HSC PHYSICS

Syllabus Notes 2007

Andrew Harvey

1st Edition

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I would appreciate and welcome your comments/corrections/suggestions, please send them to my e-mail.

Some of the sample problems are past HSC exam questions. Where this is the case the source has been acknowledged. Any solutions do not in any way reflect the Board of Studies NSW view, they are the view of the author.

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CONTENTS

PREFACE

Preamble

These syllabus notes were written to help students to understand and succeed in Physics at High School. They are based on the NSW Board of Studies HSC Physics Syllabus (Revised 2003, including 2006 updates). These notes are not a text book and as such I have tried to only include the information that is needed as the syllabus stipulates. I have taken the approach to cover each dot point on its own rather than cover topics like text books do. I have done this to make it easier to read, understand and memorise.

I have included an extensive, but still quite short coverage of syllabus topic 9.1 skills. This is meant to be integrated with the content however I decided it was easier to cover it separately. You should note that it is very rarely examined directly, except for basic graphing skills, and sometimes reliability, validity and accuracy. You should spend most of your time covering the content as you know there will a lot of that in the exam.

These notes have been proof read by Physics teachers and the information has been collected from many reliable sources and cross referenced (see the references section). However I will not be held liable for any error in these notes. My references include class lectures, HSC & university level text books, summary notes, web sites, conference proceedings, journal articles, past HSC exams, past HSC notes from the Marking Centre and many other sources. If you find any aspects which are incorrect or could be worded better please let me know and I'll do my best to fix it.

For the Student

To succeed in the HSC examination you need to be able to do three main things. Firstly, you need to *memorise* the content. Secondly, you need to *understand the concepts*. Questions do not always ask you to recall a memorised slab of information, they sometimes require you to think critically and solve problems. To be able to do this you need to have a clear and deep understanding of the physics involved. Thirdly and the most important of all, is that you need to be able to *communicate your ideas*. There is no use in knowing the answer to the question if you cannot communicate this through writing or diagrams to the marker.

So I guess the key to success in HSC Physics is to be good at those three things. These notes aim to help you on the first two points and my sister publication *HSC Physics Past Paper Solutions* aims to help you with the third and second aspects.

Different people study in different ways, you should do what works for you, however what I found most effective in studying physics was to firstly turn up to the lesson and try to understand what the teacher is saying. Don't try to memorise everything, but rather try to understand what was being said. Like everyone else, I understood very little when it was first explained. That is why you need to do more.

Within a week of the lesson you should go though the content of the lesson in various text books and study guides such as these syllabus notes. In this stage you should begin to understand much of the content. Your teacher is there to help you and many times they will help you. Consult your teacher and seek clarification of any aspects that you do not understand. Once you have finished a topic you should find some past paper questions and tackle them. But remember that this method worked for me. You should do what you find works for you.

When you refer to text books, you should not just use one book. You should get your hands on all of the main HSC Physics text books available and read and try to understand them. Don't try to learn it all at once. It may help to wait until you have covered the material in class before you begin to study it at home, but either way you should read these HSC texts. Also relying on one text or one source is a bad idea. One text may explain it in a different way, or present ideas that the other text did not. Or sometimes one source may be wrong. You should use as many as you can. But this is not limited to

HSC texts. The HSC texts are pretty much based on first and second year university level text books, so you should get your hands on the popular university level texts. I used only one, but I found myself referring to it frequently. Often it has a much clearer and accurate explanation that helps me understand the physics. There are also a wide range of journal articles, periodicals, conference proceedings, web sites, and other material that is often quite useful. You should refer to these.

As a final note I would appreciate it if you could give me feedback about these notes. The feedback would help me in future editions also I would like to know how many people have read these notes.

About the Author

Greetings fellow Physics students! I am just an ordinary physics student who found the course extremely difficult. It is not easy and I found that there was a lack of resources out there, so I decided to publish my Syllabus Notes in a bid to help out others.

I completed my HSC in 2007 at Blakehurst High School, a non-selective government school. In my school assessment I was ranked 2/39 in my school and attained a trial mark of 77%. In the external HSC examination I attained a band 5 with a mark of 89. Just for your interest my HSC exam script is available at http://andrew.harvey4.googlepages.com/. However if you are looking for solutions please view my Past Paper Solutions publication, not my exam script.

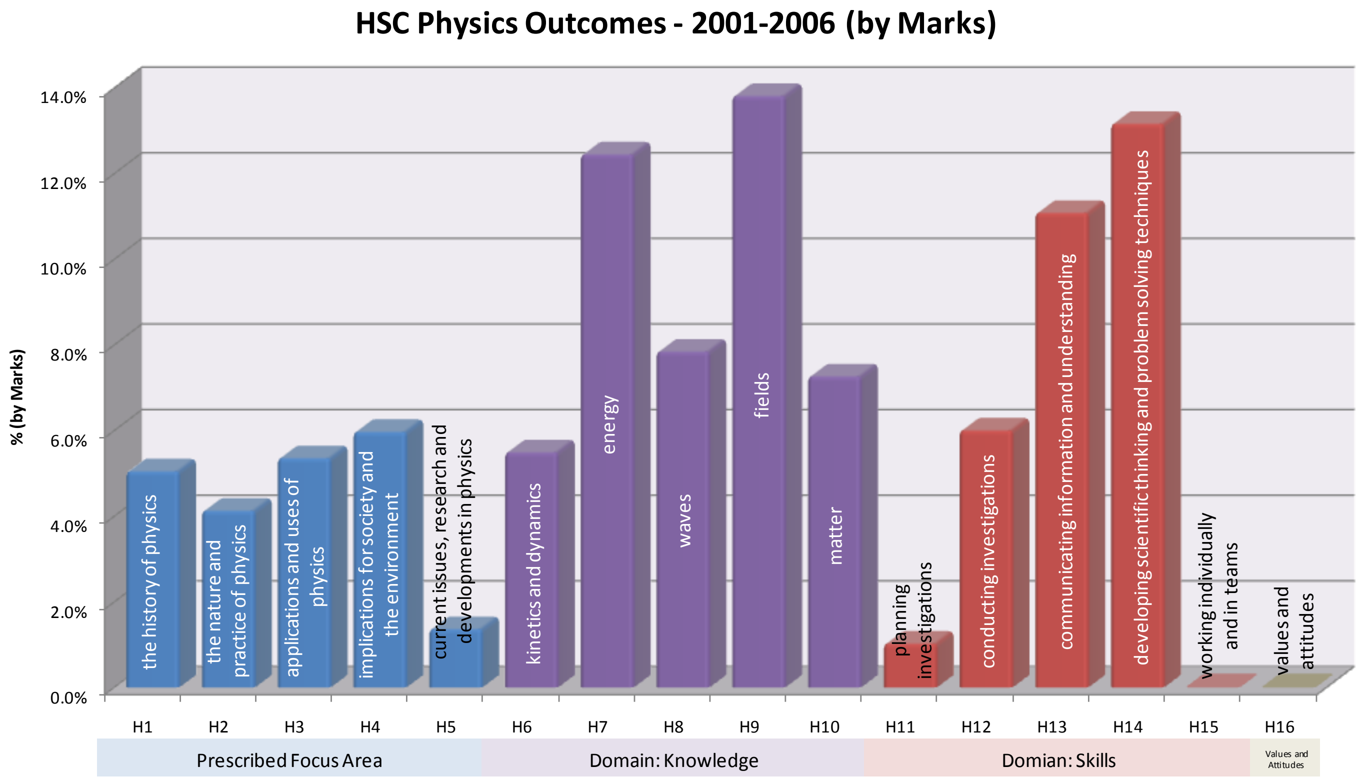
Syllabus Focus

There are 16 outcomes in the Stage 6 Physics Syllabus, and they come under the following topics.

> Students [studying Stage 6 Physics] will develop knowledge and understanding of:
> 1. the history of physics
> 2. the nature and practice of physics
> 3. applications and uses of physics
> 4. implications for society and the environment
> 5. current issues, research and developments in physics
> 6. kinetics and dynamics
> 7. energy
> 8. waves
> 9. fields
> 10. matter
> 11. planning investigations
> 12. conducting investigations
> 13. communicating information and understanding
> 14. developing scientific thinking and problem solving techniques
> 15. working individually and in teams
> 16. themselves, others, learning as a lifelong process, physics and the environment

Board of Studies NSW. (2002). *Stage 6 Physics Syllabus* . Board of Studies NSW.

The graphs below shows the distribution of these outcomes for the HSC Physics exam from 2001-2006. It has been calculated on a per mark basis from data in the *Mapping Grid* (2001-2006, Board of Studies).



The Prescribed Focus Area makes up 22% of the marks, Knowledge makes up 47% of the marks and the other 31% is Skills. So as you can see you cannot be good just at Physics, you must be good at things such as the social implications of physics and planning first hand investigations.

Syllabus Extracts

Context
Contexts are frameworks devised to assist students to make meaning of the Prescribed Focus Areas and Domain. Contexts are culturally bound and therefore communicate meanings that are culturally shaped or defined. Contexts draw on the framework of society in all aspects of everyday life. The contexts for each module encourage students to recognise and use their current understanding to further develop and apply more specialised scientific understanding and knowledge.

Prescribed Focus Areas
The Prescribed Focus Areas are different curriculum emphases or purposes designed to increase students' understanding of physics as an ever-developing body of knowledge, the provisional nature of scientific explanations in physics, the complex relationship between evidence and ideas in physics and the impact of physics on society.

The following Prescribed Focus Areas are developed in this syllabus:

History of physics
Knowledge of the historical background of physics is important to adequately understand natural phenomena and explain the applications of those phenomena in current technologies. Students should develop knowledge of:
• the developmental nature of our understanding of energy, matter and their interrelationships
• the part that an understanding of energy, matter and their interrelationships plays in shaping society
• how our understanding of energy, matter and their interrelationships is influenced by society.

Nature and practice of physics
A study of physics should enable students to participate in scientific activities and develop knowledge of the practice of physics. Students should develop knowledge of the provisional nature of physical explanations and the complex relationship between:
• existing physical views and the evidence supporting these
• the process and methods of exploring, generating, testing and relating ideas
• the stimulation provided by technological advances and constraints imposed on understanding in physics by the limitations of current technology that necessitates the development of the required technology and technological advances.

Applications and uses of physics
Setting the study of physics into broader contexts allows students to deal with real problems and applications.
The study of physics should increase students' knowledge of:
• the relevance, usefulness and applicability of laws and principles related to physics
• how increases in our understanding in physics have led to the development of useful technologies and systems
• the contributions physics has made to society, with particular emphasis on Australian achievements.

Implications of physics for society and the environment
Physics has an impact on our society and the environment, and students need to develop knowledge of the importance of positive values and practices in relation to these. The study of physics should enable students to develop:
• understanding about the impact and role of physics in society and the environment
• skills in decision-making about issues concerning physics, society and the environment.

Current issues, research and developments in physics
Issues and developments related to physics are more readily known and more information is available to students than ever before. The syllabus should develop students' knowledge of:
• areas currently being researched in physics
• career opportunities in physics and related fields
• events reported in the media which require an understanding of some aspect of physics.

Domain
Knowledge and understanding
As one of the major disciplines of science, the Physics Stage 6 course presents a particular way of thinking about the world. It encourages students to use inference, deductive reasoning and creativity. It presumes that the interrelationships within and between matter and energy in the universe occur in consistent patterns that can be understood through careful, systematic study.

The course extends the study developed in the Science Stages 4–5 course, particularly in relation to students' knowledge and understanding of the law of conservation of energy, Newton's Laws, the wave model, particle theory of matter, atomic theory, types of energy, types of force, technology and resources.

This course will build upon this fundamental knowledge to increase students' conceptual understanding of systems involving energy, force and motion as well as interactions between these systems and the living and non-living world. The course will assume that students have an elementary knowledge and understanding of energy, motion, electricity and forces as developed in the Science Stages 4–5 course.

Skills
The Physics Stage 6 course involves the further development of the skills students have developed in the Science Stages 4–5 course through a range of practical experiences in both the Preliminary and HSC courses.

Practical experiences are an essential component of both the Preliminary and HSC courses. Students will complete **80 indicative hours of practical/field work across both the Preliminary and HSC courses** with no less than 35 indicative hours of practical experiences in the HSC course. Practical experiences have been designed to utilise and further develop students' expertise in each of the following skill areas:

• **planning investigations**
This involves increasing students' skills in planning and organising activities, effectively using time and resources, selecting appropriate techniques, materials, specimens and equipment to complete activities, establishing priorities between tasks and identifying ways of reducing risks when using laboratory and field equipment.

• **conducting investigations**
This involves increasing students' skills in locating and gathering information for a planned investigation. It includes increasing students' skills in performing first-hand investigations, gathering first-hand data and accessing and collecting information relevant to physics from secondary sources using a variety of technologies.

• **communicating information and understanding**
This involves increasing students' skills in processing and presenting information. It includes increasing students' skills in speaking, writing and using nonverbal communication, such as diagrams, graphs and symbols to convey physical information and understandings. Throughout the course, students become increasingly efficient and competent in the use of both technical terminology and the form and style required for written and oral communication in physics.

• **developing scientific thinking and problem-solving techniques**
This involves further increasing students' skills in clarifying issues and problems relevant to physics, framing a possible problem-solving process, developing creative solutions, anticipating issues that may arise, devising appropriate strategies to deal with those issues and working through the issues in a logical and coherent way.

• **working individually and in teams**
This involves further increasing students' skills in identifying a collective goal, defining and allocating roles and assuming an increasing variety of roles in working as an effective member of a team within the agreed time frame to achieve the goal. Throughout the course, students will be provided with further opportunities to improve their ability to communicate and relate effectively with each other in a team.

Values and attitudes
By reflecting about past, present and future involvement of physics with society, students are encouraged to develop positive values and informed critical attitudes. These include a responsible regard for both the living and non-living components of the environment, ethical behaviour, a desire for critical evaluation of the consequences of the applications of physics and recognising their responsibility to conserve, protect and maintain the quality of all environments for future generations.

Students are encouraged to develop attitudes on which scientific investigations depend such as curiosity, honesty, flexibility, persistence, critical thinking, willingness to suspend judgement, tolerance of uncertainty and an acceptance of the provisional status of scientific knowledge. Students need to balance these with commitment, tenacity, a willingness to take risks, make informed judgements and at times, inflexibility. As well as knowing something about physics, students also need to value and appreciate physics if they are to become scientifically literate persons.

Contextual Outline:

During the HSC course, it is expected that students will further develop skills in planning and conducting investigations, communicating information and understanding, scientific thinking and problem solving and working individually and in teams. Each module specifies content through which skill outcomes can be achieved. Teachers should develop activities based on that content to provide students with opportunities to develop the full range of skills.

9.1 PHYSICS SKILLS

H11. justifies the appropriateness of a particular investigation plan

11.1 identify data sources to:

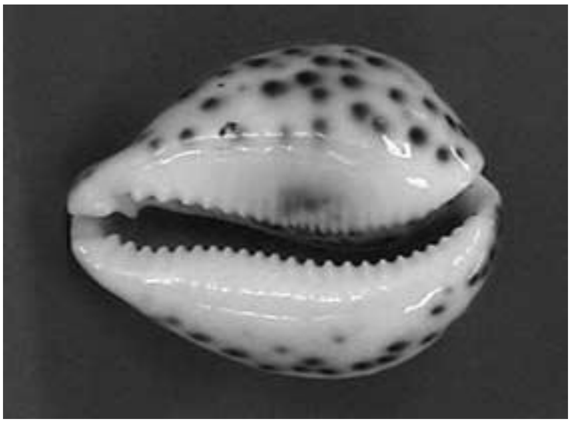
a) analyse complex problems to determine appropriate ways in which each aspect may be researched

b) determine the type of data which needs to be collected and explain the qualitative or quantitative analysis that will be required for this data to be useful

The type of data collected can vary. The data may be numerical quantities such as the mass of an object, or it may be observations such as the colour of something or its smell.

Data can be analysed qualitatively or quantitatively. Qualitative analysis refers to analysing it in regards to its qualities. For example you may observe the colour of the emission spectra of an element. You are not performing any numerical calculations, therefore you are qualitatively analysing the data. Quantitative analysis refers to analysing it in regards to numerical calculations. You may do an experiment where you change length and measure time. From this data you collect you may apply some mathematical formula to come to some conclusion. As you have performed calculations on this data, you have quantitatively analysing the data. An example of an analysis of a shell is shown below.

Qualitative observations
- pink and cream with brown spots
- pointed at one end
- long serrated opening
- very shiny surface



Quantitative observations
- 6 cm long, 4 cm wide
- centre opening 0.5 cm wide
- mass of 46 g

Fig. (1)
Learning Materials Production (LMPC). (2001). *Making and recording observations.* Retrieved November 2007, from Hints for your research project: http://www.lmpc.edu.au/resources/Science/research_projects/3%20Making&recording%20observat.pdf

Data is just data. On its own it is useless. You must analyse this data in order for the information gathered from this data to be useful.

c) identify the orders of magnitude that will be appropriate and the uncertainty that may be present in the measurement of data

This dot point is referring to **accuracy**, which is defined as "The exactness or precision of a measurement; relating to the degree of refinement in measurement or specification." Thus the orders of magnitude of measurements of data is the accuracy of the measurements. This can be explained with the concept of significant figures. I'll assume you all know what decimal places are, you may already know what significant figures are but I will explain them anyway. The number of significant figures you have in a particular quantity is just how many digits you use to make up the quantity, omitting leading zeros. For example the number 52 has two significant figures, that being the '5' and the '2'. The quantity 3.00 has three significant figures, that being the '3', the '0' and the '0'. These three digits define the accuracy of a quantity. For example the quantity 3.00 specifies that the tenths and hundredths of the quantity are zero. This is different to the quantity 3 which means that we only know that the units are 3, we don't know the tenths or the hundredths. And so 3.00 has three significant figures and 3 has one, this means that 3.00 is much more accurate.[1]

When we get to very small numbers such as 0.0001, it is best to explain these in terms of scientific notation. 0.0001 is represented as 1×10^{-4} in scientific notation. They are equivalent. However now

[1] This concept assumes the scientific context. Mathematically 3.00 and 3 are exactly the same, however in a scientific context 3 means that the value is 3 to one significant figure, the actual number could in fact be 3.45 or 2.99, etc.

that the quantity is in scientific notation we can see only one digit is used to define the quantity, hence is has one significant figures. Now you can see why significant figures are more important than the number of decimal places. Hence when we are measuring data we should ensure that we collect enough significant figures, not decimal places.

However there is another aspect to accuracy. When we measure data, we never know exactly the quantity that we measure. We may measure a length to be 35mm. However the distance may vary from 35mm by ±0.5 and still have this measurement. For example in the diagram below the piece of wood is measured to be 15mm. This is because you can only measure to the lines given, however it is actually a bit greater that 15mm. There is a region of values that are all measured to 15mm, that being from 14.5mm to 15.5mm. Hence the uncertainly of the measurement is ±0.5mm

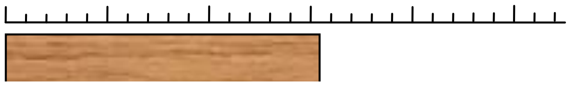


Fig. (2)

So to ensure that we collect accurate data we should use as many significant figures as possible when recording measurements. This also involves making decisions about the equipment to use, for example we can use a standard balance which has an accuracy of 0.001 or an advanced balance that is found at universities that has an accuracy of 0.0000001.

d) identify and use correct units for data that will be collected

SI Base Units:

These are the fundamental measurements, upon which all other measurements are based. The seven SI base units are shown in the table below. Please note that the first three length, time and mass are the three most important.

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

For each of these quantities, a standard has been decided upon. For example the standard of a metre is defined to be the distance travelled by light in a vacuum during a certain fraction of a second.

SI Derived Units:

Other units can be defined in terms of the base units. These are known as derived units. For example $\text{speed} = \frac{\text{distance}}{\text{time}}$. As distance and time are base units, the units of speed can be derived from these base units. Hence the unit of speed will be $\frac{\text{metre}}{\text{second}}$, ie. metre per second, ie. m s^{-1}. The units of many quantities can be derived from the formula of that quantity.

As another example, the quantity electrical resistance is measured in ohms, Ω. But the ohm is actually defined as V/A. Ampere is the base SI unit for electric current, but Volt is another derived unit for potential difference given as, W/A. Watt is a derived unit for power given as, J/s. Joule is the unit for work/energy and is given as, Nm. Newton is the derived unit for force given as, $kg \cdot m/s^2$. This shows how from the seven base units, we can derive a whole range of other derived units.

Using the SI Prefixes:

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M

10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n

The above table shows the most commonly used SI prefixes in this physics course. These are used to change units. For example, in many exam questions that require you to calculate the force of gravity, they tell you the distance in kilometres (km). You cannot just put this into the gravity formula, as if you do, you will not get newtons for the force. Similarly in questions involving Kepler's Law of Periods, r must be in metres, as the units for G on the data sheet is $\mathrm{N\,m^2\,kg^{-2}}$. To be safe, it is best practice to always change your units back to the base SI units before doing any calculations.

So referring to the table shown above, if you are told a length is $5\ \mathrm{cm}$, then this is $5 \times 10^{-2}\ \mathrm{m}$. You may also need to know that 1 metric tonne is 1000 kg.

Unfortunately in exams they do expect you to know the symbols and factors shown in the above table.

Converting Units of Higher Powers:
Sometimes you may have units such as cm^2 which need to be converted into m^2. You cannot just multiply the cm^2 by 10^{-2}, this only works for converting cm to m. So to convert cm^2 to m^2, it is best to draw a picture.

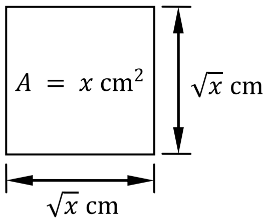


Fig. (3)

As seen in the diagram above, if the area of the square is $x\ \mathrm{cm}^2$, then the length of each side is $\sqrt{x}\ \mathrm{cm}$. Now the side length can be converted to m by multiplying by 10^{-2}, and so the side lengths are $\sqrt{x} \times 10^{-2}\ \mathrm{m}$. Now this can be squared to get the area in m^2, $\left(\sqrt{x} \times 10^{-2}\right)^2 = x \times 10^{-4}\ \mathrm{m}^2$.

