).

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?

3. How many 40.0 W light globes can you operate on a 240 V circuit protected by a 15.0 A circuit-breaker?

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.

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.

House fuse-box

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 15.0 A circuit-breaker? Explain.

7. Should you operate a 1000 W iron, a 2400 W clothes drier and a 2000 W washing machine from the same 15.0 A, 240 V power point? Explain.

8. What role, if any, do circuit-breakers, fuses and residual current devices play in preventing shock hazards?

10. The fuse or circuit breaker in the lighting circuits of a house will break the circuit if the total current exceeds 10.0 A and the fuse for the power points will break those circuits if the total current exceeds 15.0 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.

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 10.0 A. Will Alec's circuit work?

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 40.0 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?

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 1.50 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?

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 50.0 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 3.00 V, 500 mA torch bulb connected across such a supply.

(c) Explain how the 50.0 MΩ resistor acts as a safety device.

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 W 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.

Comprehension 10.1 – Electricity Around the Home

10

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.

Questions

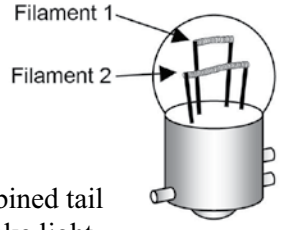
1. A motor vehicle has a combined tail light and brake light that contains two separate filaments in the same glass envelope. Filament 1 has a resistance of 18.0 Ω and filament 2 has a resistance of 32.0 Ω.

   (a) Are the filaments connected in series, or in parallel? Why did the manufacturers choose this arrangement?

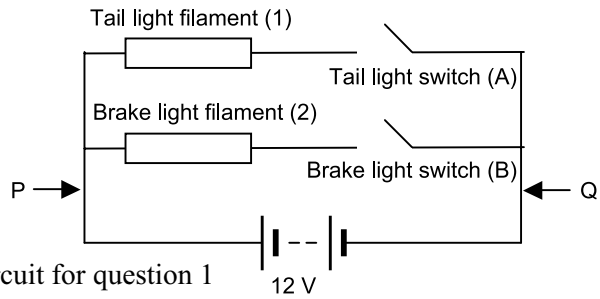
   (b) Calculate the overall resistance of the lamp when switches A and B are both closed.

   (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.



Combined tail & brake light



Circuit for question 1

(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):

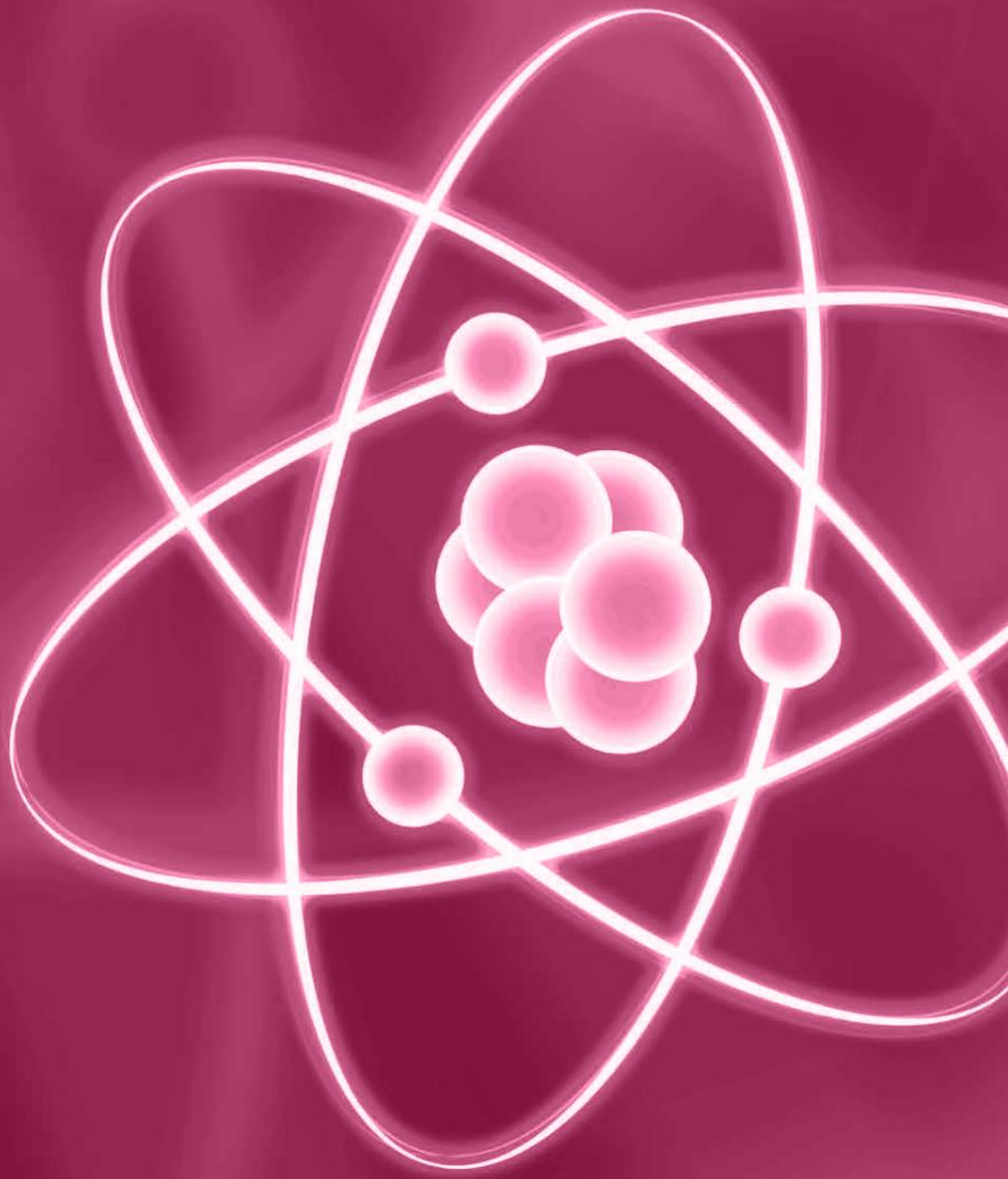
(f) What would be the effect on the lights? Explain.