Using Units in Calculations:
When using formula, there is a simple rule that the units must be the same on both sides, For example $F = ma$, so if we use the units kg and ms^{-2} for mass and acceleration respectively, then the units for force will be kgms^{-2}, which is a Newton.

e) recommend the use of an appropriate technology or strategy for data collection or gathering information that will assist efficient future analysis

In modern scientific laboratories data is collected electronically. This is usually done using specialised hardware devices which collect the data, such as data loggers. This data is then sent to a computer where it is analysed using powerful computer software. There are many advantages of this including:

- There is **no chance of human error**. For example if the electronic balance says 5.21g, but then the human accidently records this as 5.12g then a transcription error has occurred. If however the electronic balance sends the 5.21g straight to the computer then there is no chance of a transcription error.
- Humans do not need to be present to monitor the experiment. This means that someone can set up an experiment and get the computer to automatically monitor the experiment and collect data. This is **reduces the labour** needed and means that for experiments that are done over a long time do not need to be sat and watched by a human 24 hours a day.
- Humans are not exposed to **potential safety hazards**. For example if you were conducting an experiment which involved radioactive substances, it would be too dangerous to have a

human walk into the room and read some measurement. Instead this can be done by a computer and the human can stay outside in a protected room.

Specific technology includes Texas Instruments calculators, which can electronically collect and process data. MATLAB is a software package that can do statistical analysis and process a wide range of data.

11.2 plan first-hand investigations to:

a) demonstrate the use of the terms "dependent' and "independent' to describe variables involved in the investigation

Independent variables, as the name suggests, are variables that do not depend on some other value. For example if you were performing an experiment to model the temperature changes of a cooling body. The independent variable would be time. For every value of time there is a temperature. And so temperature would be the dependent variable. The temperature depends on the time. This relates to functions in mathematics. Where the independent variable is x and the dependent variable is $f(x)$. As such the independent variable is usually plotted on the horizontal axis and the dependent variable on the vertical axis. The independent variable is changed and the dependent variable is measured.

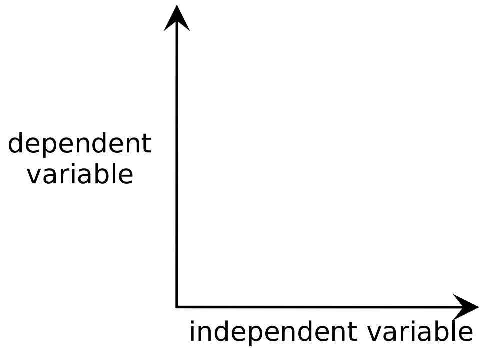


Fig. (4)

b) identify variables that need to be kept constant, develop strategies to ensure that these variables are kept constant, and demonstrate the use of a control

For every experiment you should only change one thing at a time and measure one thing. The rest of the variables should be kept constant. If need be you can do an experiment for each of the variables one at a time, ensuring that you never change two variables.

A control is where you leave it unchanged and unaffected by the experiment. This is used so that you have a reference to compare to.

c) design investigations that allow valid and reliable data and information to be collected

When people think of syllabus topic 9.1 they usually think of reliability, validity and accuracy. However their definitions and explanations differ depending upon their context. This dot point refers to **validity and reliability of first-hand data** (the other context is validity and reliability of secondary sources of information). The Science Years 7-10 Syllabus defines these terms,

Validity of first-hand data	The extent to which the processes and resultant data measure what was intended.
Reliability of first-hand data	The degree with which repeated observation and/or measurements taken under identical circumstances will yield the same results.

To explain this lets imagine that we fired an arrow at the target and our aim was to hit the bulls eye. The four different situations show validity and reliability. Some texts mention accuracy in this. It is difficult to understand what the syllabus means when it refers to accuracy however I think that it refers to the dictionary definition. (This is also the view of Curriculum K-12 Directorate, DET NSW.)[1] The 'Australian Oxford Dictionary' defines accuracy as, "The exactness or precision of a measurement; relating to the degree of refinement in measurement or specification." Thus the diagram below does not show accuracy.

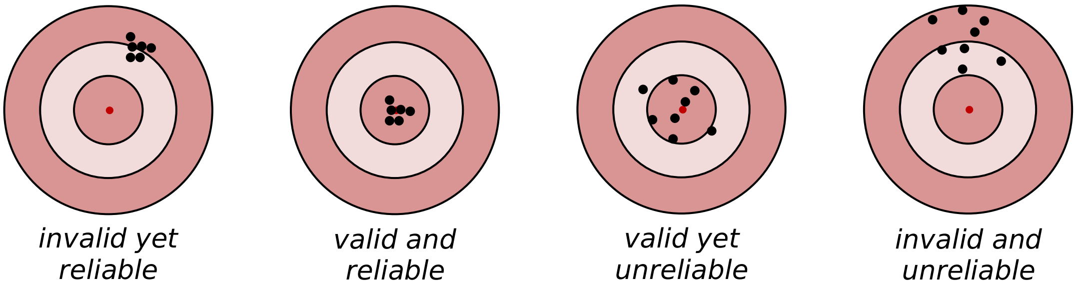


Fig. (5)

Reliability refers to whether or not you get the same result when you repeat the experiment. It relates to the consistency of results. For example if you perform the same experiment 10 times with the same conditions and each time you get relatively large differences between all 10 results, then your experiment is not very reliable. If however you get the same result all 10 times then your experiment is very reliable. To ensure a reliable experiment you should ensure that the same conditions are met when repeating the experiment.

Validity refers to if the results are correct. A valid experiment is one that fairly tests the hypothesis. To ensure validity ensure that you perform the correct calculations with no conceptual errors, and also ensure that the way you perform your experiment will test and give the correct results for the aim of the experiment. Also you can keep the variables to a minimum. For example it is difficult to establish the link between smoking and lung cancer as there are many variables involved.

However, just because your experiment is very reliable does not mean that it is valid. You may just keep getting the same wrong result all this time. In this case your experiment would be very reliable, but invalid. Similarly your experiment could be extremely valid, yet unreliable. The best experiments are valid and reliable.

d) design and trial procedures to undertake investigations and explain why a procedure, a sequence of procedures or repetition of procedures is appropriate

A procedure is just a sequence of steps that are taken to perform an experiment. A procedure for an experiment is necessary so that others can perform the same experiment as you (ie. repeat it) the same way and under the same conditions. This is necessary as for an experiment to be reliable, it must be able to be repeated all the time by different people and still yield the same result.

e) predict possible issues that may arise during the course of an investigation and identify strategies to address these issues if necessary

11.3 choose equipment or resources by:

a) identifying and/or setting up the most appropriate equipment or combination of equipment needed to undertake the investigation

Equipment is the tools you use to perform the experiment. Some of the most common equipment used in this physics course includes:

- Transformer (used to get safe voltages from the power supply for use with experiments)
- Pendulum
- Stopwatch
- Ruler
- Magnets
- Electronic Balance
- Induction Coil

[1] Reliability, validity and accuracy - what do they mean? (2006). *Curriculum Support for teaching in Science 7-12* , 11 (2), pp. 5-6.

b) carrying out a risk assessment of intended experimental procedures and identifying and addressing potential hazards

A risk assessment involves investigating and identifying any potential risks or hazards and then implementing methods to eliminate or reduce the risk or hazard. Some common risks/hazards and why they are risks/hazards in this physics course include:

- **High Voltage Electricity** is dangerous as it can cause electric shock. To reduce this risk, you should not touch the apparatus while the electricity is turned on.
- **Super Strong Magnets** can cut skin if they are brought too close together. To reduce the risk, you should be careful when handling these magnets, ensuring you don't allow them to get to close to each other.
- **Glass equipment** can break and shatter causing flying shards of glass. To reduce this risk wear safety glasses and be careful and cautious when handling the fragile equipment.
- **Radioactive substances** or **electromagnetic radiation** can cause cancer to living things. To reduce the risk, ensure methods are taken to label radioactive substances with warning signs, and store them is layer of lead.

It is important to remember the three main aspects of risk assessments:

Identify the risk.
↓
Explain why it is a risk.
↓
Explain measures taken to reduce or eliminate the risk.

c) identifying technology that could be used during investigations and determining its suitability and effectiveness for its potential role in the procedure or investigations

This is explained in H11.1 (e).

d) recognising the difference between destructive and non-destructive testing of material and analysing potentially different results of these two procedures

In destructive testing of materials, the testing process destroys the material. For example if I was testing the strength of a piece of glass, I would need to keep applying force until the glass broke. As the glass is damaged in the process of the testing, the method was destructive. In non-destructive testing the testing process does not alter the material. For example testing the resistance of a wire does not destroy the wire (unless the voltage is so great that the resistance causes the wire to melt, as this would be destructive testing).

In some cases the failure of the material in destructive testing can affect the results of the experiment. However also in some cases the non-destructive testing methods do no test the material with enough rigor and the results are not entirely accurate or correct. In some cases the material must be broken in order to test it.

H12. evaluates ways in which accuracy and reliability could be improved in investigations

12.1 perform first-hand investigations by:

a) carrying out the planned procedure, recognising where and when modifications are needed and analysing the effect of these adjustments

b) efficiently undertaking the planned procedure to minimise hazards and wastage of resources

This is explained in H11.3 (b).

c) disposing carefully and safely of any waste materials produced during the investigation

This is important as waste materials can quite often be dangerous. They may be toxic, corrosive, flammable, radioactive, biohazard, etc. If these dangerous materials are not disposed of properly then the trash bin could explode or cause damage to people or property. Also if these materials are just washed away down the drain, they could impact on the waterways which may affect marine life and may even contaminate drinking water.

Often special disposal bins are provided for different types of materials. For example at hospital waste body parts are put in special biohazard bins. Also at nuclear reactors radioactive waste is sealed away in thick lead containers and put in the ground with concrete all around it.

d) identifying and using safe work practices during investigations

Safe working practices include handling and disposing materials correctly, using equipment as it was designed to be used and ensuring any trouble makers in your class are placed in a separate room during the practical task so that they do not potentially injure other students.

See also H11.3 (b).

12.2 gather first-hand information by:

a) using appropriate data collection techniques, employing appropriate technologies including data loggers and sensors

This is explained in 11.1 (e).

b) measuring, observing and recording results in accessible and recognisable forms, carrying out repeat trials as appropriate

This means that when you are for example weighting a substance, do not just write down the weight on your hand or try to remember it (like so many of us do). Instead get a piece of paper and construct a table. Then when you go over to weigh a substance you can write in the values on the table with titles labelled. This leads to less chance of forgetting what the measurement was.

Also if you are observing a result it may be best to do it several times. For example if you are recording the smell of an ester, you may want to smell it several times before you record what smell it was.

12.3 gather information from secondary sources by:

a) accessing information from a range of resources including popular scientific journals, digital technologies and the Internet

Scientific journals are where almost all of the new discoveries and theories are published. They are an accurate source of information as the content is peer reviewed. Some of the most popular scientific journals are *Nature*, *Science* and *Scientific American*.

Digital technologies and the internet are also a great source of information. However it must be remembered that information on the internet is not always correct (but then again nor is the information in books). Some sources on the internet are more reliable than others. For example Wikipedia can be considered more reliable than somebody's personal web page, as many people edit it and review it for correctness and make appropriate changes. But then universities internet sites have content that is written by qualified professionals in their field and therefore the information would be more reliable than some random .com site. Usually if the site is .edu then it can be considered more reliable.

b) practising efficient data collection techniques to identify useful information in secondary sources

When looking at an article or scientific paper for information, it is a good idea to read the introduction, abstract or first paragraph. This will give you an idea what the paper is about and if it is not exactly what you are looking for then you have saved time from reading the whole article.

An example of an efficient data collection technique is shown below.

> **Solar cells**, or photovoltaic devices, use a silicon semiconductor material to convert sunlight, or any visible light, into electrical energy. When sunlight falls on a junction between n-type and p-type semiconductor material, electrons are ejected from atoms. These electrons are collected to form a direct electric current (DC). Solar cells are often assembled into modules designed to produce a certain current at the design voltage. The current produced depends directly on the amount of light striking the module. Typically, simple solar cells convert around ten to fifteen percent of the incoming solar energy into useful electrical energy. This efficiency can be increased by using two or more materials sensitive to light of different frequencies in tandem, in order to utilise more of the Sun's spectrum, or by using focusing devices to concentrate the sunlight.
>
> Information Source: HSC CSU Online

The information on solar cells has been collected from a secondary source, an internet site, HSC CSU Online. I have then efficiently collected data from this source, using the parts that I feel are relevant and omitting the parts that I feel are not. Also I have reworded parts that I feel are unclear or could be explained better.

c) extracting information from numerical data in graphs and tables as well as from written and spoken material in all its forms

Data can be presented in many ways. It could be in a table or a graph or it could be mixed in with a written report or it could be spoken by a lecturer.

For example the information of the scaling of Physics by UAC in 2006 is represented in a table. The numerical data can be easily gathered from this table. Presenting data in a table allows for others to take and use this data. For example because this scaling data is presented in a table, the data could be easily and accurately taken for use in Bored of Studies SAM™[1].

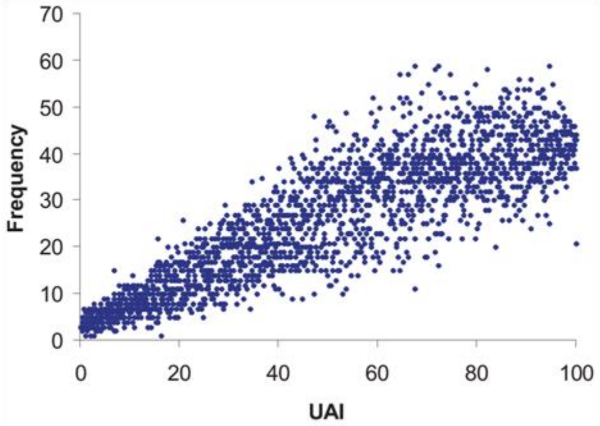
Course	Enrolment	Type of mark	Mean	S.D	Max.	P_{99}	P_{90}	P_{75}	P_{50}	P_{25}
[illegible]	267	[illegible]	35.5	[illegible]	48.5	[illegible]	43.0	[illegible]	35.0	[illegible]
		[illegible]	[illegible]	[illegible]	47.6	43.4	36.8	[illegible]	[illegible]	15.4
Physics	9116	HSC	37.5	5.6	49.0	47.0	44.0	41.5	38.0	34.0
		scaled	30.1	9.6	50.0	45.9	41.3	37.5	31.8	24.1
[illegible]	4019	HSC	[illegible]	[illegible]	[illegible]	47.5	44.0	41.0	37.5	[illegible]

Report on the Scaling of the 2006 NSW Higher School Certificate, Technical Committee on Scaling, © Universities Admissions Centre 2007

Fig. (6)

However a table is not always the best method of presenting data. For example the frequency distribution of each UAI for 2005 is represented in a graph shown below. If this data was presented in a table it would be difficult to easily understand and trends would be difficult to see. However, sometimes *approximate* numerical data can still be obtained from the graph.

[1] You can take the information accurately as the table tells you the figures; unlike if you were given a graph and you had to measure off values from the graphic, which would not be as accurate. The statement made in the text is correct in the context of the syllabus dot point, however in the context of the specific information being gathered, it if not entirely accurate as we do not know the values in between those given.



Report on the Scaling of the 2005 NSW Higher School Certificate, Technical Committee on Scaling, © Universities Admissions Centre 2006

Fig. (7)

Data can also be represented in written form. For example the extract below from a Report on Scaling of the 2005 HSC, much data is conveyed through this sample paragraph.

> In 2005 the distribution of UAIs was similar to those of previous years (see Table 4.4) for UAIs greater than 70.00, with 15.9% of the UAI eligible students receiving a UAI of 90.00 or above and 31.3% gaining a UAI of 80.00 and above. For lower UAIs the percentages in 2005 were almost identical to those of previous years. In 2005 the median UAI was similar to that of previous years (see Table 4.5).

Report on the Scaling of the 2005 NSW Higher School Certificate, Technical Committee on Scaling, © Universities Admissions Centre 2006

I must stress now that extracting data is not exactly the same as extracting information. In the first example data on the scaling of Physics has been extracted. But on its own the data is near useless. To obtain information from this data we need to sometimes perform statistical analysis on the data, or sometimes take into account where the data came from, what the purpose of the data is, etc. For example looking at the mean HSC mark and mean scaled mark in the first example, we cannot say that because the mean HSC mark of 37.5 scales down to 30.1, that Physics is a terrible scaling subject and should not be chosen. We have not considered all the other factors about this data. But if we look at how this figure was obtained, and if we compare it to all the other courses we see that, compared to other courses Physics scaled quite highly and that we should study it.

d) summarising and collating information from a range of resources

An example of summarising information is shown in H12.3 (b).

It is important to remember that you should collect information from a wide range of sources and then collate all this information together to make sense of it. These syllabus notes are a great example of this. These syllabus notes have been compiled from a wide range of sources as shown in the references section. For example, I have used text books, summary books, web resources and others dot point notes.

e) identifying practising male and female Australian scientists, the areas in which they are currently working and information about their research

If you are fanatical about covering every aspect of this course then you should go to the CSIRO web site and research some of their current research and the Australian Scientists who are performing it. However as my teacher once said, “If they [Board of Studies NSW] ever ask a question on this, someone ought to be shot.” It is impossible for this to be assessed because there is no way to know if what you write is factual or made up. If you want you can say that, John & Janet Howard, in their spare time do scientific research to combine quantum mechanics with gravitation.

12.4 process information to:

a) assess the accuracy of any measurements and calculations and the relative importance of the data and information gathered

Accuracy of measurements refers to the number of significant figures your data is to and the relative error margin of your data.

See also H11.1 (c).

b) identify and apply appropriate mathematical formulae and concepts

The most commonly used mathematical formulae used in this Physics course are shown on the formulae sheet. How to apply these formulae is Year 7 Mathematics, so I will not go into that. Identifying which formula to use comes by knowledge of the content in this course.

c) best illustrate trends and patterns by selecting and using appropriate methods, including computer-assisted analysis

A trend or pattern is what appears to be happening from the available data. Trends are best shown by the use of graphs and trend lines. Computers can greatly assist in the analysis of data. They are fast, accurate and can process huge amounts of data. For example the *CERN* particle accelerator which conducts experiments on high-energy particle physics collects huge amounts of data every second (just one of the many detectors will produce more than 60 GB of data every second!). Massive computing power must be used to process the huge amounts of data collected to make it useful. However this is a long way off that done in the high school Physics laboratory.

Trend Analysis may be done by either hand or computer-assisted methods. If done by hand you may use your own judgement on trend lines, or you may do the calculations to work out the trend line. Computer software packages that are used to analyse data include MATLAB and Microsoft Excel.

When you graph the dependent variable against the independent variable you plot the point of the data you collect. For example the graph below shows the data collected from an experiment shown in the table and a line of best fit drawn by human judgement. The blue line is the line of best fit (linear regression). It is a trend line.

Time (sec)	Displacement (m)
0	0
2	1.4
4	1.8
6	3
8	5
10	5.8
12	5.6

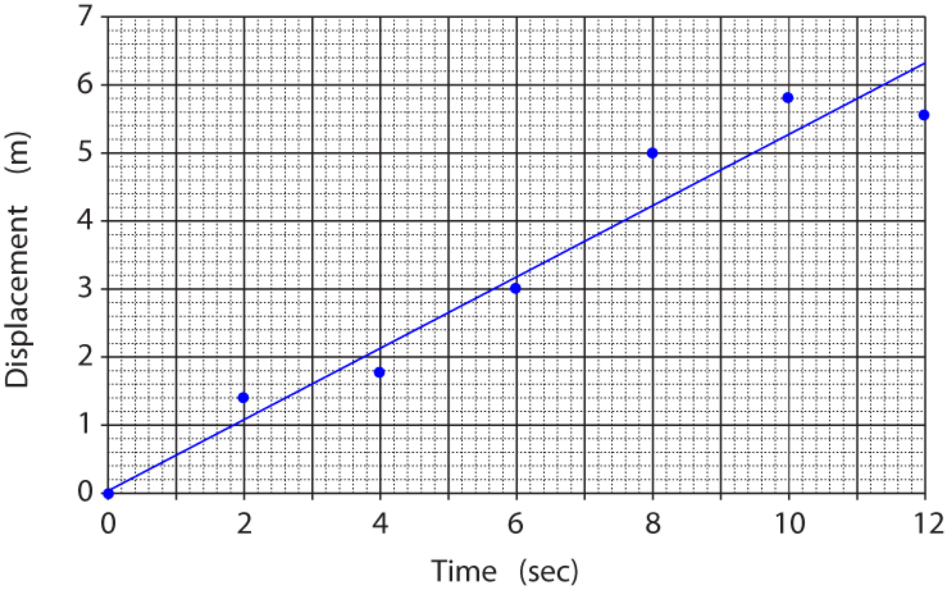


Fig. (8)

Trend lines are not always linear. For example population increase in a country would need exponential trend line. A linear trend line would not show the trend accurately.

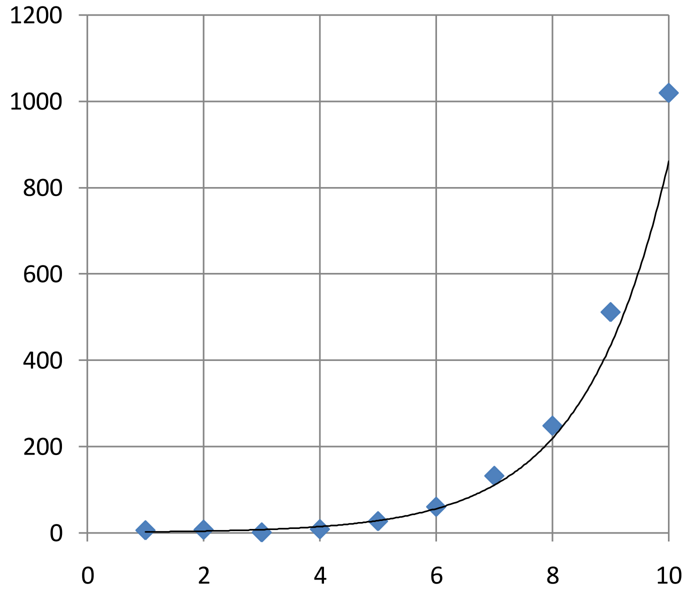


Fig. (9)

If you know the mathematical model that defines the data that you are collecting, then your trend line should use that equation. However the mathematical model is not always known and often it is the data you collect that leads to the mathematical model. Hence trend lines allows for the discovery of the mathematical model that describes the phenomena.