(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.

2. 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 11 - Investigations



Investigations 3.1 & 3.2 – Measuring 'g'

3.1 – 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.

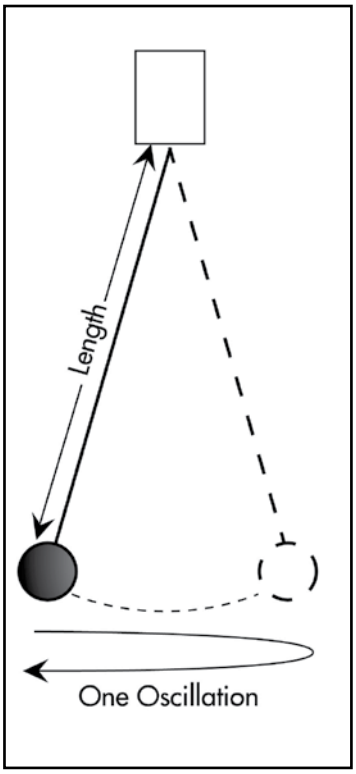
For this investigation, identify and write down your experimental hypothesis, the dependent variable and the independent variable, and which variables (if any) you intend to control.

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

3.2 – 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.

Investigation 4.1 – 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.

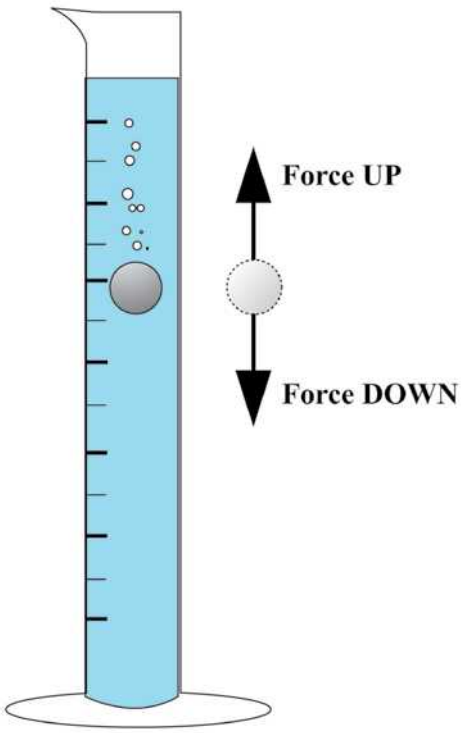
When a ball bearing is dropped into a viscous fluid then there are two forces acting on the ball bearing:

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 16.3

Investigations 5.1, 5.2, 5.3 – Energy & Power

Investigation 5.1 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 18.4

Investigation 5.2 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.

Investigation 5.3 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.

Investigation 6.1 – 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 insulated 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

Investigation 4.3 – Cooling systems

Primary 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 4.4– Food preparation and preservation

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 4.4– Food preparation and preservation

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 7.1 – Beat Patterns

Background

Two sound signals of similar frequency but equal amplitude (loudness) can produce and unique interference signal. A beat pattern is a sound signal that occurs in systems such as dual motor systems in boats, cars of similar make accelerating from a set of lights, or when a person tries to tune an instrument using tuning forks.

Aim

To produce a beat pattern for a range of systems of varying frequency difference. To measure period of the beat signal using a microphone and digital CRO (or other device).

Apparatus

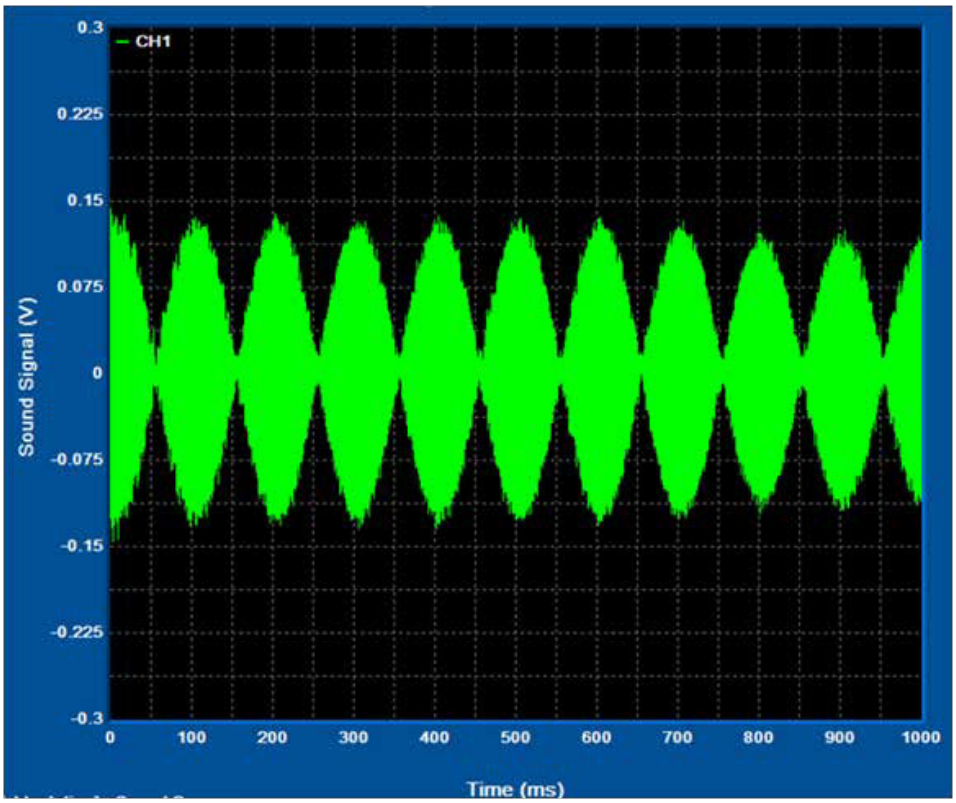
- 2 sound generators (or a range of tuning forks with sticky tape) slinky spring
- Data logging software or CRO
- Microphone

Pre-Lab Discussion

- What is a compression and a rarefaction?
- What happens when a compression from one sound source and a compression from another sound source combine for an instant?
- What happens when a compression from one sound source and a rarefaction from another sound source combine for an instant?

Lab Notes

- In a quiet area set up your two signal generators approximately 3 m apart. Place a microphone connected to a data logger (or CRO) between the two generators.
- If you are using the tuning forks ensure you have two of the same frequency. Place a very small amount of tape over both ends of one of the tuning forks. Ensure you measure the frequency of the modified tuning fork.
- Ensure that the amplitude for both generators is the same. Set one of the signals to a frequency of 1000 Hz and the other to 1010 Hz.
- Set your data logging software to record at a rate of 10 000 samples per second for 1.0 second. If you are using a CRO you will not need to set sample rate.
- A sample of an expected graph is opposite.
-



- Repeat the process and collect the signals as you decrease the difference in frequency between the two sources.
- Measure the period of the beat pattern and determine the frequency of the beat pattern.
- For one of the beats fluctuations, or for a single pulse, zoom in on the signal. Draw what you see and if possible determine the frequency.

Post-Lab Discussion

- For some signals you may not have a complete cancelling out at the destructive point in the signal. What do you think could have caused that?
- Why is in important to have the microphone between the two sound sources?
- Where else do you observe this property of sound?

Investigation 8.1 – The Nuclear Debate

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.

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.

Investigation 8.2 – Radioactive Dating

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 8.3 – Radiotherapy

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.

Investigation 10.1 – Creating & Storing Electric Charges

Background

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

- 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.

Lab Notes

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.

Investigations 10.2 & 10.3 – Electrical Charge

Creating very large charges

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.

van de Graaff generator

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.