Trend lines try to eliminate the small variations or errors that come with collecting data. Trend lines can be used to interpolate data (find values in between two know values) or extrapolate data (predict what will happen for values not in the tested domain, eg. in the first graph what will happen at time = 14 sec).

d) evaluate the relevance of first-hand and secondary information and data in relation to the area of investigation

Not all the data and information you collect is relevant. You must make a judgement as to whether the information and/or data is relevant to your investigation.

e) assess the reliability of first-hand and secondary information and data by considering information from various sources

The term reliability used here is different to the term used in the context of first-hand investigation. This term is used here in the context of gathering information and data. As such it has a slightly different meaning.

The reliability of first-hand and secondary information and data refers to collecting information and data from a **range of reputable sources** and **make comparisons** between the information and data collected.

f) assess the accuracy of scientific information presented in mass media by comparison with similar information presented in scientific journals

As mentioned in H12.3 (a), scientific journals are usually written by qualified scientists and are peer reviewed. On the other hand, information presented in the mass media (eg. newspaper/TV reports), can often bend the data to make it appear something that it is not. And so information presented in scientific journals is usually much more accurate than information presented by the mass media.

H13. uses terminology and reporting styles appropriately and successfully to communicate information and understanding

13.1 present information by:

a) selecting and using appropriate text types or combinations thereof, for oral and written presentations

Written presentations in Physics use the report text type. As such a physics paper or report should contain features such as an abstract, body and references. If the paper or report is presenting information on an experiment, then features such as procedure, results, conclusion, etc. should be present. Appendices may also be used to present information, especially the raw data collected, that may be not be necessary to understand the report or the data may be too long and too great.

Oral presentations, such as seminars, lectures or talks, may also contain visuals such as a slide show that accompanies the talk. This allows people listening to also see any visuals such as graphs that are related to what the speaker is talking about.

b) selecting and using appropriate media to present data and information

Information can be presented though conferences, magazine articles, journal publications, newspapers, online articles, published reports, etc. The medium used to present this data and information depends on the purpose of the data and information and also the technicality of the information will vary depending upon the audience.

c) selecting and using appropriate methods to acknowledge sources of information

When writing a report it is important to acknowledge sources of information. This is done in the references/bibliography section. There are many conventions on how to acknowledge a source, one method is shown below.

> Yang, Y., (2003) "Dimensions of Socio-economic Status and Their Relationship to Mathematics and Science Achievement at Individual and Collective Levels", *Scandinavian Journal of Educational Research*, 47, 1, 21-41

d) using symbols and formulae to express relationships and using appropriate units for physical quantities

This involves using formula and equations to represent relationships among variables. Some symbols that are used in physics that you should be aware of are,

Symbol	Words	Explanation
Δ	Delta	Change in a quantity. i.e. $final - initial$
$\propto$	Proportional to	For example, $r^3 \propto T^2$. This means that $r^3 = kT^2$, where k is a constant.
$\boldsymbol{x}$ OR $\vec{x}$	Vector	If any variable is bold or has an arrow above it this indicates that this variable is a vector.[1]
$\boldsymbol{\Sigma}$	Sigma	Sum. For example $\Sigma F = ma$ means that the sum of all forces equals ma.

See H12.4 (b) and H11.1 (d).

e) using a variety of pictorial representations to show relationships and presenting information clearly and succinctly

This involves using graphs and illustrations to represent relationships among variables, without any ambiguity. It also involves using the type of graph that is relevant. For example it is not appropriate to use a sector (pie) graph to graph the variation in temperature over a day. Line and scatter graphs are used for continuous independent variables and column and pie graphs are used when the independent variable is discreet.

---

[1] As the HSC Syllabus dulls down on the maths you do not really need to know this. However once you get to uni physics you will need this.

f) selecting and drawing appropriate graphs to convey information and relationships clearly and accurately

Different types of graphs are used for different purposes. Some of the different types of graphs are shown below. The scatter graph is the most common graph type in physics.

Microsoft Excel 2007

Some key things to remember when drawing graphs include: (they frequently ask you to draw graphs in the exam and these are some of the things that you are assessed on)

- Always place the **independent variable on the horizontal axis (x)** and the **dependent variable on the vertical axis (y)**.

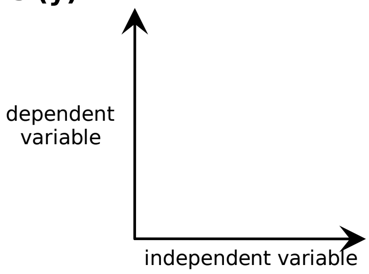


Fig. (10)

- Mark each axis with the **quantity** that is being changed/measured and include the **units**.

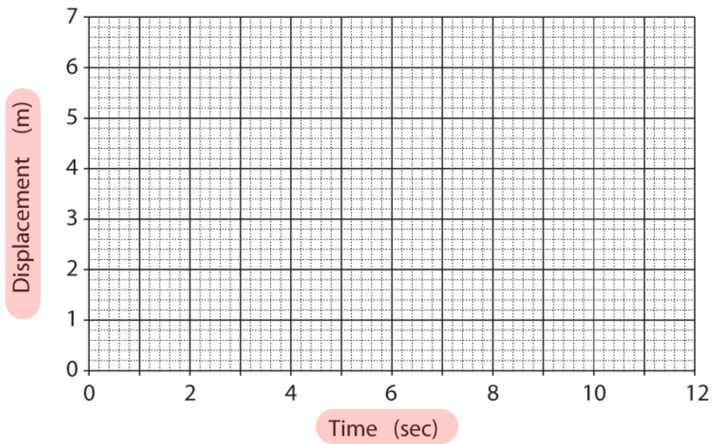


Fig. (11)

- The axis should be labelled with a **scale**. This scale should be linear, however in some special cases a non-linear scale can be used.

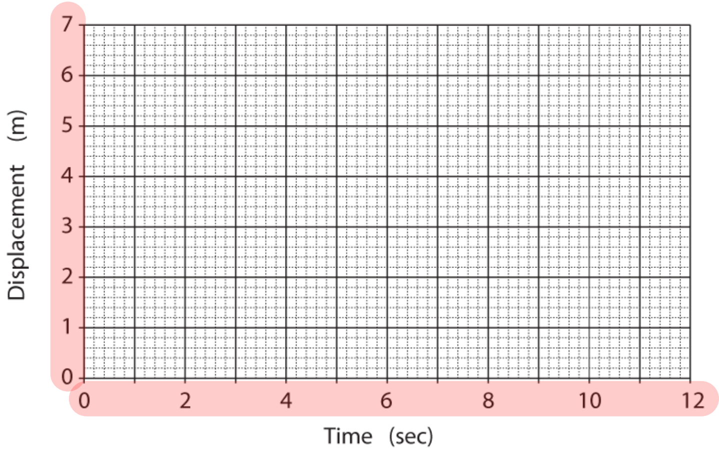


Fig. (12)

- Points from the data should be represented on the graph as dots. You should also join these dots, using linear interpolation if the data being represented is continuous.[1]

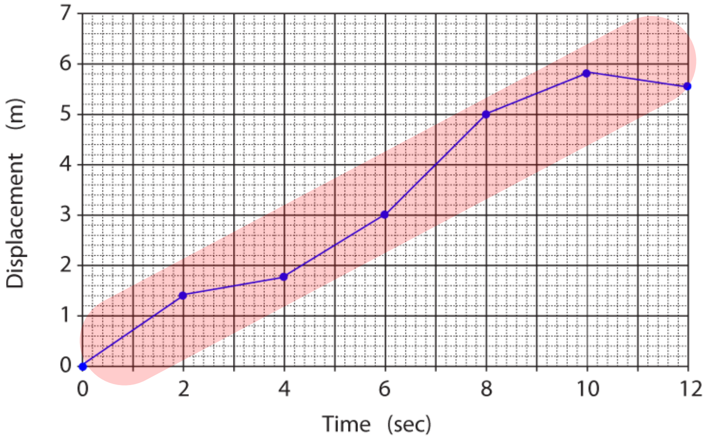


Fig. (13)

- You should also draw either a **line or curve of best fit** (line is the safest option in the exam). Even if the question did not ask for a trend line[2]. Outliers should be ignored in the line of best fit.

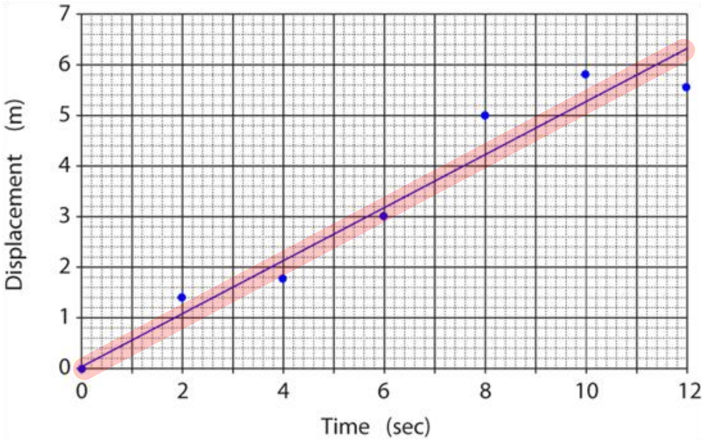


Fig. (14)

- Depending upon what the data you are collecting is, the graph usually passes though the origin (0,0). However be sure to thing about this before you go ahead and do it. Think to yourself, what would the y value be when $x = 0$?

Plotting points, or reading values from plotted points sounds easy but can sometimes be a little tricky. The diagram below shows the simplest case, where each labelled value is one unit and has 10 subdivisions, hence if you were to measure the blue it would be 1.2.

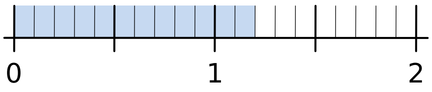


Fig. (15)

The next diagram shows the next type, where again we can see that each subdivision is 0.2 hence the blue would be measured to be 2.4.

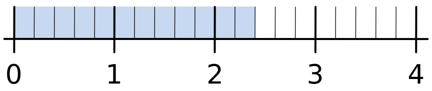


Fig. (16)

[1] As noted in (Gould & Morante, 2007) you do not always join the dots to form a line graph. For example if you plot the temperature at midday each day for a month, then you should not join the dots. “The points on the line joining the dots is not a good indicator of the temperature at points much removed from midday so there should not be a line connecting these two points.”

[2] 2006 Chemistry HSC Exam + Marking Guidelines, Question 25 (a). Board of Studies NSW.
2005 Chemistry HSC Exam + Marking Guidelines, Question 22 (a). Board of Studies NSW.
2003 Chemistry HSC Exam + Marking Guidelines, Question 28 (a). Board of Studies NSW.

A slightly more difficult example is shown below, and although you can still work it out using the above methods, sometimes in the stress of the exam it is best to take a systematic approach. For the example shown below, you can calculate that one subdivision will be $\frac{0.01}{5}$, thus the measurement will be $0.02 + 2 \times \frac{0.01}{5} = 0.024$.

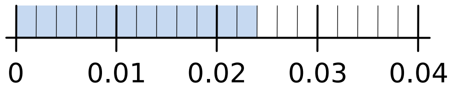


Fig. (17)

g) identifying situations where use of a curve of best fit is appropriate to present graphical information

Depending upon what data you are representing and what the points you have collected look like sometimes a curve of best fit is needed rather than a line of best fit. Some common types of regression are listed below.

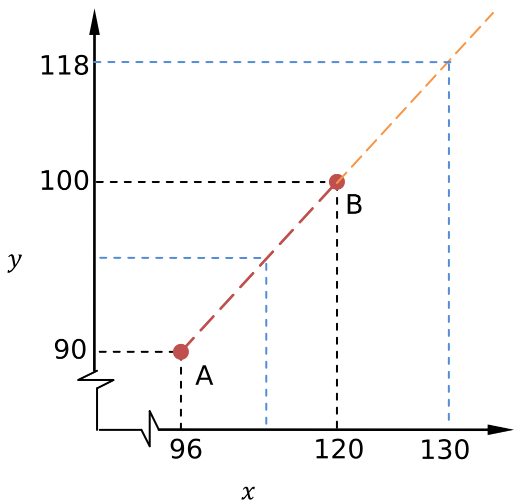
Type	Equation
Linear	$y = mx + b$
Exponential	$y = Ae^x$
Power	$y = x^n$
Sine/Cosine	$y = a\sin(nx + \alpha)$
Polynomial	$y = Ax^n + Bx^{n-1} + \cdots$

For linear regression the m and b are given by,

$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$b = \frac{\sum y - m\sum x}{n}$$

Curves of best fit allow you to interpolate data (find values in between known values) and extrapolate data (find data outside the known range of values). For example just say we know the two points A and B, but we want to know that the y value will be when x is half way between A and B, well we can use linear interpolation to find this value. Similarly if we want to find the y value when $x = 130$, then we can use extrapolation methods to find the y value. Interpolation is usually more reliable than extrapolation.



H14. assesses the validity of conclusions from gathered data and information

14.1 analyse information to:

a) identify trends, patterns and relationships as well as contradictions in data and information

See H12.4 (c).

Contradictions in data are when one source of data says one thing and another source says the opposite.

b) justify inferences and conclusions

An inference is an educated guess that cannot be proved. For example if I see a car driven furiously out of a car sale yard, I may infer that that car was stolen. However I cannot prove that. It may have been stolen or they may just have been taking it out for a test drive. However it is a hypothesis, because I have made this conclusion about the car being stolen based on the evidence that the car was being driven furiously.

c) identify and explain how data supports or refutes an hypothesis, a prediction or a proposed solution to a problem

A hypothesis is your opinion. What you think is happening. You then test your hypothesis to either prove it right or wrong. For example I may have a hypothesis that no one contributes to this Bored of Studies Wiki. I then have to perform an investigation to test my hypothesis. So I will go and look at the recent changes and see that no one has contributed for a week. Hence I may conclude that my hypothesis is correct. I have used the data of the recent changes to test my hypothesis, and the data supports it.

Similarly if I make a prediction or a proposed solution to a problem, I need to then obtain the relevant data to support or refute that proposal or prediction.

d) predict outcomes and generate plausible explanations related to the observations

e) make and justify generalisations

Generalisations are when you observe something for a small sample and you say that the same will apply for everyone. For example, if land on Antarctica and all the penguins that I can see are black and white then I can make a generalisation that all penguins on Antarctica are black and white. This generalisation may be true but I cannot know for sure unless I track down every single penguin.

f) use models, including mathematical ones, to explain phenomena and/or make predictions

A model is just something that represents what is happening in real life. Mathematical models are often made to explain phenomena. These mathematical models can be used to make predictions. Non-mathematical models can also be used such as physical models of the planets orbiting the sun.

> Science attempts to explain phenomena or predict events by identifying consistent trends and patterns from which can be generated a:
> - **model**: a mathematical, physical, experimental or logical representation based on a simplified set of assumptions. Models are often elaborated to develop theories;
> - **theory**: a coherent explanation of a body of experimental evidence, based upon a small number of assumptions. A theory provides predictions that can be tested against observations;
> - **law**: a simple and precise statement that has, at one time, been regarded to be universally valid. It describes phenomena that occur with unvarying regularity under the same conditions.

Board of Studies NSW. (1999). *Science Stages 4–5 Syllabus*. Board of Studies NSW. p13.

g) use cause and effect relationships to explain phenomena

Phenomena are something that you observe to be happening. So I may notice the phenomena that when I drop an apple, it falls to Earth. I can explain this phenomenon with a cause effect relationship. That is, the effect of the apple falling is caused by the force of gravity between the apple and Earth.

h) identify examples of the interconnectedness of ideas or scientific principles

One example of the interconnectedness of ideas or scientific principles in this course is that a current-carrying conductor in a magnetic field will experience a force and also that a charged particle moving in a magnetic field will experience a force. These two ideas are essentially the same thing, as current is just the flow of electrons, a charged particle.

14.2 solve problems by:

a) identifying and explaining the nature of a problem

b) describing and selecting from different strategies those which could be used to solve a problem

c) using identified strategies to develop a range of possible solutions to a particular problem

d) evaluating the appropriateness of different strategies for solving an identified problem

Problems can be solved mathematically, through iterative or algebraic processes, or through logical reasoning and experimentation, or many other methods.

14.3 use available evidence to:

a) design and produce creative solutions to problems

b) propose ideas that demonstrate coherence and logical progression and include correct use of scientific principles and ideas

c) apply critical thinking in the consideration of predictions, hypotheses and the results of investigations

d) formulate cause and effect relationships

9.1 TOPIC REVIEW

9.1 Summary

- **Accuracy** is “the exactness or precision of a measurement; relating to the degree of refinement in measurement or specification.”
- Use the **correct units** in calculations.
-

Validity of first-hand data	The extent to which the processes and resultant data measure what was intended.
Reliability of first-hand data	The degree with which repeated observation and/or measurements taken under identical circumstances will yield the same results.

- **Risk assessment** involves, identifying the risk, explaining why it is a risk and explaining measures taken to reduce or eliminate the risk.
- The **reliability of first-hand and secondary information** and data refers to collecting information and data from a **range of reputable sources** and **make comparisons** between the information and data collected.
- Make sure you can **draw a graph** from given data.

Contextual Outline:

Scientists have drawn on advances in areas such as aeronautics, material science, robotics, electronics, medicine and energy production to develop viable spacecraft. Perhaps the most dangerous parts of any space mission are the launch, re-entry and landing. A huge force is required to propel the rocket a sufficient distance from the Earth so that it is able to either escape the Earth's gravitational pull or maintain an orbit. Following a successful mission, re-entry through the Earth's atmosphere provides further challenges to scientists if astronauts are to return to Earth safely.

Rapid advances in technologies over the past fifty years have allowed the exploration of not only the Moon, but the Solar System and, to an increasing extent, the Universe. Space exploration is becoming more viable. Information from research undertaken in space programs has impacted on society through the development of devices such as personal computers, advanced medical equipment and communication satellites, and has enabled the accurate mapping of natural resources. Space research and exploration increases our understanding of the Earth's own environment, the Solar System and the Universe.

This module increases students' understanding of the history, nature and practice of physics and the implications of physics for society and the environment.

9.2 SPACE

1. The Earth has a gravitational field that exerts a force on objects both on it and around it

1. define weight as the force on an object due to a gravitational field

Every object has mass. Mass is the amount of matter in a body, it doesn't change depending on where you are in a gravitational field. Weight however varies depending on the bodies mass and the gravitational pull acting on it. Weight is a force and thus a vector quantity.

$$\text{Weight Force} = \text{Mass} \times \text{Acceleration due to Gravity}$$

2. explain that a change in gravitational potential energy is related to work done

To have a change in the gravitational potential energy of an object in a gravitational field, work must be done. This means that if you move an object in a gravitational field then work must been done on the object in order for it to move.

If you move an object against the gravitational field, positive work must be done. If you move the object with the gravitational field, negative work must be done.

Work needs to be done to change energy from one form to another, in this case from kinetic energy to gravitational potential energy or vice versa.

3. define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field

As we have seen from the first dot point, all objects in a gravitational field will experience a weight force. If this weight force is not opposed then the object will experience acceleration due to this weight force. For example if we dropped a ball from a tall building then (ignoring air resistance) the ball will keep getting faster and faster. The ball is accelerating, which means that the velocity of the ball is increasing. As its velocity is increasing the ball's kinetic energy will also be increasing. That is, the object is gaining energy in the form of kinetic energy. However energy cannot be created, so where is this energy coming from? Well the object has energy due to its presence in a gravitational field, which is known as gravitational potential energy. As the ball falls towards Earth its gravitational potential energy is being converted into kinetic energy of the ball. Thus the closer the object is to the mass that creates the gravitational field, then the less the gravitational potential energy of the object in the gravitational field will be. Because as the object gets closer its kinetic energy is increasing, so as energy must be conserved, the gravitational potential energy must be decreasing.

The next thing to consider is at what distance would an object in a gravitational field have to be at in order to have a gravitational potential energy of zero. Well it would have to be nowhere in the gravitational field, that is at infinite distance. This reasoning explains why gravitational potential energy is negative, because at $d = \infty$, $E_p = 0$ and as the distance becomes less the gravitational potential energy decrease, hence the gravitational potential energy of an object in a gravitational field must be negative. The graph of gravitational potential energy compared to the distance of the object in the gravitational field is shown below.

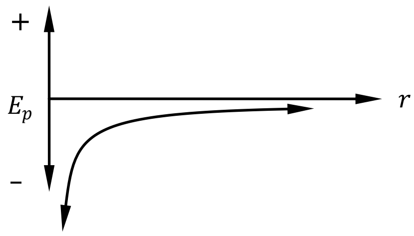


Fig. (18)

We can now give a definition of gravitational potential energy. But firstly we must understand what is meant by the term 'work done'. When work is done, energy is changed (converted) from one form to another. For example if we increase the distance of an object in a gravitational field then we have to apply work to it in order to move the object against the gravitational field. Hence work has been done on the object to move it and so kinetic energy has been converted into gravitational potential energy. We define gravitational potential energy as the work done to move an object from a distance of infinity (where the gravitational potential energy will be zero) to a point in a gravitational field. However, as we cannot get an object at infinite distance away, the term 'at a very large distance away' is used instead. It is okay to use this as at a very large distance away the gravitational potential energy is close enough to zero.

The formula for gravitational potential energy is given by,

$$E_p = -G\frac{m_1 m_2}{r}$$

Where,
E_p = Gravitational potential energy (J)
G = Universal gravitational constant (6.67×10^{-11} N m^2 kg^{-2})
m_1 = Mass of object that creates the gravitational field (kg)
m_2 = Mass of object in the gravitational field which you are measuring the gravitational potential energy of (kg)
r = distance of the object from the centre of the gravitational field (m)

1. perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reason for possible variations from the value 9.8 ms^{-2}

One way to determine acceleration due to gravity (g) is to use a pendulum, other methods include using computer-assisted technology to determine acceleration due to gravity from direct measurements of a falling object. However the experimental values for acceleration due to gravity will vary from 9.8 ms^{-1} due to experimental reasons and physical reasons.