Investigation 10.4 – The Mechanical Power of an Electric Motor

Background

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, $W = \Delta Ep = mg\Delta h$, 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. 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:

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\left(\frac{mg\Delta h}{\Delta t}\right)}{VI}$$

Aim

To investigate the efficiency of an electric motor.

Pre-Investigation

- 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.

_____

_____

_____

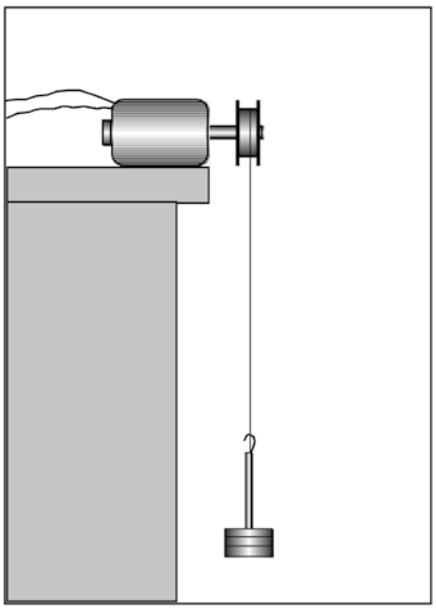
_____

- Prepare a table to record the data you will gather.

Apparatus

You will need at least the following list. Negotiate with your teacher or technician for 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



Apparatus for Investigation 10.4

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.

Post-Investigation

1. What was your experimental hypothesis?
2. Identify the following variables:
   (a) Independent variable
   (b) Dependent variable
   (c) Control variables
3. You should have a range of measurements of m, Δh, Δt, V, and I for the motor. Use these to calculate the efficiency of the motor.
4. Summarise your findings.
5. Look carefully at your experimental technique. What might you have improved?
6. Describe any errors that may have affected the validity of your results.
7. 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.

Investigation 10.5 – Characteristic Curves

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 10.6 – Resistivity

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.

Investigation 10.7 – EMF in Series & 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 only close the circuit for short time periods to prevent overheating.

Post-Lab Discussion

1. How does connecting cells in series effect the current produced?
2. How does connecting cells in series effect the total emf provided?
3. How does connecting cells in parallel effect the current produced?
4. How does connecting cells in parallel effect 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.

Investigation 10.8 – 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 (*on following page*) 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)

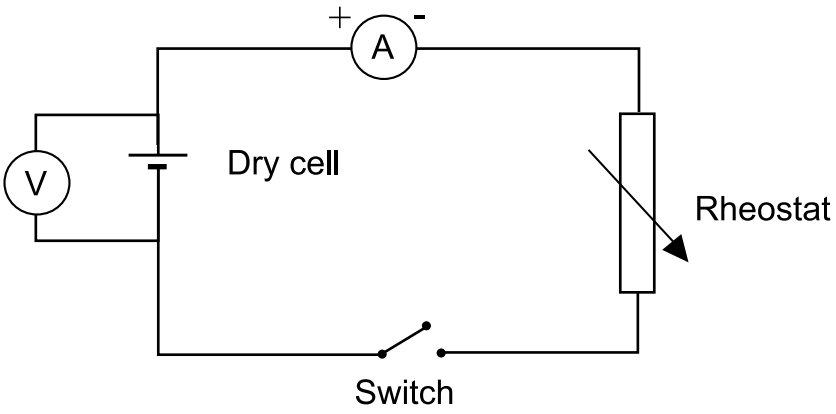
or, in symbols, $\varepsilon = IR_{ext} + IR_{int}$

- 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 $V = \varepsilon - Ir$ 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.

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 12.4

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.

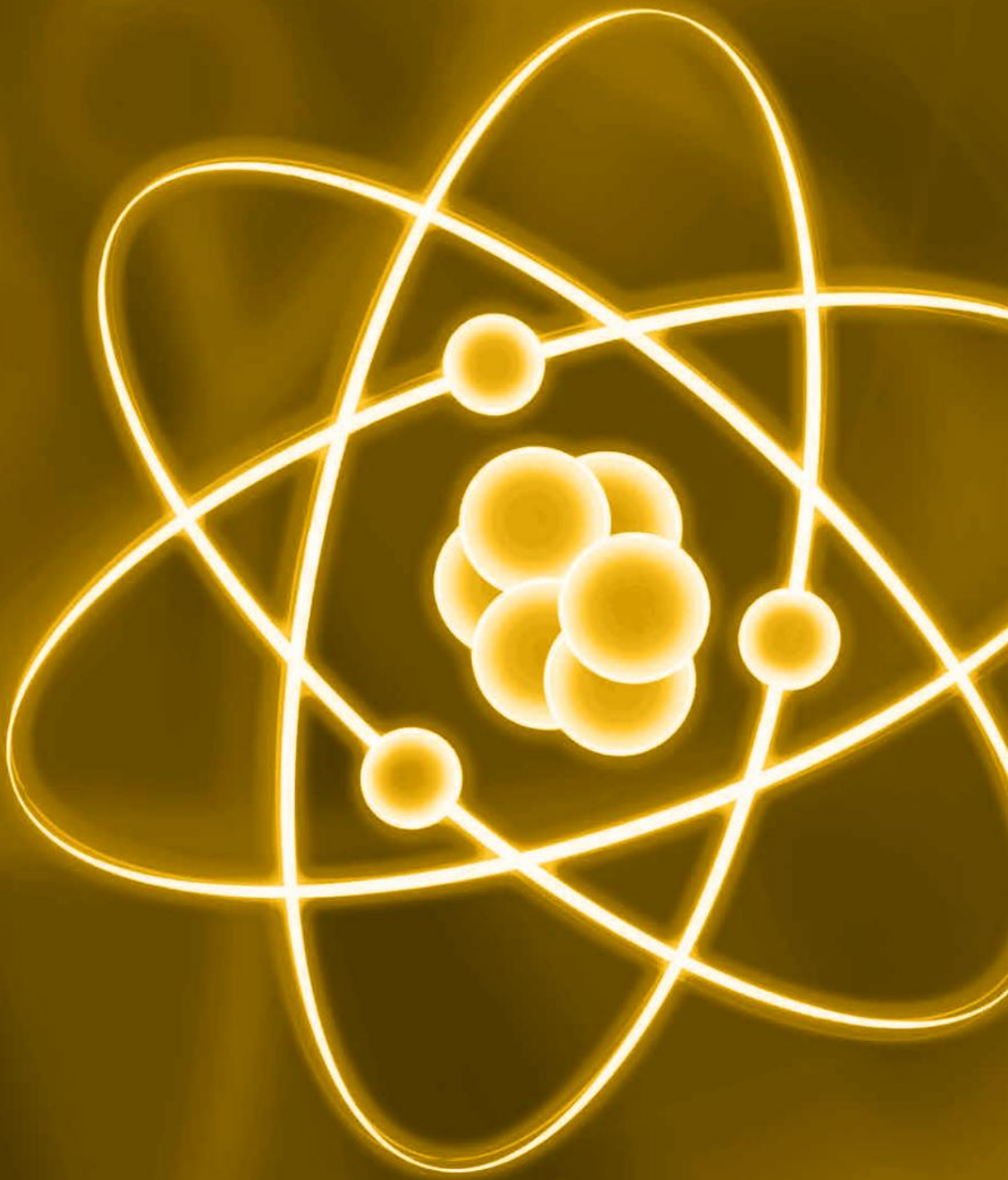
Investigation 10.9 – RCDs & circuit breakers

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 are 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.

Chapter 12 - Answers



Chapter 1

1.	2	and	4.2×10^{-6} J
	4	and	2.223×10^{2} °C
	1.2, 3 or 4	and	1.4×10^{3} kg (2 s.f)
	5	and	4.1213×10^{1} km
	5	and	1.3002×10^{3} m s^{-1}
2.	2.32×10^{-1} s	and	3.00×10^{-7} m
	1.00×10^{4} m	and	2.03×10^{10} Hz
	9×10^{-7} Sv	and	8.52×10^{7} N
3.	0.91 ± 0.05 mm		
	31.5 ± 1.3 m s^{-1} (may vary slightly)	and	18 ± 1 °C

4. (a) 10%
   (b) 11%

5. (a) 0.440 K
   (b) 4.04 N

6. (a) 2.20 ± 0.06 m
   (b) 0.385 ± 0.022 m^2

7. 366 ± 55 m s^{-1}

Chapter 2

Set 2.1

1. Velocity, speed in a given direction, is a vector quantity - has both magnitude and direction.
2. 294 N
3. (a) 42.2° (b) 3.36 m s^{-1} at 53.5° to the bank, downstream (c) 29.6 m downstream
4. 47.2 m s^{-1} away from the player or -170 km h^{-1}
5. 42.4 m s^{-1} at right angles to the bat
6. 42.8 m s^{-1} horizontally
7. Horizontal: 20.5 m s^{-1}; Vertical: 14.3 m s^{-1}
8. 4.14 m s^{-2} down the slope
9. (a) The plank could be set at an angle to reduce the normal force that is required. (b) 32.6°

Chapter 3

Set 3.1

1. (a) 26.8 m s^{-1} (b) 96.5 km h^{-1}
2. (a) 110 km h^{-1}
3. (a) 15.0 km east (b) 30 km h^{-1} east