Using the pendulum method, a weight of negligible mass (i.e. the mass will not affect the results) is attached to a string of arbitrary length (the length can be any length, our calculations will incorporate this length though). The mass should be held up at an angle and let go. The mass will oscillate, where the period is the time for one oscillation (i.e. for the mass to return back to its starting position).

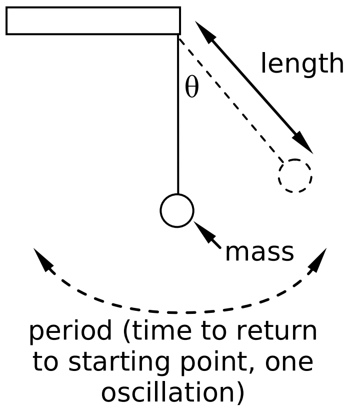


Fig. (19)

The period of a pendulum is given by the formula,

$$T = 2\pi\sqrt{\frac{l}{g}}$$

As you can see time for one oscillation is only dependent on the length and acceleration due to gravity. So the mass and the angle don't alter the period. If you rearrange the formula to make g the subject, the formula becomes,

$$g = \frac{4\pi^2 l}{T^2}$$

, therefore g can be determined by measuring the period of a pendulum at a given length.

To improve the accuracy of the experiment, the pendulum was allowed to oscillate several times and an average time for one oscillation was used. This reduced the effect of human response time when using the stopwatch. Also a long length of string was used as this made the period longer and thus the value for g was more accurate.

Using computer assisted technology we can drop an object and use the formula, $\Delta y = u_y t + \frac{1}{2} a_y t^2$, where t, u_y and Δy are known to solve for a_y. In order to yield valid results for g, we need to use computer assisted technology. For this method to be accurate we need to use an object that will have minimal air resistance. We will also need to use a small enough distance to avoid the object reaching its terminal velocity. The time will need to be measured very accurately and precisely and only computer assisted technology can do this. A small ball could be dropped from a height of just say 1 metre and the time could be determined by using sensors or a high speed video camera. This allows for a_y which is g to be calculated accurately.

When we say that $g = 9.8 \text{ ms}^{-2}$ on Earth, we do not mean that any and every experiment you do to measure g will yield the results that $g = 9.8$. Of course when you do an experiment to calculate g, you answer will vary due to experimental problems such as air resistance, or inability to accurately calculate certain variables. However, the actual value of g will vary depending on where you are. The first factor that will affect g is your **altitude**. As $g = \frac{Gm_p}{r^2}$, we can see that as we increase r, g will become less. Thus if we were standing on the top of a tall mountain we would find g to be less than 9.8, and if we were standing on the bottom of the deepest sea, then we may find g to be greater than 9.8.

Another factor that affects g is your **latitude** on Earth. Because the Earth is not a perfect sphere, i.e. it is **flatter at the poles**, if you were at the north and south poles then you would be closer to the centre of the Earth than if you were at the equator. Another thing to consider is that the Earth is spinning on its own axis. This axis is given by the north-south pole. We know that if you are in circular motion, then you will have a centripetal force that holds you in that motion which is given by $F = \frac{mv^2}{r}$. Now we also know that as the centripetal force is greater, the **centrifugal force** that you feel will be larger, and the larger this centripetal force is, the less you will measure g to be. Thus if you are at the poles you will have zero centripetal force (as r will be zero) and thus zero centrifugal force. So there will be no effect on g. However if you are at the equator you will be experiencing the largest centripetal force and hence a large centrifugal force, so you will measure g to be slightly less.

The graph below shows how g varies with latitude due to centripetal force (rotation of Earth) and due to the Earth being flatter at the poles (Oblate Spheroid).

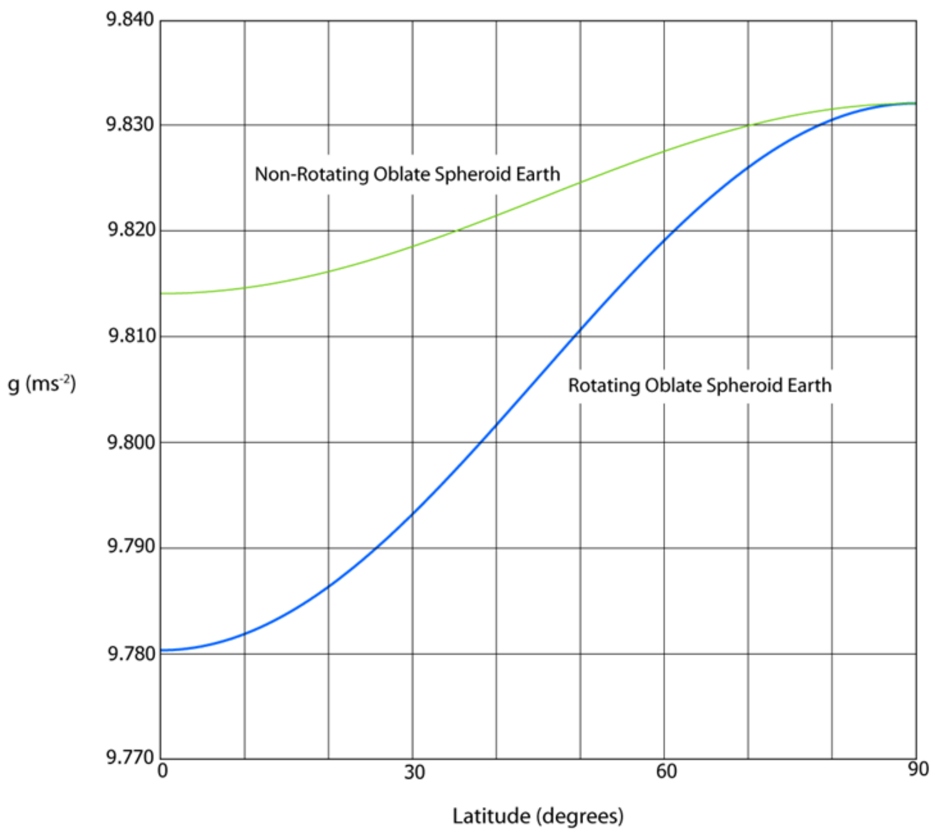


Fig. (20)

The other main factor is that the Earth does not have consistent density, i.e. the **density of the Earth varies** and this will have an impact on g.

These are the main reasons for discrepancies with 9.8 are,
- Altitude
- Earth is flatter at the poles
- Centripetal force
- Varying density of Earth

A smaller issue is the moon and other large objects that come close to Earth. This can be seen by the tides.

2. gather secondary information to predict the value of acceleration due to gravity on other planets

$$\text{acceleration due to gravity} = \frac{G \times \text{mass of planet}}{\text{radius of planet}^2}$$

$$g = \frac{Gm_p}{r^2}$$

This formula can be derived by equating $F = mg$, with $F = \frac{Gmm_p}{d^2}$. Giving, $g = \frac{Gm_p}{r^2}$.

Let's look at the case of a person, Alice, standing on the surface of the Earth. Alice will be experiencing a force due to the Earth's gravitational field. This force will be given by, $F_A = \frac{Gm_E m_A}{r^2}$. Now we also know by Newtons second law that $F_A = m_A a$, where the force that Alice feels will be the gravitational force, hence the F_A is the same in both equations and we can equate them and make a the subject of the formula. The mass of Alice will cancel out and we will come to the result that is stated at the top.

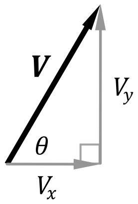
3. analyse information using the expression: *F = mg* to determine the weight force for a body on Earth and for the same body on other planets

$$\text{Weight Force (N)} = \text{Mass (kg)} \times \text{acceleration due to gravity } (\text{ms}^{-2})$$

2. Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

1. describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components

When an object on the Earth's surface is launched it undergoes projectile motion. The trajectory of this object is the path that it follows (the trajectory will be parabolic). Now the velocity of the object at various instants is changing. Because velocity is a vector we need to split it up into two components in order to analyse its motion. These **horizontal** (x) and **vertical** (y) components, when summed together equal the vector and so these two components have the same effect of the single vector. The diagram below shows how a vector can be split into vertical and horizontal components. It also has the equations to convert a horizontal and vertical component back into a single vector.



$$V_x = V\cos\theta \qquad V_y = V\sin\theta$$

$$V = \sqrt{{V_x}^2 + {V_y}^2} \qquad \theta = \tan^{-1}\left(\frac{y}{x}\right)$$

We can now analyse the trajectory of an object in projectile motion in terms of these vertical and horizontal components. The two main things to note are that the horizontal component of motion has no acceleration acting on it and hence will remain constant for the duration of flight. The vertical motion has acceleration due to gravity acting on it, and so its velocity will alter throughout the duration of the flight.

The notation used in the formulae on the formula sheet should be addresses here. u is initial velocity, v is final velocity and a is acceleration. The subscript denotes either the horizontal component (x) or vertical component (y). Another thing to note is the Δ which represents change in. So Δx is change in horizontal displacement (ie. horizontal distance) and Δy is change in vertical displacement (ie. vertical distance)

2. describe Galileo's analysis of projectile motion

Galileo's analysis of projectile motion is that the motion of a body can be split into two components, horizontal and vertical. Where the horizontal motion will have no acceleration acting on it and the vertical motion will have acceleration due to gravity acting on it. The trajectory of the projectile will be parabolic.

3. explain the concept of escape velocity in terms of the:

Escape velocity is the velocity needed to propel an object into space so that it will not return to Earth (or the planet that it is launched from). The escape velocity does not depend on the direction that a projectile is fired. However it is easier to attain the escape velocity when the projectile is fired in a direction that takes advantage on the rotational motion of the Earth.

When a projectile is fired from the surface of a planet, it will have a kinetic energy given by,

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

And a gravitational potential energy given by,

$$E_p = -G\frac{Mm}{r}$$

(where m is the mass of the projectile, and M is the mass of the planet.)

Normally when you fire a projectile upwards it will slow, stop for a moment, and then return back to Earth. The escape velocity is the velocity needed so that the projectile will never return to Earth, that is, it will only stop when it reaches infinite distance from the planet. When the projectile stops at this point it has no kinetic energy (because it is not moving) and no potential energy (as it is at infinite distance from the planet), so its total energy must therefore be zero. From the principle of conservation of energy, its total energy at the plant's surface must also have been zero, so,

$$E_k + E_p = 0$$

$$\frac{1}{2}mv^2 + \left(-G\frac{mM}{r}\right) = 0$$

This gives the result that,

$$v = \sqrt{\frac{2GM}{r}}$$

– gravitational constant

From the relationship $v = \sqrt{\frac{2GM}{r}}$ we can see that, $v \propto \sqrt{G}$.

– mass and radius of the planet

Also from $v = \sqrt{\frac{2GM}{r}}$ we can see that $v \propto M$ and $v \propto \frac{1}{r}$. Which means that, the greater the mass of the planet, the greater the escape velocity and that the greater the radius of the planet, the less the escape velocity.

4. outline Newton's concept of escape velocity

Newton's concept of escape velocity was that if a body is launched from a very high building, as the velocity of horizontal launch is increased, the body's rate of fall would match the Earth's curvature. The escape velocity was equal to the horizontal velocity needed for the body to stay in orbit. If the object was launched at a speed less than this then the object would return back to Earth and if it was launched with a speed greater than this then it would go off into space and never return to Earth.

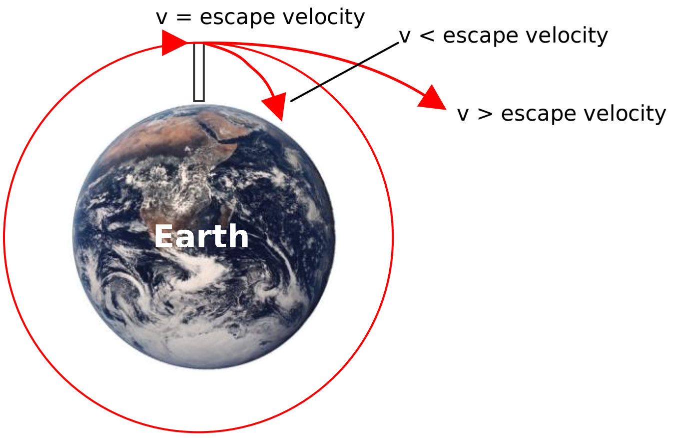


Fig. 21

The diagram below shows the path of 5 different projectiles being launched from a very tall tower with progressively larger initial velocities. Newton reasoned that if you launch an object will a low velocity it will take the path of A. He reasoned that if you make this velocity larger then the path will travel further around Earth before crashing back into it such as in path B and C. He went on to say that if you made this velocity large enough then the objects horizontal velocity will be great enough to prevent the object from crashing back into Earth. The object will be in orbit. Also he said that if the velocity was made even larger then the object would not go into orbit but instead have enough speed to travel out into space and never return back to Earth.

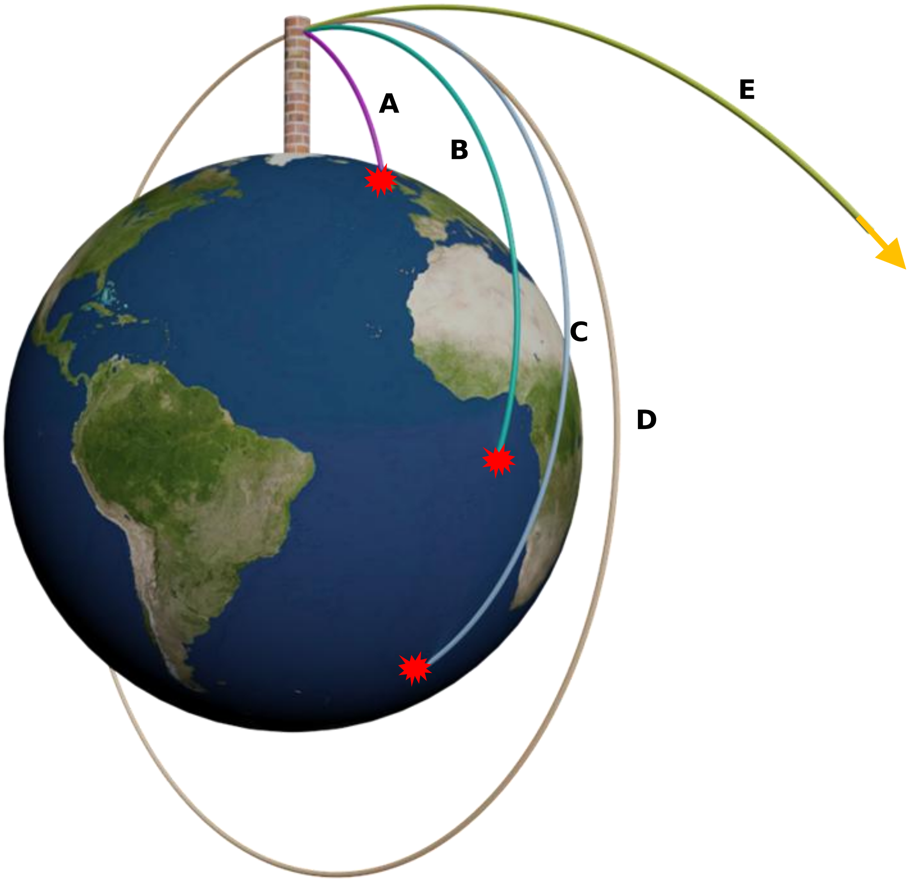


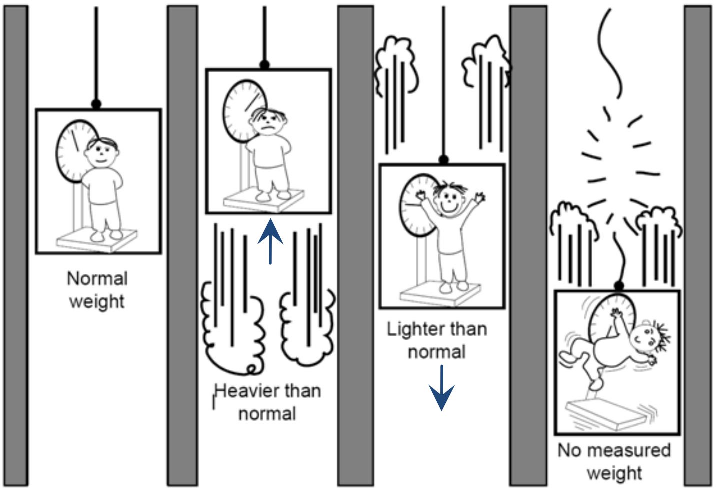
Fig. 22

5. identify why the term 'g forces' is used to explain the forces acting on an astronaut during launch

In order to understand g-forces, we need to take a closer look at weight. Any mass in a gravitational field will experience a weight force. This weight force is known as your true weight. For all inertial frames of reference, that is non-accelerating bodies, your apparent weight equals your true weight. This means that if you measure your weight, it will equal your mass multiplied by the acceleration due to gravity. Your apparent weight is the weight that you feel. Also if you try to measure your weight, you will always be measuring your apparent weight. Now we said that for all inertial frames of reference your true weight equals your apparent weight, but what about in non-inertial frames of reference (i.e. accelerating bodies)? Well in this case, your measured weight, that is your apparent weight, will not be the same as your true weight, that is your mass multiplied by acceleration due to gravity.

For example if you are standing on your bathroom scales in your house, you are not accelerating. So if you measure your weight using your scales, then the scales will read the same value that you would obtain if you multiplied your mass with the acceleration due to gravity.

However if you were standing on scales in an elevator that is either going up or down a level, then the elevator is accelerating and as such your apparent weight (i.e. the weight measured by the scales) will not be the same as your true weight (i.e. your mass multiplied by the acceleration due to gravity). This is shown in the diagram below.



NASA. (2000). *The Mathematics of Microgravity.* NASA. p3

Fig. 23

The term 'g force' is used to express a person's apparent weight as a multiple of their normal true weight.

$$\text{g force} = \frac{\text{apparent weight}}{\text{true weight}}$$

During launch, the apparent weight is quite large, this means that astronauts can feel up to several g's during launch.

When standing on the Earth's surface the weight you feel (apparent weight) is the same as your true weight, thus you are experiencing 1g. If you are in a spaceship which is in orbit around Earth, then your apparent weight is zero, hence you are experiencing 0g.

6. discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket[1]

Because the Earth rotates, both on its own axis and around the sun, when a rocket is launched from Earth the horizontal velocity of the rocket will be the same as the rotational speed of the Earth plus the orbital motion of Earth (depends where on Earth you are). This will affect the path of the rocket in outer space. It will also contribute to the rockets speed. Where on Earth the rocket is launched from and what time of day and year it is will affect where the rocket will initial be heading and its speed. So to fully utilise this and minimise fuel usage the location on Earth of the rocket and what time of day and year it is is chosen to get the rocket to head in a particular way and with minimal effort.

Remember, the axis of Earth's rotation on its own axis is from pole to pole. Thus **launching from the equator** will result in the most velocity boost from Earth's rotation. Earth rotates on its own axis one revolution every 24 hours. The diagram below shows how the Earths rotational motion on its own axis is used to give the rocket a velocity boost. You should also note that the Earth rotates towards the East.

[1] As seen in Question 19 (a) in the 2004 Physics HSC Exam, unfortunately you need to know which way the Earth rotates around the Sun.

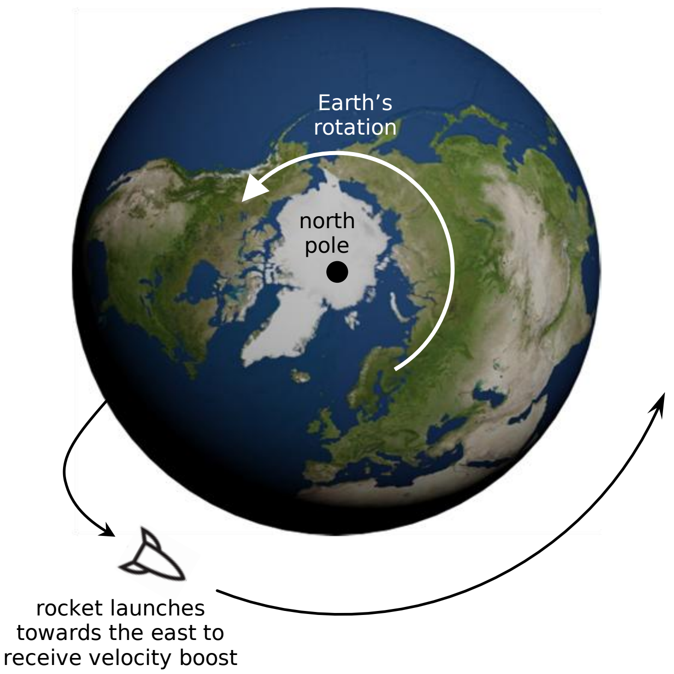


Fig. 24

Diagram adapted from '*Space*' produced by Learning Materials Production, OTEN.

Not only does the Earth rotate on its own axis, but it also rotates around the sun once every year. This does not affect satellites that are sent into orbit, however this is an issue that needs considering if you are launching an object that will travel to other planets or extraterrestrial places.

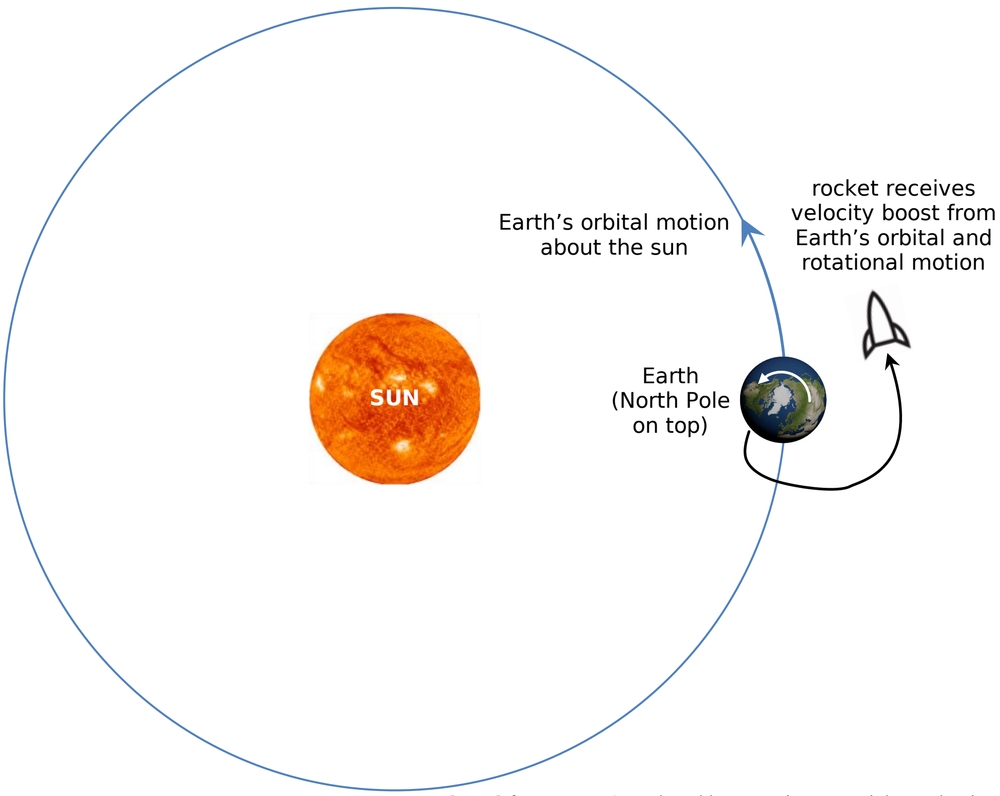


Fig. 25

Diagram adapted from '*Space*' produced by Learning Materials Production, OTEN.

7. analyse the changing acceleration of a rocket during launch in terms of the:[1]
– Law of Conservation of Momentum
– forces experienced by astronauts

The momentum ($p = mv$) of a rocket during launch is conserved. As fuel is burnt and the gasses expelled, the mass of the rocket decreases. But as **momentum is conserved**, velocity must increase at the same rate that mass is decreasing. So as velocity of the rocket is increasing the rocket must be accelerating.

We can also analyse the changing acceleration of rocket during launch in terms of the forces experienced by astronauts. There are two forces acting on a rocket during launch, the thrust, which is provided by the burning of fuel (Newton's third law) and the weight force. These are shown in the diagram below.

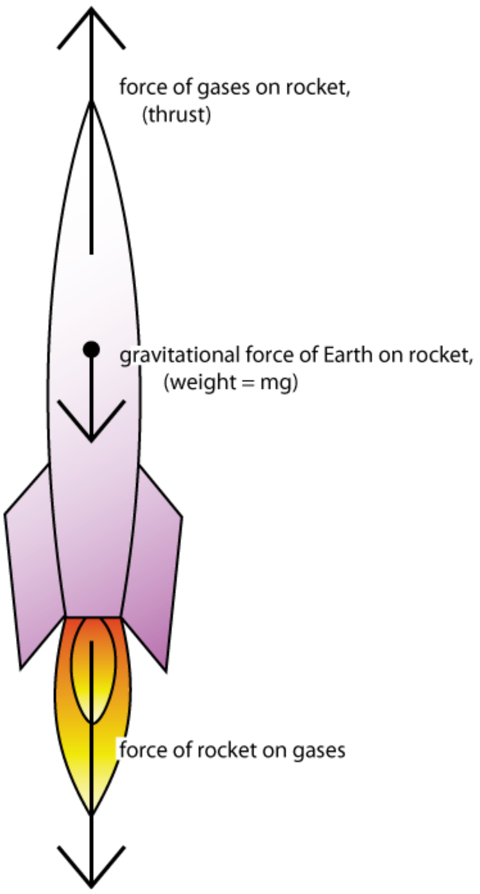


Fig. 26

Diagram adapted from '*Space*' produced by Learning Materials Production, OTEN.

The net force on the rocket can be obtained by summing these two forces, ie. $Net\ Force\ = T - w$. As weight $= mg$,

$$Net\ Force\ = T - mg.$$

We know that mass will be decreasing because fuel is being burnt and we also know that g will be decreasing as the rocket is moving further away from Earth. As mg is becoming less with time, **the net force is increasing** with time. We know that $F = ma$, which can be rearranged as $a = \frac{F}{m}$. So if the force is increasing and the mass is decreasing, then the **acceleration will be increasing**.

If we want to calculate the acceleration of a rocket we can simply use the equation from above. Where $ma = T - mg$, therefore,

$$a = \frac{T - mg}{m}$$

[1] See http://www.hq.nasa.gov/osf/qanda.html#13

The graph below shows how acceleration varies depending upon the mass of the rocket for different levels of thrust. You will notice that as the mass of the rocket decreases, because it is burning fuel, the acceleration will increase. The negative parts of the graph are not important as in this region the force is not great enough for the mass of the rocket in order for it to accelerate upwards. However the key thing to note is that as fuel is consumed and burnt, the mass decreases which results in increasing acceleration.

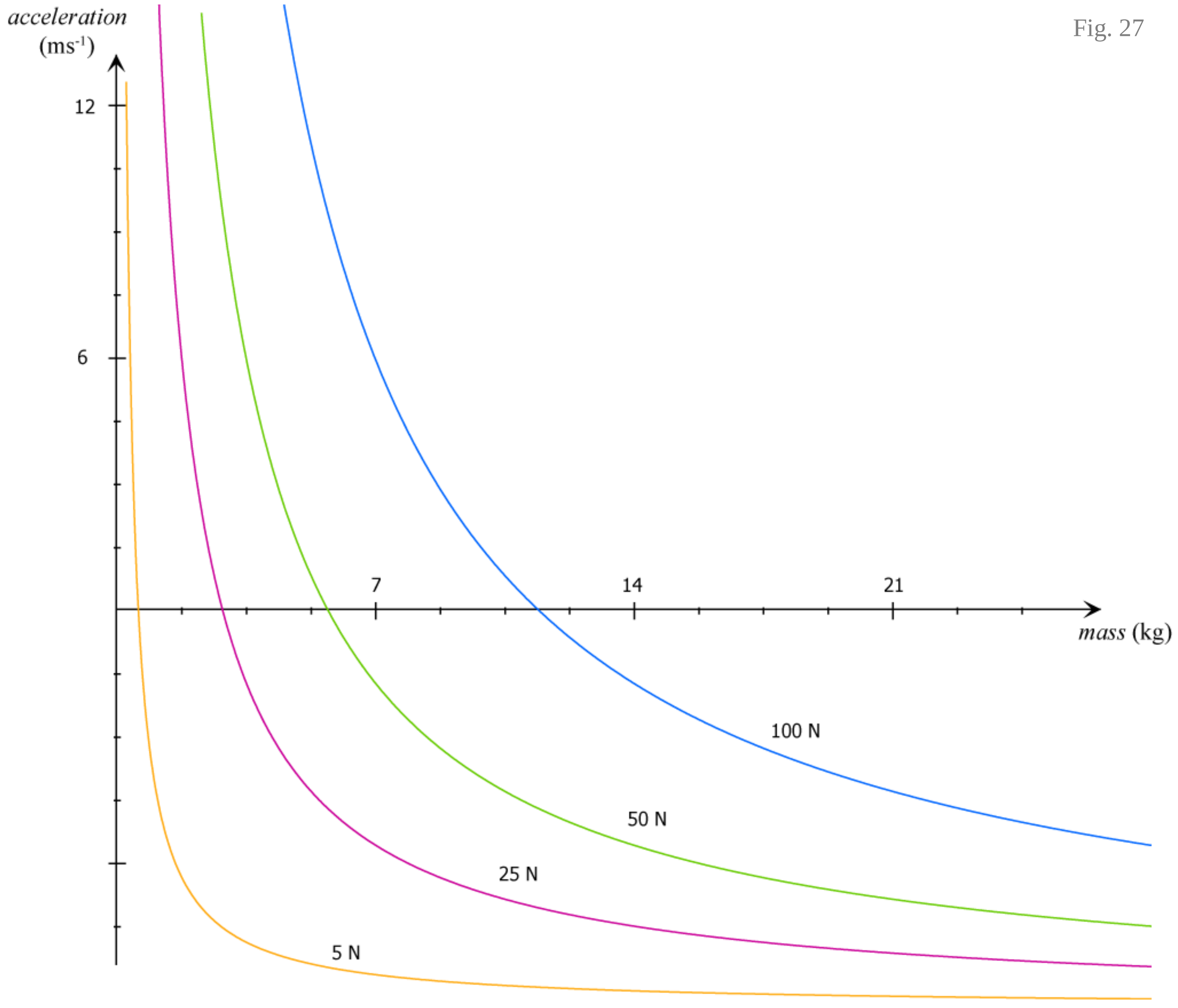


Fig. 27

8. analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth

When a body is undergoing uniform circular motion (such as when in orbit), then the magnitude of the force is constant and the direction it is acting is always towards the centre of the orbit. The magnitude of the velocity of an orbiting body is constant, but the direction is changing.

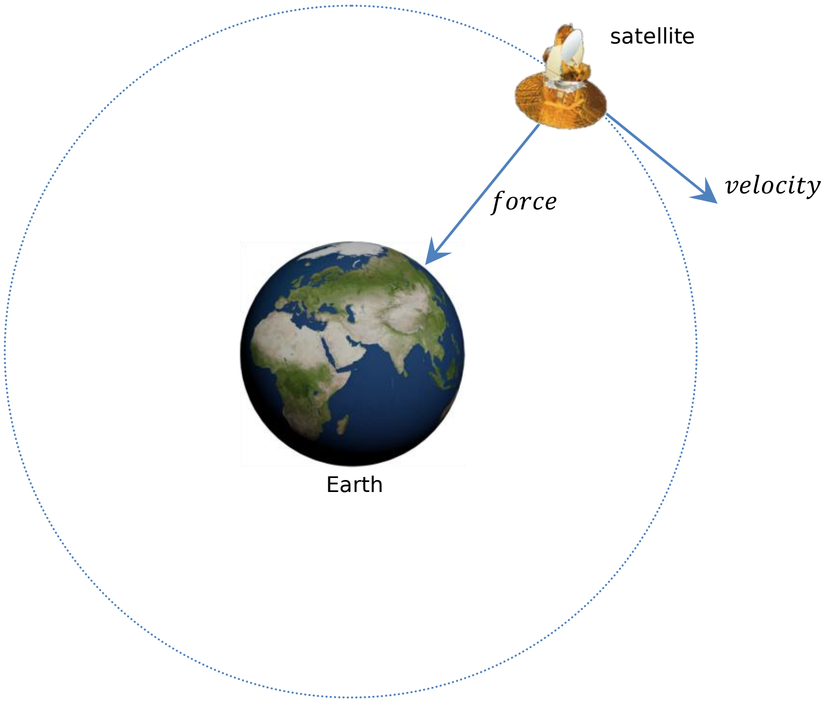


Fig. 28

From Newton's first law, we know that an object will keep moving in its state of uniform motion unless acted upon by a force. So for an object in uniform circular motion it has a force which is acting towards the centre. This force is known as the centripetal force. In the case of a satellite in orbit the centripetal force is provided by the force of gravity between the two masses. Another example of uniform circular motion is swinging a mass on a string. In this case the centripetal force is provided by the tension in the string. The centripetal force is given by the equation,

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

The diagram below shows some cases of uniform circular motion, in each case there is a centripetal force which holds the object in the circular motion.

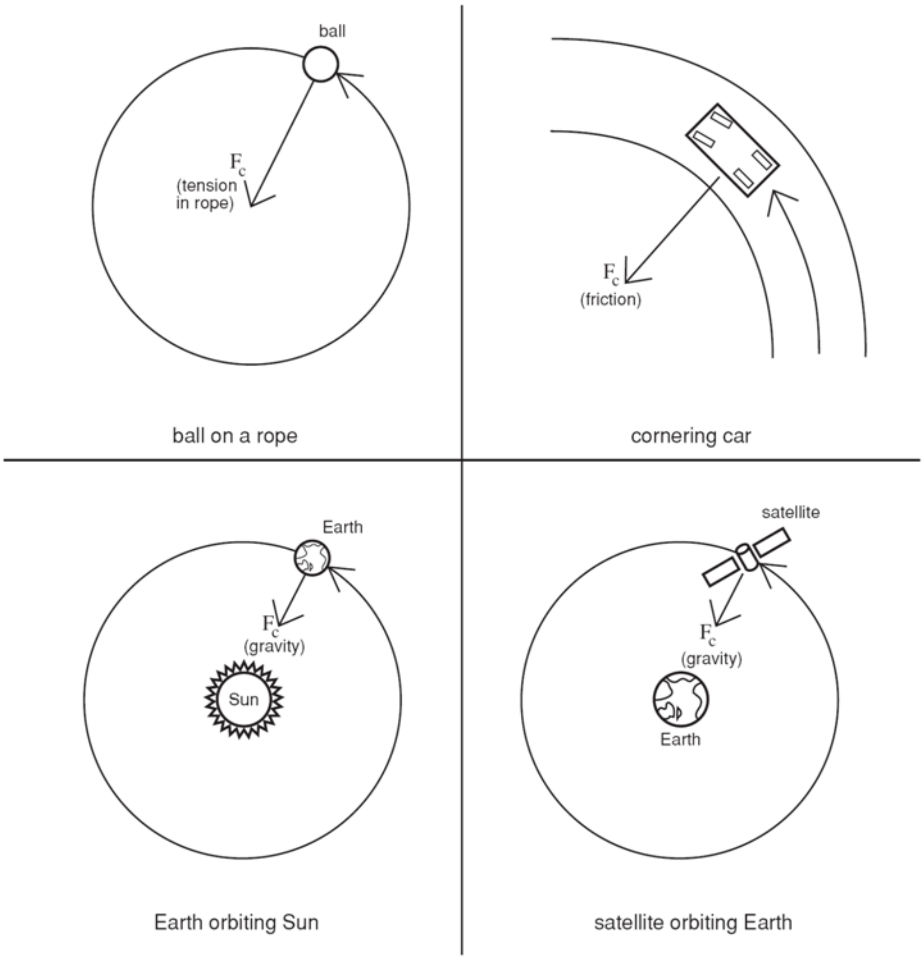


Fig. 29

Diagram from '*Space*' produced by Learning Materials Production, OTEN.

9. compare qualitatively low Earth and geo-stationary orbits

There are two main types of orbits for satellites orbiting the Earth. They are low Earth orbits and geo-stationary orbits.

Satellites in **low Earth orbit**, orbit the Earth at a different speed to the rotational motion of the Earth. This means that at different times the object in the low Earth orbit will see different parts of the Earth. Low Earth orbits are named so because they relatively close to Earth. The orbital distance of satellites in low Earth orbits varies but it is never less than about 250km above the Earth's surface, as any lower and the atmospheric drag would be too great. The highest low Earth orbits get to is about 1000km. At this altitude the satellite is just below the Van Allen radiation belts. This avoids any problems that the intense levels of radiation in this region may have on the life and operation of the satellite. It also allows the satellite to be maintained easier as shuttles can easily be sent to make repairs below the Van Allen belts. Low Earth orbits vary a great deal in terms of the angle of the orbit. However the most useful angle of orbit for a satellite in low Earth orbit is to orbit from pole to pole, that is, on the north-south pole plane.

Because the satellites have such a low altitude, their orbital velocity is quite fast and some can orbit the Earth in about one and a half hours. If a satellite of this speed is also in a pole to pole orbit, then within the space of one day it can capture the whole surface of the Earth. Satellites that use low Earth orbits include **weather** satellites and **imaging** satellites. Also because they are close to Earth, the resolution of images is quite high.

Satellites in **geo-stationary** orbits, orbit the Earth at the same rotational speed as the Earth (that is, they have the same period as the Earth), they orbit on the equatorial plane (see diagram), and they have circular orbits. These factors result in the satellite always being at the same place above the Earth. Meaning it will always appear at the same place in the sky when viewed from Earth. Also geo-stationary orbits have a greater altitude than low Earth orbits. We can calculate this altitude as we know the period will be the same as Earth. They lie above the Van Allen belts. Because the satellite always appears at the same place in the sky when viewed from Earth, geo-stationary orbits are used mostly in **television satellites** and communication satellites. This way the receiving dish on Earth doesn't have to move or track the satellite.

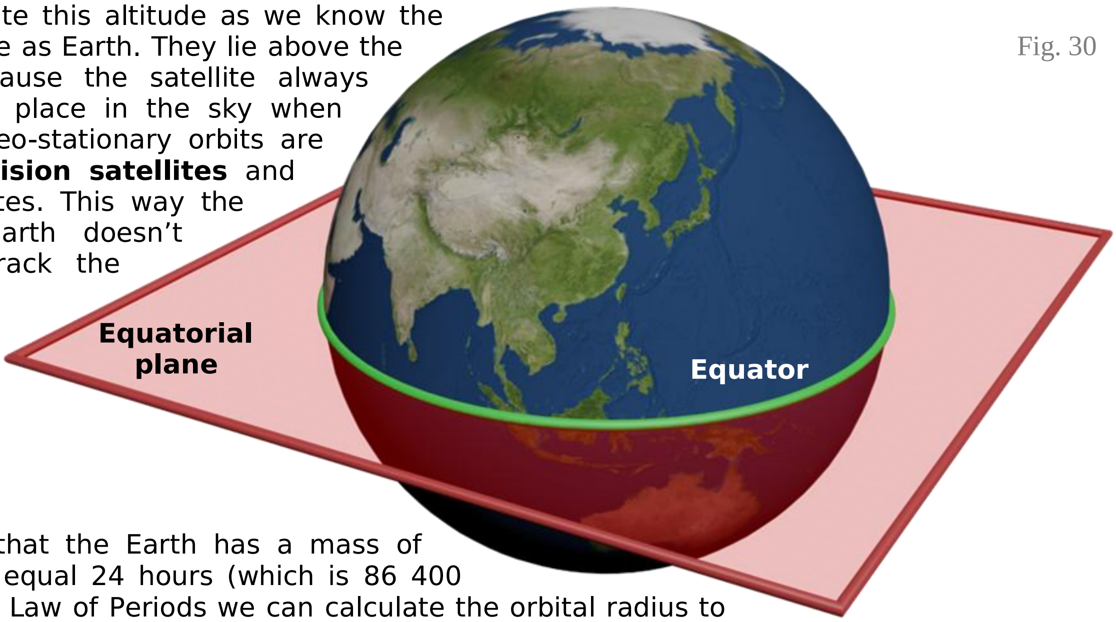


Fig. 30

Using Kepler's Law of periods,

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

,and since we know that the Earth has a mass of 6.0×10^{24} kg and T will equal 24 hours (which is 86 400 sec), so using Kepler's Law of Periods we can calculate the orbital radius to be,

$$r = \sqrt[3]{\frac{(6.67 \times 10^{-11}) \times (6.0 \times 10^{24}) \times 86\,400^2}{4\pi^2}} \approx 42\,000 \text{ km}$$

As Earth has an approximate radius of 6400 km, the altitude of a satellite in geo-stationary is about $35\,600$ km.

10. define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

Where,
T = time for period (1 revolution) (seconds)
r = radius of orbit (m)
M = mass of central body (i.e. planet) (kg)
G = gravitational constant (6.67×10^{-11} N m^2 kg^{-2})

Orbital velocity is the velocity than an object in orbit is travelling at in order to stay in orbit. This orbital velocity can be calculated. The first method is as follows. $\Delta x = vt$ so $v = \frac{distance}{time}$. From Kepler's Law of Periods, the radius of orbit and time of orbit can be found from a given mass. So,

$$\text{orbital velocity} = \frac{2\pi \times \text{ radius of orbit}}{\text{time of orbit}}$$

Now if we use Kepler's Law of Periods and substitute in the expression for the time of orbit then we will obtain the same results derived below, which shows an alternate method of calculating the orbital velocity. Either method will yield the same results and are essentially the same.

Orbital velocity can also be obtained by equating the centripetal force of an object in orbit with the gravitational force between the two bodies, as the centripetal force is the gravitational force (this is essentially the same as the above method, see below for reasoning). That is,

$$\frac{m_{satellite}\, v^2}{r} = \frac{G m_{satellite}\, m_{planet}}{r^2}$$

By making v the subject of the formula we get,

$$v = \sqrt{\frac{G m_{planet}}{r}}$$

You should note that the orbital velocity is independent of the mass of the satellite.

If we take $v = \frac{2\pi r}{T}$ and use Kepler's Law of periods to find T. Then we will obtain the same equation for orbital velocity as derived using the second method.

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

$$T = \sqrt{\frac{r^3}{\left(\frac{GM}{4\pi^2}\right)}}$$

$$v = \frac{2\pi r}{\sqrt{\frac{r^3}{\left(\frac{GM}{4\pi^2}\right)}}} = \frac{2\pi r}{\left(\frac{r^{\left(3\times\frac{1}{2}\right)}}{\left(\frac{GM}{4\pi^2}\right)^{\frac{1}{2}}}\right)} = \frac{2\pi r}{1} \times \frac{\left(\frac{GM}{4\pi^2}\right)^{\frac{1}{2}}}{r^{\left(\frac{3}{2}\right)}} = \frac{2\pi r \frac{(GM)^{\frac{1}{2}}}{2\pi}}{r^{\left(\frac{3}{2}\right)}} = \frac{\sqrt{GM}}{\sqrt{r}} = \sqrt{\frac{GM}{r}}$$

11. account for the orbital decay of satellites in low Earth orbit

Satellites in low Earth orbit are at an altitude where there is a very low amount of air in the atmosphere. So therefore the satellite will slow down due to friction with these air particles. It will only slow at a slow rate as the density of the air at this altitude is very low. Because the satellite slows down, it gets closer to Earth as its orbital velocity is not enough to keep the satellite in orbit.

12. discuss issues associated with safe reentry into the Earth's atmosphere and landing on the Earth's surface

Fig. 31 (Source: Anon)

Heat is one of the main issues associated with safe re-entry. When a spacecraft re-enters to Earth, gravity accelerates it to high speeds. The friction with the atmosphere created at these high speeds creates high temperatures for the spacecraft. The shape of the spacecraft will influence the spread and dispersion of the heat that the spacecraft experiences. Blunt noses are preferred over sharp noses. This is because spacecraft with blunt noses create a shockwave which absorbs most of the heat. Also the heat is spread out more rather than focused on one particular point.

Heat is also reduced by the use of a protective layer or insulation on the spacecraft. A ceramic material may be placed on the outside of the spacecraft which will vaporise first, preventing the spacecraft from vaporising. Another method is to place an insulating material which is made up of mostly air on the outside of the spacecraft. The air will absorb the heat preventing the spacecraft from becoming too hot.