4. (a) 3.20 km (b) 2.67 m s^{-1} (c) 2.00 x 10^3 m north (d) 1.67 m s^{-1} north
6. 16.7 h
7. (a) D to E (b) B to C (c) D (d) 30 km (e) 37.5 km h^{-1} (f) direction of travel
8. (a) 1.5 m s^{-1} (b) 40 minutes

Set 3.2

1. (a) 32 m s^{-1} (b) 24.4 km (c) 115 km h^{-1} (d) 30.3 m s^{-1}
2. (a) 114 m s^{-1} upwards (b) its initial velocity
3. (a) 250 s (b) 25 s (c) 200 s (e) 5.6 x 10^3 m
4. 32 m
5. all equal (9.8 m s^{-2} downwards)
6. (a) 38.4 m s^{-1} (b) 5.90 s
7. (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 = 4.3 s, stopping distance = 39.3 m (g) 1.39 m s^{-1}
8. (a) 24.5 m s^{-1} up (b) 24.5 m s^{-1} down
9. (a) 15 m s^{-1} (c) 109 m
10. (a) 30 m (b) -5 m s^{-2} (c) 15 m s^{-1} (d) 14 m

Chapter 4

Set 4.1

3. (a) equal (b) $F_{w(Earth)}$ = 2.63 times greater than $F_{w(Mars)}$ (c) equal, F = 80 N (d) yes
4. 65 N in opposite direction to motion
5. 9.5 m s^{-1} east
6. (a) forces are same size (b) the small car
7. (a) 1715 N upwards (b) 1978 N upwards (c) 1715 N upwards (d) 1190 N upwards
8. Tension in rope between truck and first car = 3480 N, Tension in rope between first and second car = 1740 N

Set 4.2

1. 608 kg m s^{-1} north
2. (a) 0.107 m s^{-1} south (b) 16.0 m s^{-1} south
3. (a) 6.3 N sin direction of the bat's velocity (b) 0.50 kg m s^{-1} away from the cushion (or 6.500 N s)
   (c) 5.05 x 105 kg m s^{-1} north east (or 5.05 x 10^5 N s) (d) 600 N s east
4. (a) 16.4 m s^{-1} in the original direction of motion (b) 18.0 m s^{-1} in the original direction of motion
5. (a) 1.2 N6.
6. 766 m s^{-1} in the original direction of motion
7. (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
9. 1.11 m s^{-1} in the original direction of motion

10. (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
11. 2.4m s^{-1}

Chapter 5

Set 5.1

1. 287 J
2. 29.4 kJ
3. (a) 16.0 J (b) 237 J
4. (a) 2.16 MJ
5. 120 N
6. 980 kJ
7. (a) 417 W (b) 62.0 W (c) 59.2 W (d) 150 W
10. (a) 140 m s^{-1}
11. (a) 4390 W (b) 0.163 m s^{-1}
12. (a) 3 W (b) 150 W (c) 66.7 W
13. (a) 152 J (b) 90.0 J (d) 5.18 N up the ramp

Chapter 6

Set 6.1

3. 38.4 MJ
4. 21.2 ºC
5. 450 J kg^{-1} K^{-1}
6. 47 ºC
8. 8.76 kg
9. 3.48 x 103 J kg^{-1} K^{-1}
10. 74.8 ºC
11. 88.5 ºC

Set 6.2

1. (a) 9.55 x 106 J (b) 9.56 x 105 J (c) 1.08 x 104 J
2. 8.89 x 104 J kg^{-1}
5. (a) 9.68 MJ (b) 50.3 ºC
6. (a) 176 m
7. (a) 80 s (b) 590 s (c) 670 s
8. 127 J s^{-1}
9. (a) 452 J kg^{-1} K^{-1} (b) 21.5 kg

10. (a) 432 g (b) 383 g
11. 254 g

Chapter 7

Set 7.1

1. 14.7 m s^{-1}
2. 2.65 m s^{-1}
3. T = 8.33 ms;λ = 2.88 m
4. 4.96 m s^{-1}
7. 5 ºC
8. 82 m
9. (a) 50 mm (b) 0.4 m s^{-1} (c) 8.4 Hz
10. (a) 0.5 Hz (b) 2 s
12. Signal I: T = 0.0060 s or 6.0 ms; f = 170 Hz; A= 0.40 nm; λ. = 2.0 m
    Signal 2: T = 0.0072 s or 7.2 ms; f= 140 Hz; A= 0.30 nm; λ= 2.4 m
    Signal 3: T = 0.0052 ms; f = 192 kHz; A= 0.50 mm; λ = 1.76 mm
13. Signal 1: T = 0.06 s; f= 17 Hz; λ = 21 m
    Signal 2: T = 0.018 ms; f= 56 kHz; λ= 6.3 mm
14. (a) George (b) Jane (c) George