G-Forces are another main issue associated with safe re-entry. The g-forces that are felt by astronauts during re-entry must be kept minimal. This is because large g-forces can cause:

- humans to black out (because the blood can't reach the brain)
- eyeballs to pop out of their sockets
- internal organs are put under large stress (which can cause internal damage and bleeding)
- death (if the g-forces are too large then the body may be crushed)

G-forces are felt by astronauts because the force of gravity that causes the spacecraft to accelerate towards Earth is opposed by a frictional force with the air. This gives the spacecraft a much larger apparent weight than its true weight and hence large g-forces are felt. These g-forces kept to a minimum by having astronauts lay down facing upwards. As the frictional force is the force that is felt by astronauts which slows the spacecraft, from Newtons first Law of motion, occupants will want to keep falling at the same speed and since the spacecraft is slowing the occupants feel a force pushing them to the floor of the spacecraft.

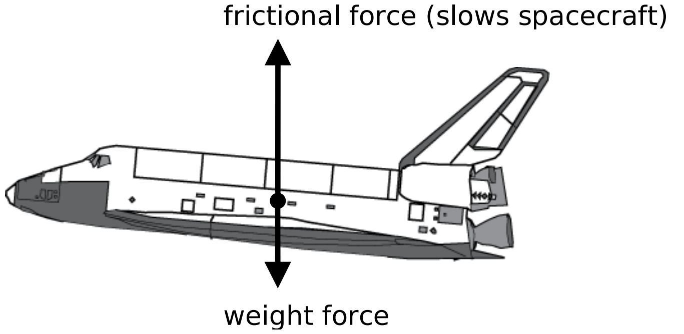


Fig. 32

By lying down the force is spread through the body and also eyes feel a force pushing them into the sockets rather than out of their sockets. Also a body moulded couch is used to help distribute the g-forces and minimise the potential problems of g-forces on the human body.

The space shuttle, as opposed to the capsule, will 'zig zag' back and forth to minimise the speed that it is falling to reduce the g-forces.

Another more minor issue associated with re-entry is what is known as **ionisation black-out**. As the heat around a spacecraft accumulates, atoms in the air around the spacecraft become ionised. These ions form a layer around the spacecraft than prevents radio signals being transmitted to and from the spacecraft. The signals simply cannot penetrate the ionisation layer. Although this poses no real threat to the safety of the mission it is still an issue associated with re-entry.

The **angle of re-entry** is critical. If the angle of entry is too steep, the space craft may burn up on re-entry and/or be subject to massive g-forces. However if the angle is too shallow, the space craft may bounce off the atmosphere and will go back into space.

With all this in mind there is still the issue of actually landing on the Earth's surface. This has, historically, been achieved in various ways. Initially when the capsule got close to Earth they used parachutes to slow the capsule and then it landed on the water where it was collected by the navy. This was the method used when NASA send a chimpanzee to outer space. Later when Russia sent a man to outer space, the astronaut ejected from the capsule and they skydived back to Earth, landing on land. More recently with the use of the space shuttle returning astronauts have been able to land just like aeroplanes land.

Image courtesy of NASA.

Fig. 33

13. identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle

If a spacecraft comes in with a large (step) angle, it will travel too fast and either crash into Earth or burn up on re-entry. The astronauts inside will experience large g-forces which may kill them and the heat will be very large, which may even vaporise the spacecraft. If the spacecraft comes in with a small angle, it will bounce off the atmosphere and go back out into space. The Apollo capsules needed to ensure that they had a re-entry angle between 5.2° and 7.2°.

1. solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using :

$$v_x^{\ 2} = u_x^{\ 2}$$

$$v = u + at$$

$$v_y^{\ 2} = u_y^{\ 2} + 2a_y \Delta y$$

$$\Delta x = u_x t$$

$$\Delta y = u_y t + \frac{1}{2} a_y t^2$$

These equations are used to describe projectile motion. They can easily be derived by integrating from the known accelerations for the horizontal and vertical components. As the syllabus does not mention this I will not go into it, however if you are studying Mathematics Extension 1 then you will learn this.

You should remember from the preliminary course that a vector is a quantity with a magnitude and direction. This description has been dulled down a lot, and it is much better to understand vectors in a mathematical context.

Matrices can be used to represent vectors. An n dimensional vector must be described by n scalar values. For example the vector, $\boldsymbol{v} = \begin{bmatrix} 5 \\ 0 \\ 0 \end{bmatrix}$ represents both a direction and a magnitude, the direction will be in along the x axis, and the magnitude will be 5. However in this course we mostly work in two dimensions which can be represented in matrix from by $\begin{bmatrix} x \\ y \end{bmatrix}$. This matrix combines both the components of the vector. I would hope that if you were asked to calculate a vector quantity it would be acceptable to leave your answer in this matrix from, however somehow I think that you would not receive full marks even though this is correct and is what is done by non-HSC people.

The two main coordinate systems used for two dimensions are Cartesian and polar. Most people would say that you may write your vector answer in either form and the Cartesian is the preferred, however when it comes to HSC Physics, the maths is dulled down and you may not get away with this.

2. perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis

There are many different ways to do this, one method which is probably not the best method has been written up as a full report and provided on page 131 as an example of an independent investigation report. However a better first-hand investigation for this dot point has been provided here.

To calculate the initial and final velocity, maximum height reached, range and time of flight of a projectile we can use a video camera and grid. A projectile is launched in front of a grid which is filmed by a video camera. The film can then be downloaded to a computer where it can be analysed accurately.

The diagram below shows a stroboscopic image (i.e. at regular intervals of time). From this image and the grid we can analyse the projectiles motion. Just say that the grid is 100mm by 100mm and that each image has been taken at 0.1 second intervals.

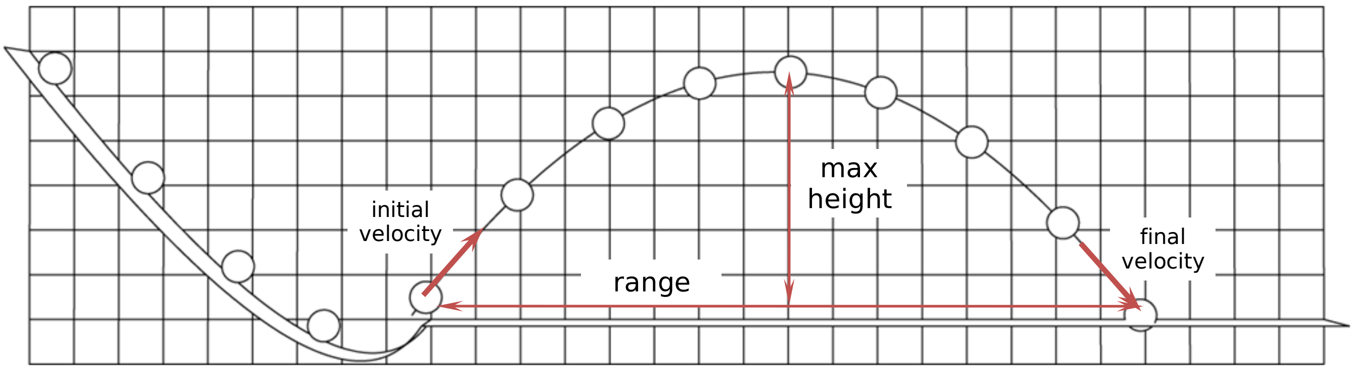


Fig. 34

The range, maximum height and time of flight is easy to calculate. Just by looking at the image we can see that the range is about 16 grid units, which is $16 \times 100\text{ mm} = 1.6\text{ m}$. The maximum height can also be found in a similar way, $5.5 \times 100\text{ mm} = 0.55\text{ m}$. Also we know that the time intervals are 0.1 seconds, so the time of flight is 8 seconds (this could be found more accurately by using the time code for the frame of both the start and end of the trajectory).

Calculating the initial and final velocity is slightly more difficult. To get this more accurately we can look at the starting frames and the ending frames on a frame by frame basis. Also we can subdivide the grid on the computer screen to get a better resolution grid, although that goes beyond the syllabus requirement. Basically to calculate the initial and final velocity, we calculate the vertical and horizontal components of the velocity at the start and end instants and these components can be converted into magnitude direction vectors. However since we cannot calculate the instantaneous velocity, we can take an average over a few frames. The more frames we use, the more accurate the measurements will be, but the less valid the results will be as the velocity is changing (you should note that the horizontal velocity component will be constant (ignoring air resistance)).

I could go into a lot more detail and technicalities however I think this will suffice. But I should mention that this apparatus is prone to parallax error. To minimise this, the ball should be placed as close to the grid as possible. Also I should mention that this experiment does not need a grid behind it, all you need is some reference points and the grid can be calculated on the computer.

3. identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun

Goddard,

- contributed to the development of rockets
- conceived ideas and tested them, making many patents.
- designed and built a **liquid-fuelled** rocket, including the technical aspects.
- proved that rockets would work in a **vacuum**
- used a **gyroscope** for navigation
- was the first to **separate the payload** from the rocket and then returned it to Earth.

4. solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using:

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

5. solve problems and analyse information using:

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

Note that SI units must be used for M, r and T as G on the data sheet has units in terms of the SI units.

This is Kepler's third law, the law of periods. The RHS is a constant for the centre mass. In the case of satellites orbiting the Earth this means that $\frac{r^3}{T^2}$ for each satellite will be the same.

3. The Solar System is held together by gravity

1. describe a gravitational field in the region surrounding a massive object in terms of its effects on other masses in it

Newtonian gravity is a force of attraction between two masses. The heavier the masses the larger the gravitational force between them. This force between these two masses is proportional to $\frac{1}{d^2}$. The relationship between these variables is given by Newton's Law of Universal Gravitation (see next dot point). A gravitational field surrounds all masses and the interaction of masses in this gravitational field results in a force between the two masses.

2. define Newton's Law of Universal Gravitation

Newton's Law of Universal Gravitation states that every mass in the universe is attracted to every other mass in the universe by a force of gravitation. This force can be calculated with the formula,

$$F = G\frac{m_1 m_2}{d^2}$$

3. discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites

Satellites must have a certain velocity in order to stay in orbit. If not they will either crash into Earth or go out into space and never return. This velocity depends on the force of gravity acting on the satellite. Satellites paths of motion are affected by gravity, this can be seen by orbits and the slingshot affect.

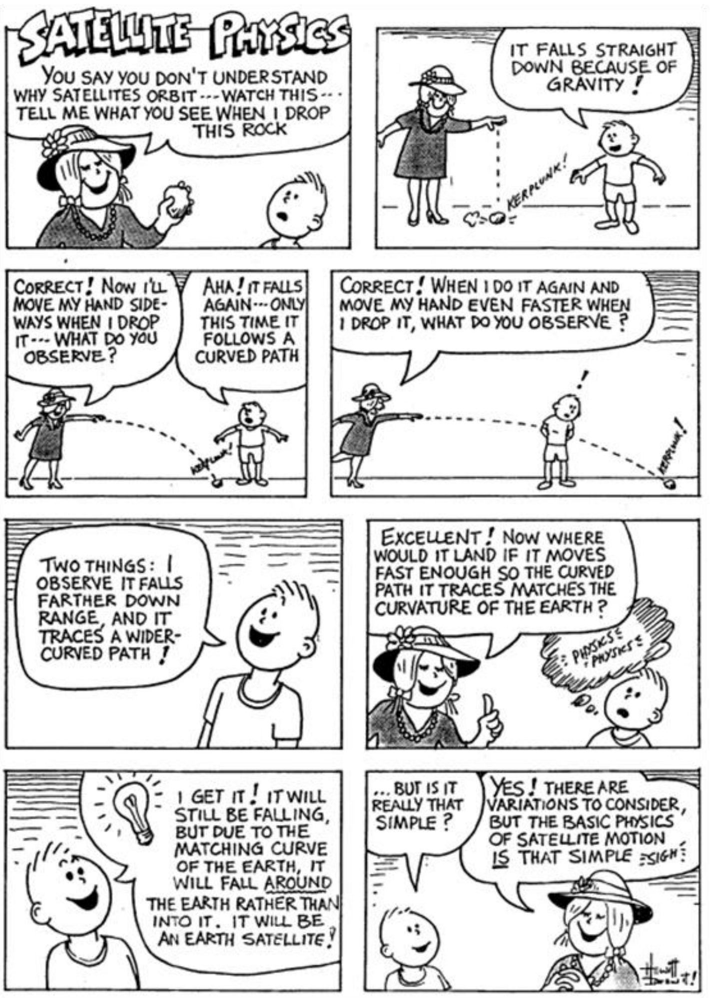


Fig. 35

Cooper, I. (2002). Using MS Excel for Data Analysis and Simulation. *Science Teachers' Workshop 2002*, (p. 15).

4. identify that a slingshot effect can be provided by planets for space probes[1]

The slingshot effect allows satellites to change speed and direction. The change in direction is due to the gravitational field which applies a force to the space probe which changes its direction. The satellite can also be sped up or slowed down. An increase in speed is because, relative to the sun, the passing space probe has gained velocity from the moving planet. Gravitational slingshots involve gravitational potential energy being converted into kinetic energy. Some of the angular momentum and kinetic energy of the planet is transferred to the space probe.

1. present information and use available evidence to discuss the factors affecting the strength of the gravitational force

From the formula, $F = \frac{Gm_1m_2}{d^2}$, the factors that affect gravitational force are Universal Gravitational Constant, mass of both bodies and the distance separating these two bodies.

In regards to the gravitational force on Earth see section 1 blue dot 1.

2. solve problems and analyse information using:

$$F = G\frac{m_1m_2}{d^2}$$

Where,
F = force (N)
m_1 = mass of body 1 (kg)
m_2 = mass of body 2 (kg)
d = distance of separation of bodies (m) (from centre of mass to centre of mass)
G = gravitational constant (6.67×10^{-11} N m^2/kg^2)

Remember that the universal constant G given on the data sheet is such that d must be in metres, and m must be in kilograms. F will be in newtons.

[1] This dot point only asks you to identify, i.e. recognise and name. So you only really need to know what the slingshot effect is and what it does. You do not need to know how it works. Although I have included a brief outline of how it works, just for you interest.

4. Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light

1. outline the features of the aether model for the transmission of light [1]

- The aether was thought to be the medium that light travelled through.
- The aether filled all space (ie. it permeated all matter).

2. describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether

The Michelson Morley experiment attempted to measure the relative velocity of the Earth through the aether. Since the Earth rotated around the sun, by performing the experiment at various times they could ensure that they did not just test at a time where the ether and the Earth were moving at the same speed.

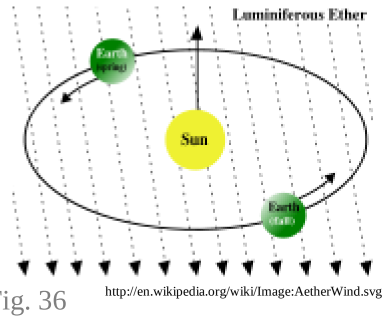


Fig. 36

In their apparatus they set up a light source which was split into two perpendicular rays upon hitting a half-silvered mirror. This allowed for half of the light to travel to mirror B and the other half to mirror A. These reflected beams then joined back up and were shown in a screen. Because the distance from the screen to B and from the screen to A could not be made exactly the same, when the two beams joined they produced an interference pattern (bright and dark fringes) which was shown on the screen. This apparatus which is called a Michelson interferometer is shown below.

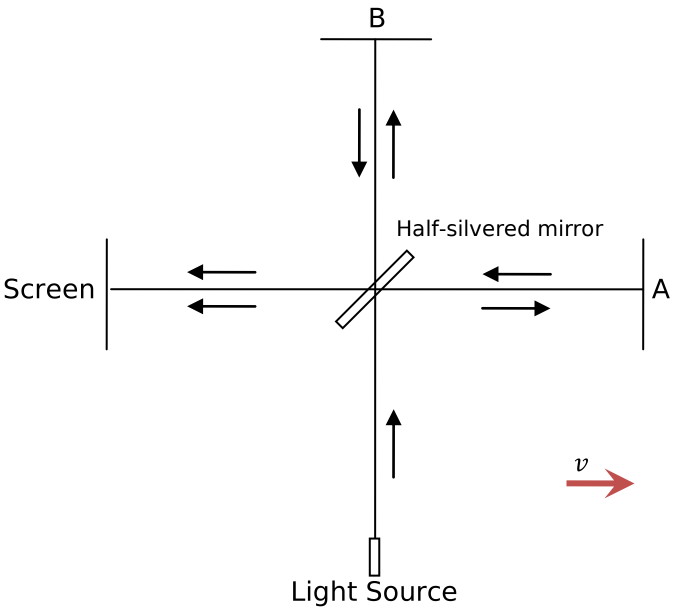


Fig. 37

Now suppose the Earth carries this apparatus in the direction shown, the light travelling to beam B (the one perpendicular to the motion of the Earth) will reach B and then back to the half silvered mirror faster than it will take the light to reach A and then back again (see the boat analogy below). So we know that because one of the beams is moving with the aether and the other is moving perpendicular to the aether, the beams will be out of phase when they reach the screen.

When this apparatus is rotated 90° as shown below, the interference pattern should be shifted as now it is A that takes longer than B. However no such change in interference pattern was observed. They had obtained a null result. That is that there is no relative motion between the aether and Earth.

[1] You must be careful not to include properties as features see, 2003 Physics HSC & Notes from the Marking Centre (Marking Guidelines page 4, Notes from the Marking Centre page 6). Board of Studies NSW.

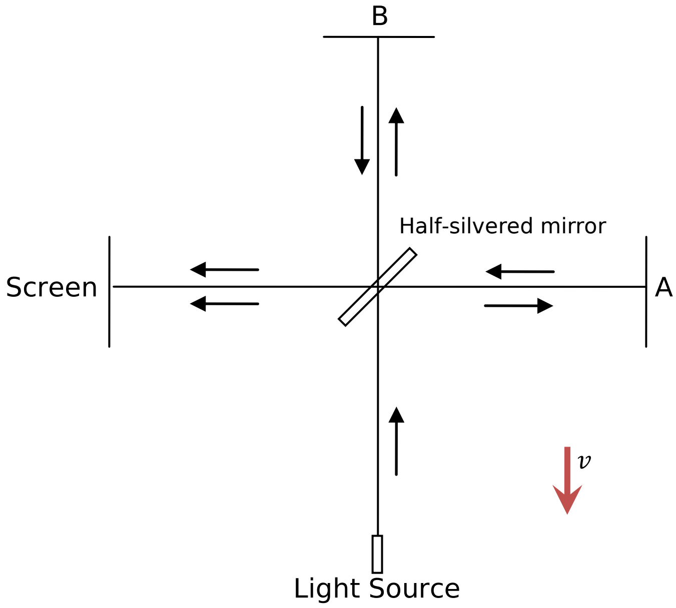


Fig. 38

Boat Analogy:
Two boats are travelling perpendicular to each other in the presence of a current. Boat A is initially travelling with the current and then against it. Boat B has to travel at an angle in order to return to the same point.

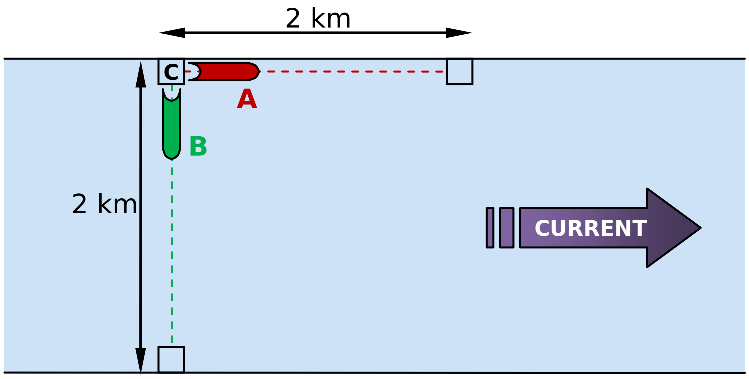
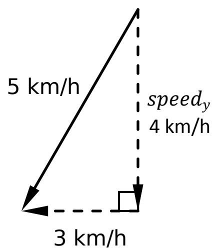


Fig. 39 - *The boat travelling in the direction of the current will take longer to travel the same distance as the boat travelling perpendicular to the current.*

Both boats travel at 5 km/h and the current is 3 km/h. When Boat A is travelling with the current, its speed relative to the moving water is 5 km/h, and relative to the external point C is 8 km/h. As it is travelling 2 km, $\text{time taken} = \frac{distance}{\text{speed}} = \frac{2}{8} = 0.25\text{ h}$. On its return trip, it is travelling against the current, so relative to the water its speed is still 5 km/h, but relative to the stationary point C its speed is 2 km/h. So $\text{time taken} = \frac{distance}{\text{speed}} = \frac{2}{2} = 1\text{ h}$ and the total time taken for Boat A to travel 2 km is 1.25 h.



Boat B, as shown below, must travel at an angle so that it does not move downstream with the current. Its speed is still 5 km/h, however this is not its speed in the straight direction. By Pythagoras theorem, $speed_y = \sqrt{5^2 + 3^2} = 4\text{ km/h}$. So the $\text{time taken} = \frac{distance}{\text{speed}} = \frac{2}{4} = 0.5\text{ h}$. Coming back in the other direction will be the same so the total time taken for Boat B to 2km is 1h. This is quicker than Boat A.

Sample Response to Exam Question: (for all those who like to rote learn everything)
Michelson and Morley attempted to measure the relative speed of the Earth through the aether, a substance conjectured to be the medium in which light is propagated, that filled all space. Their method involved splitting a beam of light, from a single source into two beams that travelled perpendicular to each other. The two beams were brought together and shown on a screen, creating an interference pattern. If the Earth moves relative to the aether, then the speed of one beam will be different from that of the other, just as the speed of a boat going first upstream and then downstream is different from that of a boat travelling across the stream. The difference in speed of the two beams would alter the interference pattern when the apparatus is rotated through 90°. No such alteration was found. This and similar failures to detect the motion of the Earth through the aether led later to the development by Einstein of the special theory of relativity, and the subsequent abolishment of the aether theory.

3. discuss the role of the Michelson-Morley experiments in making determinations about competing theories[1]

The Michelson-Morley experiment provides experimental support for the theory of relativity.

4. outline the nature of inertial frames of reference

Inertial frames of reference are frames of reference where Newton's Laws are observed. (i.e. an object will continue in its state of motion unless acted upon by a force, $F = ma$ and for every action there is an equal and opposite reaction.) Inertial frames of reference are moving at a constant velocity, they are not accelerating or experiencing a force.

5. discuss the principle of relativity[2]

The principle of relativity states that all inertial motion is relative and cannot be detected without reference to an outside point. This means that you can only measure inertial motion with reference to a frame of reference. This means that you cannot perform any experiment within an inertial frame of reference to detect the motion of the frame of reference. Also the laws of mechanics are the same for a body at rest and a body moving at constant velocity, these frames are the same.

For example if you were in a spacecraft that was on its way to the moon with its rocket engines turned off. Then the spacecraft is an inertial frame of reference (neglecting the minute forces of gravity). If you close all the windows and stand inside then there is no way of you knowing how fast you are travelling or if you are moving at all. This is the principle of relativity, that is, there is no way of detecting inertial motion without reference to an outside point. So in our example, you can only detect the motion of the spacecraft you are in when you open the windows and look outside and see the Earth getting smaller and the moon becoming larger. To detect your motion you are referring to an outside reference point. However according to the principle you can only measure the relative velocity between the two frames, no frame is preferred and you cannot measure your 'absolute' velocity.

6. describe the significance of Einstein's assumption of the constancy of the speed of light

Just say you were in a train travelling at 0.5c, which has a light source in it. According to Newtonian physics, you (in the same frame of reference as the train) should see the light travelling at c, and an observer standing outside of the train who observes the train passing should notice the light travelling at 1.5c. Einstein in his theory of special relativity proposed that light should be observed to travel, in a vacuum, at the same value c regardless of the motion of the source of the light. This means that the principle of relativity must be true. As if the principle of relativity was not true, that is, you could detect the 'absolute' motion of an inertial frame of reference, then the speed of light must not have been the same for all observers.

The significance of this constancy of the speed of light is that time and space must be relative. This means that time and space must change depending on your speed. *(See blue dot point number 3)*

7. identify that if c is constant then space and time become relative

If the speed of light is constant then space and time must change depending upon your speed. This can be understood by the thought experiment in the *blue dot point number 3*. As space and time change depending upon speed, they become relative.

8. discuss the concept that length standards are defined in terms of time in contrast to the original metre standard

Originally 1 metre was defined as the length of a block of metal which was located in Paris. In the SI system, this definition was changed to the length that light travels in a vacuum in a given amount of time, to make it more accountable of relativity.

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[1] I am unable to find sufficient evidence to complete this dot point.

[2] This dot point often creates confusion. The principle of relativity is not Einstein's postulates of relativity (The Relativity Postulate and The Speed of Light Postulate). The principle of relativity dates back to Galilean relativity and states that all inertial motion can only be measured with reference to an external point.

9. explain qualitatively and quantitatively the consequence of special relativity in relation to:

– the relativity of simultaneity[1]

If two events appear simultaneous in one frame of reference, they are not necessarily simultaneous in another frame of reference. This can be explained with a thought experiment involving a train, where Alice is in the centre of the moving train and Bob is stationary externally to the train.

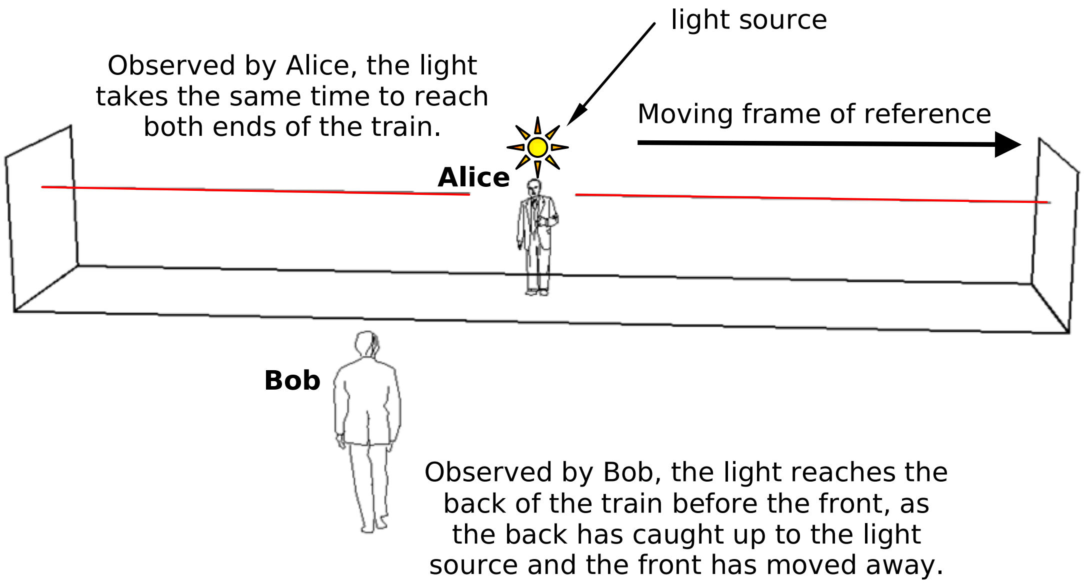


Fig. 40

When a flash of light is emitted from Alice, she should see the light hit the two ends at the same time. This is because the speed of light is constant irrelevant of the frame of references motion. However Bob will see things differently, he will see the light reach the back of the train before it hits the front of the train, this is because the back of the train has moved closer to the source and the front of the train has moved away from the source, remembering that he also observes the light to travel at c.

And so in Alice's frame of reference these two events appear simultaneous, but in Bob's frame of reference they do not appear to be simultaneous.

In terms of a quantitative analysis, simultaneity can be explained in terms of how each observer observe the others' coordinate system.

– the equivalence between mass and energy

As seen in mass dilation below, if you speed up an object then it becomes heavier. But where does the extra mass come from, well it comes from the energy you use to speed up the object. So if you accelerate an object to really fast speeds then the energy/force used to accelerate it is converted to mass, thus making the object heavier. Similarly when an object is slowed down, the mass is converted back into energy. This leads to $E = mc^2$. As c^2 is a huge number you need a lot of energy to get just a little bit of mass, but on the other hand on a small amount of mass yields large amounts of energy. This result means that mass dilation is a result of the energy put into the system to make it faster, it does not just happen as a result of speed. The equivalence between mass and energy is given by Einstein's famous formula,

$$E = mc^2$$

Where,
E = rest energy (J)
m = mass (kg)
c = speed of light (ms^{-1}) (3.00×10^8)

[1] The syllabus requires a quantitative analysis of simultaneity. Unfortunately I cannot fully explain this without delving into advanced physics.

– length contraction

(The following explanation probably extends beyond the syllabus requirement.)

Length contraction is a direct consequence of time dilation (see next page). Let's imagine that Alice is on a train platform, while Bob is on a train that passes the platform at velocity v.

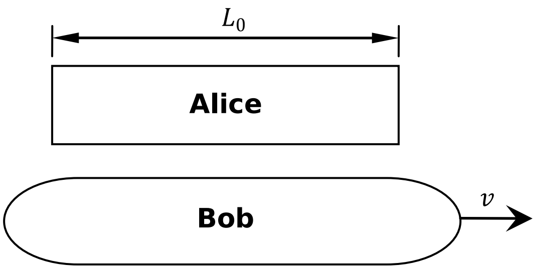


Fig. 41

Alice measures the length of the station to be L_0. Because she is stationary relative to the station, this can be considered the proper length. Alice also notes that Bob, on the train, travels through this length in a time of $t_v = \frac{L_0}{v}$, which means that $L_0 = vt_v$. This time interval t, is not a proper time interval because Alice observes these two evens of the train passing the start and end of the station at different places.

However in Bob's frame of reference, Alice is moving and he is stationary. Bob finds that the two events measured by Alice occur at the same place in Bob's frame of reference. So to Bob, the length of the platform is given by $L = vt_0$. Now if we divide Bob's length by Alice's length we get,

$$\frac{L}{L_0} = \frac{vt_0}{vt_v}$$

Now if we substitute in the time dilation formula we get,

$$\frac{L}{L_0} = \frac{vt_0\sqrt{1-\frac{v^2}{c^2}}}{vt_0}$$

which leads to,

$$l_v = l_0\sqrt{1-\frac{v^2}{c^2}}$$

Where,
l_v = length observed for observer moving at velocity relative to the event
l_0 = rest length (proper length) (as observed for observer in same frame of reference as the object)
v = velocity of observer
c = speed of light

The result of this formula is that the faster you are travelling the smaller length becomes for you. As $v \to c$, $l_v \to 0$. Also remember that this length contraction is in the direction of motion only.

A note about units, v and c must be in the same units, and so will l_v and l_0. Apart from that you may use any units you want.

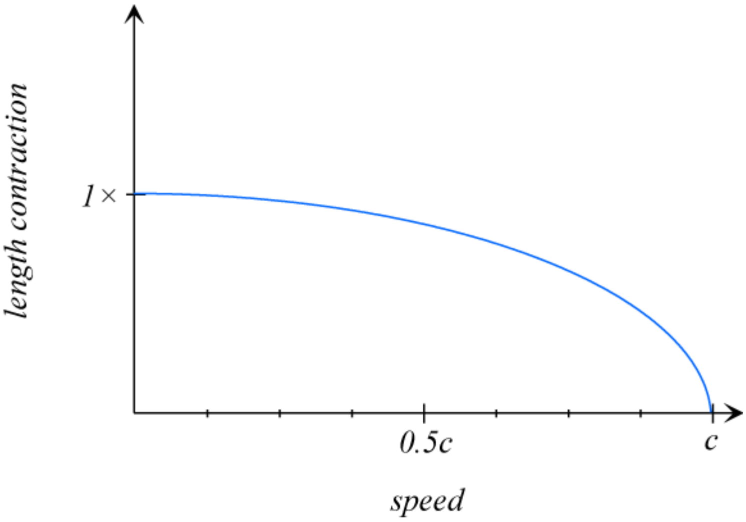


Fig. 42

– time dilation

(The following explanation probably extends beyond the syllabus requirement.)

Time dilation can be explained by looking at an experiment that investigates how two different observers in different frames of reference measure time relative to a light clock (the apparatus shown). As shown in the diagram below, two observers Alice and Bob use the fact that $speed = \frac{distance}{time}$ to measure one 'tick' of time. They decide that one 'tick' of time will be the time taken for light to travel from a source to a mirror and then be reflected back to the source. Alice is stationary relative to her apparatus, but Bob's apparatus is moving at velocity v relative himself.

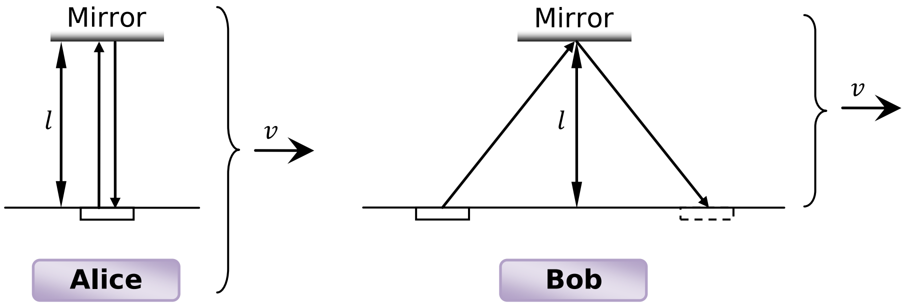


Fig. 43

Rearranging $speed = \frac{distance}{time}$ we get $time = \frac{distance}{speed}$. So for Alice one 'tick' of time will be $t_A = \frac{2l}{c}$. The light travels straight up and then down at the speed of light. (t_A can be considered the 'proper time', which is t_0 in the time dilation formula. This is because the light is emitted and received at the same location.) However for Bob, who's apparatus is moving at velocity v relative to the himself (this can also be considered as Bob is moving and his apparatus is stationary), as observed by Bob the light has to take a slightly longer path. This means that the distance will be greater and so the time will be greater. From a little algebra we see that $t_B = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$. And so time passes slower for Bob's frame of reference than for Alice's frame of reference. This effect is time dilation.

By generalising this result we get,

$$t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Where,
t_v = time observed for observer moving at velocity (relative to the event)
t_0 = time observed for stationary observer relative to the event (proper time/rest time)
v = velocity of observer
c = speed of light

The result of this formula is that the faster you are travelling the slower time becomes for you. As $v \to c,\ t_v \to \infty$.

A note about units, v and c must be in the same units, and so will t_v and t_0. Apart from that you may use any units you want.

(See also blue dot point 3)

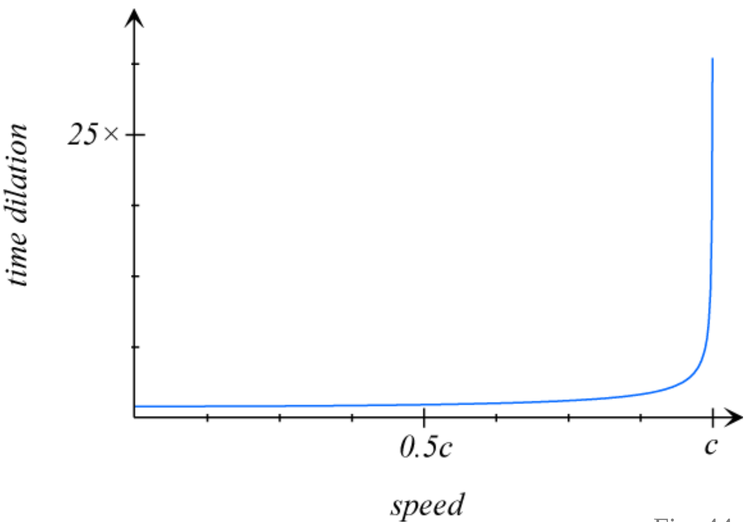


Fig. 44

– mass dilation

As you speed up an object the energy you use in order to accelerate it turns into kinetic energy which results in the acceleration of the object. But what happens at relativistic speeds? Well at relativistic speeds the object does not speed up as you would normally expect, so this energy cannot be turning into kinetic energy as the object is not gaining much speed. Instead this energy you use to accelerate the object turns into mass and the object becomes heavier. This is mass dilation, which in turn makes it harder to accelerate the object even further.

$$m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Where,
m_v = mass observed for observer moving at velocity (relative to the event)
m_0 = mass observed for stationary observer relative to the event (proper mass/rest mass)
v = velocity of observer
c = speed of light

The result of this formula is that the faster you are travelling the heavier your mass becomes for you. As $v \to c,\ m_v \to \infty$.

A note about units, v and c must be in the same units, and so will m_v and m_0. Apart from that you may use any units you want.

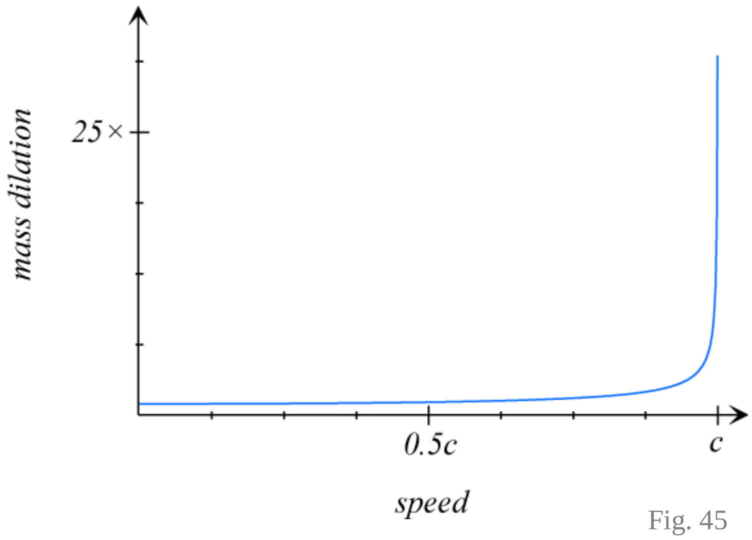


Fig. 45

10. discuss the implications of mass increase, time dilation and length contraction for space travel

Mass increase means that spacecraft cannot travel at or above the speed of light. It also means that the faster the spacecraft gets, the heavier it will be and thus the more force needed to accelerate it. This means that the spacecraft cannot simply allow constant acceleration to increase the speed at a constant rate for as long as they want. This limits the speeds spacecraft can travel at, and it limits them to low speeds relative to c.

However **time dilation** and length contraction help for space travel as if relativistic speeds can be achieved then the length needed to travel will become less and as time slows people can travel further in their lifetime, however if they return to Earth people would have aged much more.

For **length contraction**, it is best to use Einstein's Relativity Postulate that states, the laws of physics are the same for observers in all inertial reference frames. No frame is preferred. This means that the spaceship speeding though space could equally say that they in the spaceship are stationary and the rest of the space is speeding past the craft. In this respect, the space will contract in length and hence the spaceship will have less length to travel in order to reach the destination.

1. gather and process information to interpret the results of the Michelson-Morley experiment

2. perform an investigation to help distinguish between non-inertial and inertial frames of reference

We know that an inertial frame of reference is where Newtons Laws of motion are observed and that these laws are not valid for non-inertial frames of reference. So do distinguish between non-inertial and inertial frames of reference we can test to see if Newtons Laws are observed or not.

One of the simplest investigations is to hang a mass from a string. If the frame of reference is accelerating (e.g. you are standing still then begin to run forward) you will see that the mass has a force applied to it and is no longer hanging straight down. If however you are in an inertial frame of reference (e.g. you are walking forward with constant velocity) then the mass will hand straight down.[1]

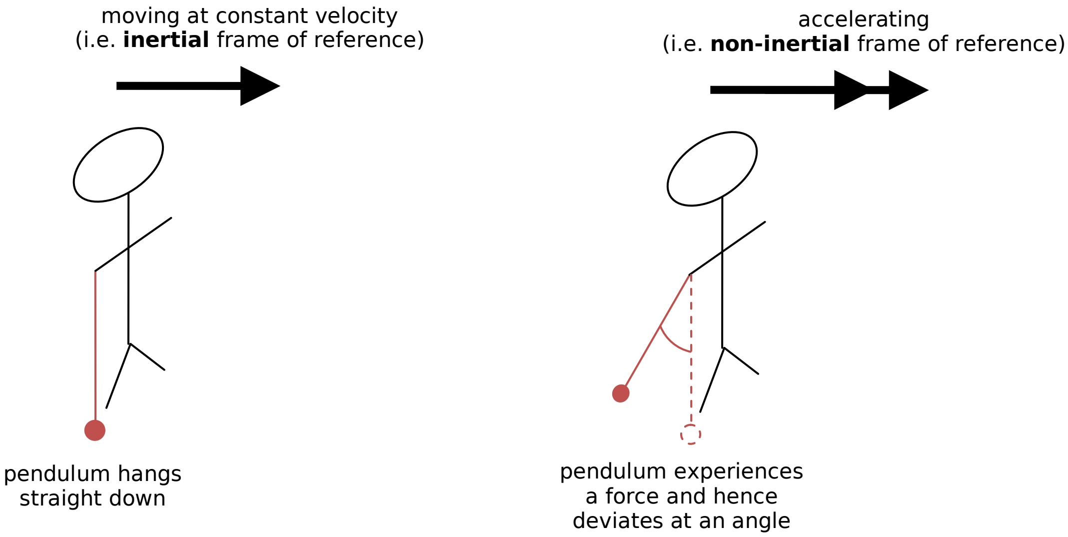


Fig. 46

Another method is to use an accelerometer. A simple design is where a small ball is placed inside the accelerometer which is surrounded by devices which measure force (the same design as bathroom scales can be used). This device can now measure forces. If the accelerometer measures a force, in any direction then it can be said that the accelerometer is in a non-inertial frame of reference. However this poses another problem because gravity could be responsible for this force. However this is explored in general relativity.

3. analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality

"Imagine that you are sitting in a train facing forwards. The train is moving at the speed of light. You hold up a mirror in front of you, at arm's length. Will you be able to see your reflection in the mirror?

The experiment could have one of two possible outcomes, each of which involves a dilemma for the scientific community of the time that believed in the aether model:

- No, the reflection will not appear. This is the result predicted by the aether model, since light can only travel at a set speed (3×10^8 ms^{-1}) through the aether. If the train is travelling at that speed then the light cannot catch the mirror to return as a reflection. Unfortunately, this violates the principle of relativity, which states that in an inertial frame of reference you cannot perform any experiment to tell that you are moving.

- Yes, the reflection will be seen because, according to the principle of relativity, it would not be possible for the person in the train to do anything to detect the constant motion with which he or she is travelling. However, a person watching this from the side of the track should see the light from your face travelling at twice its normal speed!

Einstein decided that:

- The reflection will be seen as normal, because he believed that the principle of relativity should always hold true
- The person at the side of the track sees the light travelling normally. BUT, this means that time passes differently for you on the train and for the person at the side of the track
- The aether model has nothing to do with it. Einstein described it as superfluous."[2]

---

[1] This test will work for the demonstration described; however this is not a definitive test and it will not work in all situations. There is no test that can be done that is definitive. This is Einstein's fundamental postulate of gravitation, that you cannot tell if you are accelerating, just say in a rocket ship in space at 9.8ms^{-2} (which is a non-inertial frame of reference) or if you are standing on the surface of Earth experiencing a weight force of 9.8ms^{-2} (which is an inertial frame of reference, assuming that the Earth is an inertial frame of reference).

[2]

4. analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it

Experimental evidence for time dilation on the macroscopic level can be seen by synchronising two atomic clocks, leave one on Earth and send the other around the Earth in a jet at high speeds, and in the opposite direction to the rotation of the Earth (to maximise the relative velocity). When the two clocks are brought back together, the one left on Earth should have recorded more time to have passed than the other clock. This is because the clock on the rocket was travelling at a faster speed and so time dilation has caused the time to slow.

Another piece of experimental evidence on the microscopic level is the time dilation of muons. When high-energy particles from space hit the Earth's atmosphere, subatomic particles called muons are produced. Muons are unstable and have only a very short lifetime before they decay. The rest time of these particles is about 2 microseconds. With this lifetime, even if they travelled at speeds near the speed of light, they could only travel 600m before decaying (without taking into account special relativity). Yet muons are seen on the Earth's surface, which is about 10 km of distance from when they were produced. The reason they make it this far is that as these particles are moving so fast, time passes much more slowly for them as observed by us.