Set 7.2

3. (c) 34 Hz to 17 kHz
5. 72.8 m
8. 720 Hz
9. (a) 512 m s^{-1} (c) 84 Hz, 168 Hz, 252 Hz
12. (a) 0.64 m, 328 m s^{-1} (b) closed
18. (a) 1.64 m, 0.0822 m

Chapter 8

Set 8.1

1

	# Protons	# Neutrons	Element
a	8	9	Oxygen
b	19	21	Potassium
c	92	142	Uranium
d	95	146	Americium

2. a. ${}^{1}_{1}p$ b. ${}^{239}_{94}Pu$ c. ${}^{0}_{1}\beta^{+}$ d. ${}^{131}_{53}I^{*}$ e. ${}^{4}_{2}\alpha$

3. a. ${}^{10}_{5}B + {}^{1}_{0}n \rightarrow {}^{7}_{3}Li + {}^{4}_{2}\alpha$

   b. Lithium-7 & helium-4 are formed in the reaction

4. ${}^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}\alpha$

5. ${}^{42}_{19}K \rightarrow {}^{42}_{20}Ca + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$; the product formed is calcium-42

6. ${}^{141}_{56}Ba \rightarrow {}^{141}_{55}Cs + {}^{0}_{+1}\beta + {}^{0}_{0}\nu$; a positron and a neutrino are formed

7. ${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$; the product formed is xenon-131

8. ${}^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$; NB: also acceptable to write ${}^{99}_{43}Tc^{*}$

9. ${}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}\alpha$; product formed is polonium-218

10. (a) ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{1}_{0}n + {}^{4}_{2}\alpha$; (b) a neutron is also released

11. ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}p$; the cosmic radiation is a neutron

12. ${}^{239}_{94}Pu \rightarrow {}^{235}_{92}U + {}^{4}_{2}\alpha$;

    followed by ${}^{235}_{92}U \rightarrow {}^{231}_{90}Th + {}^{4}_{2}\alpha$

    followed by ${}^{231}_{90}Th \rightarrow {}^{231}_{91}Pa + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

13. ${}^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}\alpha$

    ${}^{228}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

    ${}^{228}_{89}Ac \rightarrow {}^{228}_{90}Th + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

    ${}^{228}_{90}Th \rightarrow {}^{224}_{88}Ra + {}^{4}_{2}\alpha$

    ${}^{224}_{88}Ra \rightarrow {}^{220}_{86}Rn + {}^{4}_{2}\alpha$

14. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n$; three neutrons are also released

15. (a) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{134}_{51}Sb + {}^{95}_{39}Y + 3{}^{1}_{0}n + {}^{4}_{2}\alpha$; (b) an alpha particle is also released

16. ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$

    ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta + \bar{\nu}$

    ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta + \bar{\nu}$

17. ${}^{11}_{5}B + {}^{4}_{2}\alpha \rightarrow {}^{14}_{7}N + {}^{1}_{0}n$; the particle produced is a neutron

18. p = uud
    d = p – uu
    = (+1) – (+2/3) – (+2/3)
    = -1/3

19. n = udd = (+2/3) + (-1/3) + (-1/3) = 0

20. Since they are fundamental, they are not made up of anything.

21. (a) 9.11×10^{-31} kg (b) $+1.60 \times 10^{-19}$ C

22. $\bar{p}$, $\bar{n}$

23. $\overline{uud}$

24. u = +2/3 and d = -1/3; so $\bar{u}$ = -2/3 and $\bar{d}$ = +1/3
$\bar{p} = \overline{uud}$ = (-2/3) + (-2/3) + (+1/3)
= -3/3 = -1

Set 8.2

1. (a) 22 hours (b) 50% (c) ¾
2. (a) 6 hours (b) about 48 hours
3. 120 years
4. 300 kBq
5. (a) 37.5 minutes
6. (a) 3.2×10^6 Bq (b) 2×10^5 Bq
7. (a) 5×10^{23} atoms (b) ${}^{239}_{94}P\ u \rightarrow {}^{4}_{2}He + {}^{235}_{92}U$
8. (a) 26.8 GBq (b) 53 years
9. sample X
10. (a) 1.33 MBq (b) ${}^{198}_{79}Au \rightarrow {}^{0}_{-1}e + {}^{198}_{80}Hg + {}^{0}_{0}\bar{\nu}$
12. 17200 years ago
13. (a) ${}^{24}_{12}Mg + {}^{1}_{0}n \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H$ or ${}^{1}_{1}p$; ${}^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$ (b) 50 h
14. (a) 120 Bq
15. (a) 125 years
16. (a) about 11000 years

Set 8.3

6. 0.72 Sv
8. (a) 0.206 Gy (b) 4.12 Sv (c) yes
9. 0.070mJ y^{-1}
12. (a) 0.447 Gy (b) 0.447 S (c) no
13. (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
16. (a) 121 days per year

Chapter 9

Set 9.1

1. about 1 u
2. (a) ${}^{0}_{0}\gamma \rightarrow {}^{0}_{-1}\beta + {}^{0}_{+1}\beta$ (b) 1.64 x 10^{-13} J
3. 7.34 MeV nucleon^{-1}
4. B
5. (a) total BE = 37.7 MeV; BE/nucleon = 5.38 MeV nucleon^{-1}
   (b) total BE = 1075.7 MeV; BE/nucleon = 8.21 MeV nucleon^{-1}
6. tritium
7. carbon-12
8. (a) positron. (b) 2.59 x 10^{-30} kg (c) 1.46 MeV
9. (a) 0.01833 u (b) 17.1 MeV
10. 4.27 MeV
11. (a) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{142}_{54}Xe + {}^{90}_{38}Sr + 4{}^{1}_{0}n$
13. (a) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n$ (b) 178 MeV (c) 3.90 x 10^{-25} kg
    (d) 2.56 x 10^{24} atoms (e) 7.30 x 10^{13} J (f) 1.34 kg
14. (a) ${}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He$ (b) 4.98 MeV (c) 2.99 x 10^{26} atoms (d) 2.38 x 10^{14} J
15. 2.32 MeV
16. (a) ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}p$ (b) 2.04 x 10^{-30} kg (c) 1.84 x 10^{-13} J (d) 1.48 x 10^{7} m s^{-1}
17. (a) ${}^{7}_{3}Li + {}^{1}_{1}p \rightarrow 2{}^{4}_{2}He$ (b) 8.42 MeV or 1.35 x 10^{-12} J
18. 1.88 x 10^{4} MeV
19. (a) ${}^{222}_{86}Rn \rightarrow {}^{4}_{2}He + {}^{218}_{84}Po$ + energy (b) gamma
20. (a) ${}^{198}_{79}Au \rightarrow {}^{198}_{80}Hg + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$ (b) 0.860 MeV

Chapter 10

Set 10.1

1. (a) 5.00 A (b) 48.0 Ω
2. (a) 12.0 V (b) 24.0 Ω
3. (a) 2.88×10^4 J (b) 24.0 W (c) 2.40×10^3 C
4. (a) batteries or transformer (b) 15.9 Ω
5. (a) 4.58 A (b) 2.620 Ω
6. (a) $2.35 (b) $0.43 (c) $2.78 (d) 4.12 c
7. (a) $1.74 (b) $2.57 (c) 28 cents
8. (a) 1.73×10^6 J (b) 8.18 h
9. 64.4 min

Set 10.2

1. (a) 21.3 Ω (b) 23.3 μA (c) 28.3 mA
2. 56.0 V
3. 28.0 Ω
4. 1.50 V
5. (c) 24.0 Ω (d) 2.40 kW
6. (a) 0.65 Ω (b) 652 mV
7. (a) 0-6 A (b) 0.67 Ω
9. (c) 343 Ω

Set 10.3

2. 360 Ω
3. (a) 24.0 V (b) 0.400 A (c) 6.67 Ω (d) brighter
4. 5.00 Ω
5. (a) 4.00 Ω (b) 4.50 A (c) both closed (d) 11.7 kJ
6. (a) 26.5-39.7 mA (b) 26.5-39.7 mA (c) 118 mA-6.00 A (d) C
7. (b) 3.0 V (c) 200 mA
8. (a) 2.5 Ω (b) 8.0 V (c) 1.0 A (d) 200 mA
9. (a) parallel (b) 576 Ω (c) 0.417 A
10. (a) 8.55 A (b) increase
11. (a) 200 Ω (b) 50 Ω (c) parallel
12. (a) double (b) $A_1 = 12.0$ A, $A_2 = 6.0$ A, $A_3 = 6.0$ A (c) all the same
13. (a) 140 W (b) 1.03 Ω (c) 2.40 Ω (d) 14.4 Ω (e) 11.7 A
14. (b) 4.0 V

Set 10.4

3. 90
4. 5 A
6. (a) 5.00 A (b) yes
7. No
10. (a) 24 (b) yes
11. No
12. (a) 6.0 k Ω (b) 1.46 A
13. (a) 6.25 A (b) 24.0 Ω (c) yes
14. (a) 60 μA
15. (a) 54.5 mA (b) increase (c) 28.6 mA