Length contraction also provides an alternative, equivalent explanation of why these muons can reach the Earth's surface before they decay. From the muons frame of references, the Earth is rushing towards them at a speed close to the speed of light. And so the Earth's atmosphere has contracted to small enough length to allow the muons to reach the Earth's surface before it decays.

5. solve problems and analyse information using:

$$E = mc^2$$

$$t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$l_v = l_0\sqrt{1-\frac{v^2}{c^2}}$$

$$m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Because you the quantities for velocity and c are entered as the same units, the units cancel out and so the units for both the lengths, masses or times will be the same. Hence you can use whatever units you like for the length, mass or time.

9.2 TOPIC REVIEW

9.2 Summary

- A pendulum can be used to calculate acceleration due to gravity, g. The value obtained for g will vary due to different altitudes, the centrifugal force due to the rotation of the Earth, the Earth being flatter at the poles and varying density and distribution of the crust.
- To analyse projectile motion, the motion is described in terms of horizontal and vertical components.
- The escape velocity is the velocity needed for an object to be fired off a planet so that it never returns. The escape velocity can be calculated by equating the formula for kinetic energy and gravitational potential energy. Newton's concept of escape velocity is that if you are standing on a very tall building and if you could launch a projectile fast enough then its path would match the curvature of the Earth and it would be in orbit.
- G-force is the acceleration you are felling as a multiple of acceleration due to gravity.
- The Earth's motion will affect the path of a rocket launched into space. During a rocket launch, momentum is conserved, the net force is increasing and the acceleration is increasing.
- Objects in uniform circular motions, such as satellites orbiting the Earth, have a centripetal force directed towards the centre that holds then in orbit and an instantaneous velocity that is tangent to the path.
- The two main types of orbits are geo-stationary orbits and low Earth orbits.
- Orbital velocity can be calculated by equating the centripetal force with the force of gravity.
- Satellites in low Earth orbit suffer from orbital decay due to air resistance.
- When returning to Earth from space several issues that must be taken into account are heat due to friction, large g-forces, ionisation black-out and angle of re-entry. If the angle is too shallow the space craft will bounce of the atmosphere and if it is too large the g-forces will be too great.
- Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill and von Braun contributed to the development of space exploration.
- The sling shot effect can change the speed and direction of space probes.
- The aether was thought to be the medium that light travelled through. It was the 'absolute' frame of reference. The Michelson Morley experiment attempted to measure the relative velocity of the Earth through the aether. The experiment obtained a null result. No relative motion existed.
- Newton's laws of motion are observed in inertial frames of reference. These are non-accelerating frames.
- The principle of relativity states that all inertial motion is relative and cannot be detected without reference to an outside point.
- The significance of this constancy of the speed of light is that time and space must be relative. This means that time and space must change depending on your speed.
- These days, length is defined in terms of time, rather than a pre-decided length.
- If two events appear simultaneous in one frame of reference, they are not necessarily simultaneous in another frame of reference.

- Mass and energy are equivalent. Mass can be converted into energy and vice versa. This is given by the equation, $E = mc^2$.
- At relativistic speeds, length contracts, mass increases and time slows. This has an effect on space travel.
- Imagine that you are sitting in a train facing forwards. The train is moving at the speed of light. You hold up a mirror in front of you, at arm's length. Will you be able to see your reflection in the mirror? Einstein said yes you would, but for this to happen space and time must vary for you.
- The two main pieces of experimental evidence for relativity are time dilation in atomic clocks are different speeds and muons produced in the atmosphere.

9.2 Review Questions

Q1. An object is stationary in space and located at a distance 10 000 km from the centre of a certain planet. It is found that 1.0 MJ of work needs to be done to move the object to a stationary point 20 000 km from the centre of the planet.

Calculate how much more work needs to be done to move the object to a stationary point 80 000 km from the centre of the planet. (3 marks)[1]

Solutions on page 138.

9.2 Tough Problems

Q1. An astronaut is standing on the surface of Mars. The acceleration due to gravity on the surface of Mars is $3.7\ \mathrm{ms}^{-2}$. The astronaut weights herself using her bathroom scales from that were designed for use on Earth. Her scales say that her mass is $26.4\ \mathrm{kg}$.

a. Obviously this mass is wrong, what her actual mass?
b. The astronaut realises that she can correct the reading by multiplying it by a constant. Find this constant.

Q2. The formula for acceleration due to gravity, $g = \frac{GM}{r^2}$, only works for values of r that are on or above the surface of the Earth. The formula does not work when you are deep down inside Earth. Derive an equation for acceleration due to gravity that works when you are inside the Earth. (Assume that the Earth has uniform density and is a perfect sphere.)

Q3. The equations for projectile motion described in this topic assume that the gravitational field lines are parallel. But in fact they are not; they are just very close to parallel. The discrepancies begin to arise when the projectiles are fired at huge speeds. Derive the equations of projectile motion that take into account the radial gravitational field lines of Earth.

[1] From 2006 HSC Physics Exam, Q18. © Board of Studies NSW 2006.

9.3 MOTORS AND GENERATORS

Contextual Outline:

Modern industrialised society is geared to using electricity. Electricity has characteristics that have made it uniquely appropriate for powering a highly technological society. There are many energy sources that can be readily converted into electricity. In Australia, most power plants burn a fuel, such as coal, or use the energy of falling water to generate electricity on a large scale. Electricity is also relatively easy to distribute. Electricity authorities use high-voltage transmission lines and transformers to distribute electricity to homes and industries around each state. Voltages can be as high as 5 × 105 volts from power stations but by the time this reaches homes, the electricity has been transformed to 240 volts. While it is relatively economical to generate electric power at a steady rate, there are both financial and environmental issues that should be considered when assessing the long-term impact of supplying commercial and household power.

The design of a motor for an electrical appliance requires consideration of whether it will run at a set speed, how much power it must supply, whether it will be powered by AC or DC and what reliability is required. The essentials of an electric motor are the supply of electrical energy to a coil in a magnetic field causing it to rotate.

The generation of electrical power requires relative motion between a magnetic field and a conductor. In a generator, mechanical energy is converted into electrical energy while the opposite occurs in an electric motor.

The electricity produced by most generators is in the form of alternating current. In general AC generators, motors and other electrical equipment are simpler, cheaper and more reliable than their DC counterparts. AC electricity can be easily transformed into higher or lower voltages making it more versatile than DC electricity.

This module increases students' understanding of the applications and uses of physics and the implications of physics for society and the environment.

1. Motors use the effect of forces on current-carrying conductors in magnetic fields

1. discuss the effect on the magnitude of the force on a current-carrying conductor of variations in:

– the strength of the magnetic field in which it is located

$\uparrow B = \uparrow F$

– the magnitude of the current in the conductor

$\uparrow I = \uparrow F$

– the length of the conductor in the external magnetic field

$\uparrow l = \uparrow F$

– the angle between the direction of the external magnetic field and the direction of the length of the conductor

$\uparrow \theta = \uparrow F$

Use $F = BIl \sin\theta$ to easily find the above.

2. describe qualitatively and quantitatively the force between long parallel current-carrying conductors:

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

We know that a wire with a current flowing though it will create a magnetic field around it. And we know that if we have two wires with current flowing though them that are parallel to reach other then the magnetic fields will interact and create a force on the wires.

If the current of the two wires is flowing in the **same** direction then they will **attract**. If the current is flowing in **opposite** directions they will **repel**. You can work this out by applying the right hand grip rule (see below) to the wires. If the current is in the same direction then the magnetic field will be in the same direction and the two wires will attract to create one big magnetic field. The opposite can be said when the current in the wires is in the opposite direction. The above formula only works for long wires.

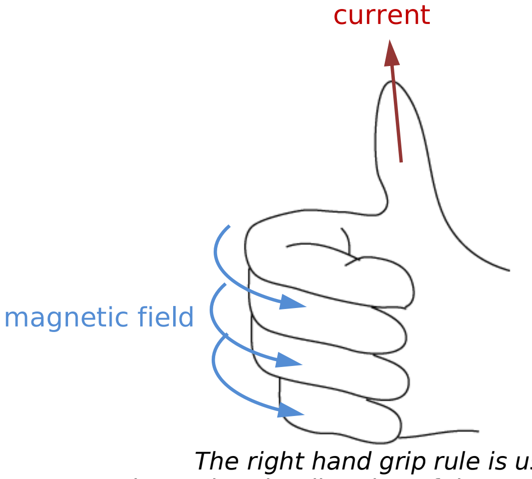


Fig. 47

The right hand grip rule is used to determine the direction of the magnetic field around a current carrying conductor.

The diagrams below show how the magnetic field surrounding two wires with the current in the same direction result in the attraction of the wires, and when the current is in opposite direction they repel.

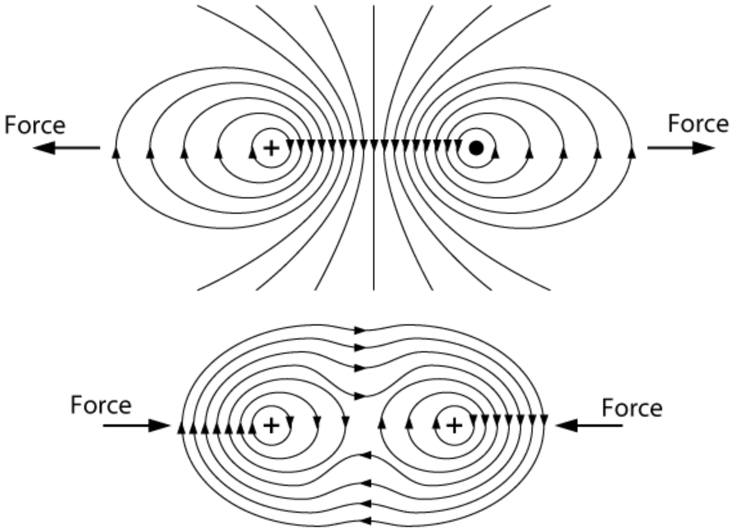


Fig. 48

Diagram adapted from '*Motors and generators*' produced by Learning Materials Production, OTEN.

The force between these two wires is given by,

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

3. define torque as the turning moment of a force using:

$\tau = Fd$

Torque is just a turning moment.
τ = torque (Nm)
F = force (N)
d = perpendicular distance (m)

Consider the situation below, a force of 3 N is acting on a block of wood that is pivoted. To calculate the torque we can either use $\tau = \sqrt{2} \times 3 = 3\sqrt{2}\,\text{Nm}$, or $\tau = 2 \times 3\cos 45° = 3\sqrt{2}\,\text{Nm}$.

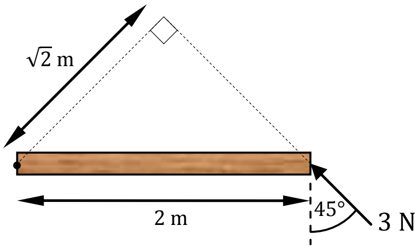


Fig. 49

Torque is important when dealing with motors as it determines the turning moment of the motor.

4. identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field

The motor effect is the action of a force experienced by a current carrying conductor in an external magnetic field.

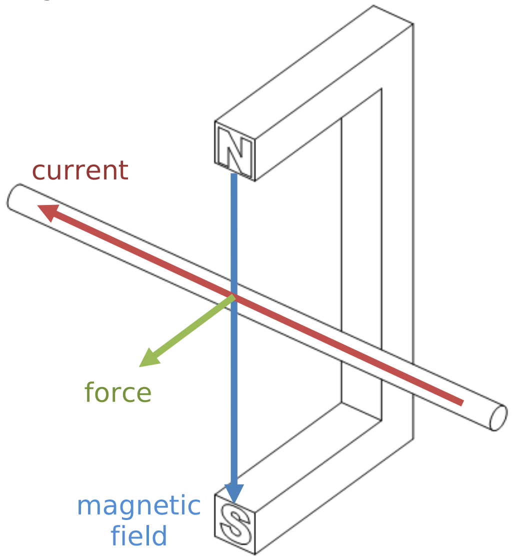
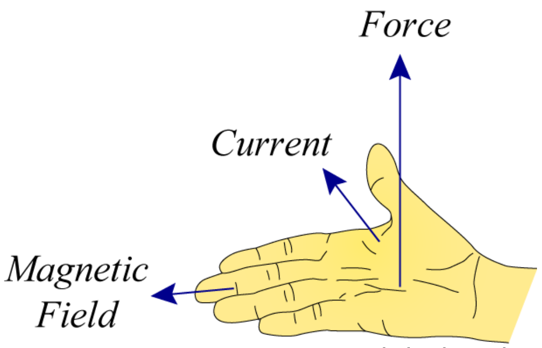


Fig. 50

The direction of the force can be determined by the right hand push rule. Remembering that magnetic field lines go from north to south. The magnitude of the force can be determined by $F = BIl\sin\theta$

The motor effect is the basis of a motor, in which two opposite forces on opposite sides, create a torque, creating a spinning motion used in motors.



Right hand push rule.
Fig. 51

5. describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces

If a current is flowing though the coil and an external magnetic field is present then there will be forces acting on the coil. That is, each side of the coil that is perpendicular to the magnetic field will experience a force due to the motor effect. By the right hand palm rule, the left side (in the diagram below) will experience a force down, and the right will experience a force up. Together these forces create a turning moment. The coil will experience maximum torque at this point.

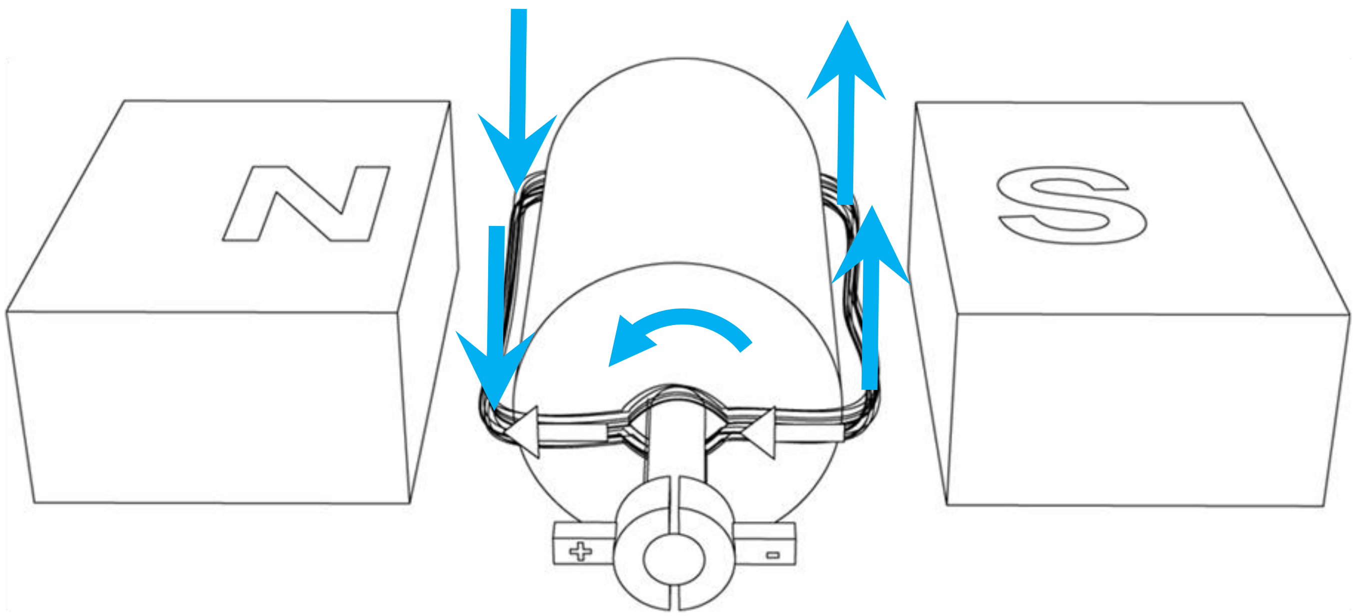


Fig. 52 - *In a motor, the two sides will experience a force that together creates a turning force, a maximum force occurs when the plane of the coil is parallel to the magnetic field.*

When the coil has rotated to the position shown below, then the two forces for both sides of the motor will be acting in opposite directions along the same line of action and hence they will cancel each other out. However momentum pushes the coil past this point, along with the change in direction of the current due to the split ring commutator, the coil will start to experience a turning force again.

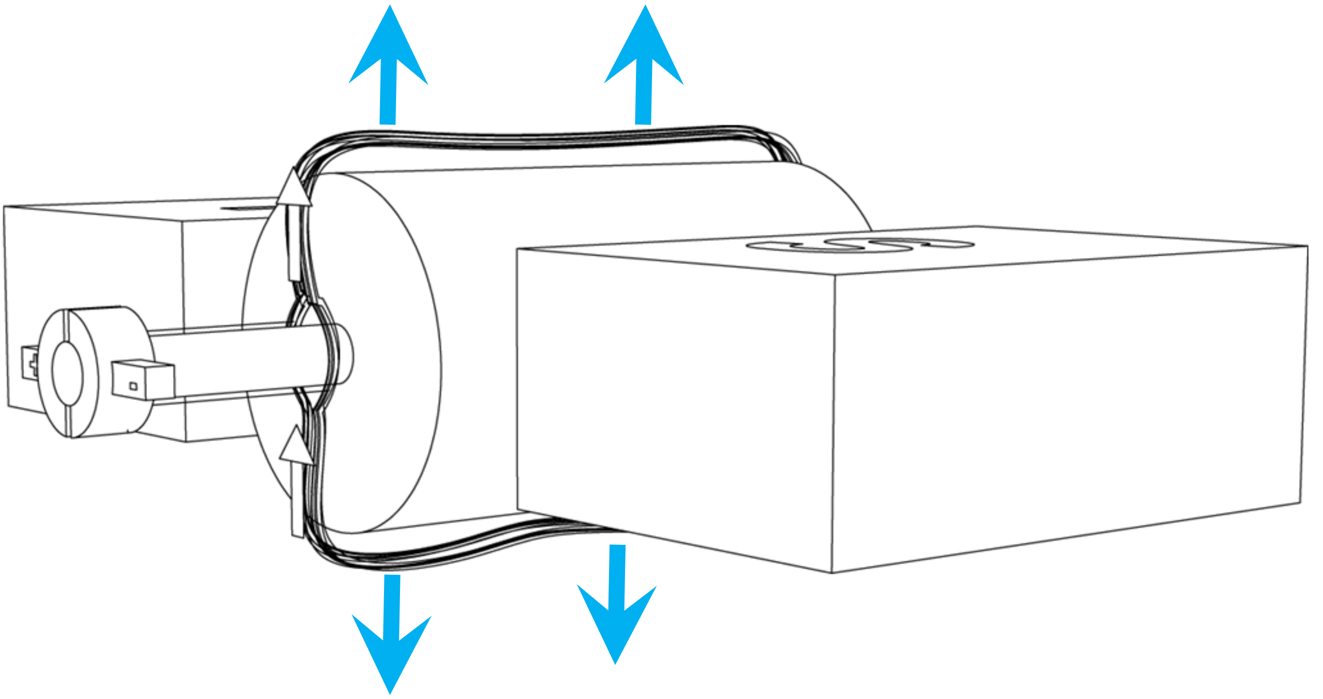
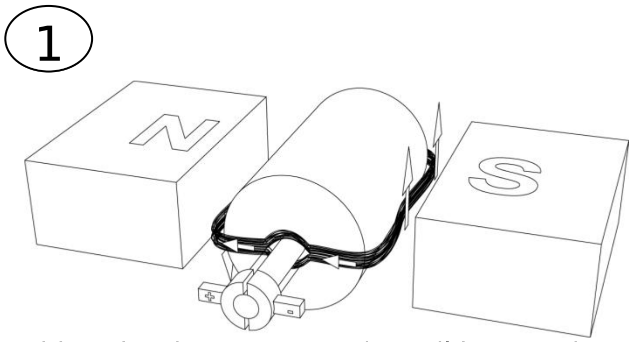
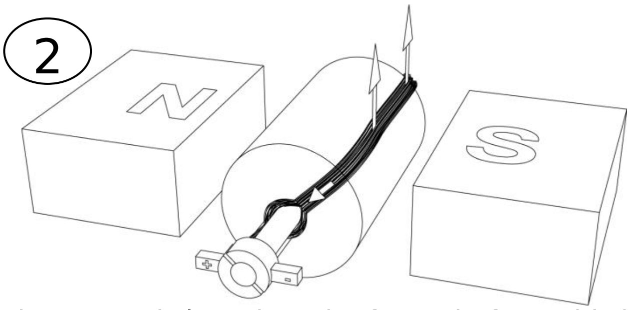


Fig. 53 - *In a motor, there will be no net force on the coil when the plane of the coil is perpendicular to the magnetic field.*

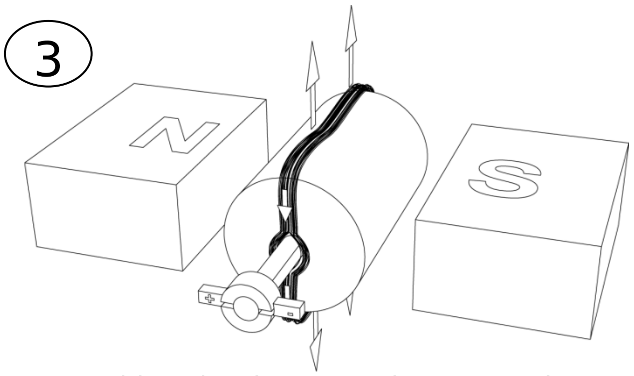
The diagrams below show the operation of a DC electric motor.



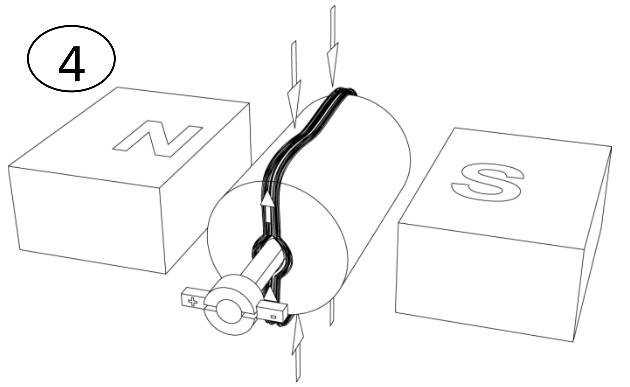
At this point the torque on the coil is a maximum.



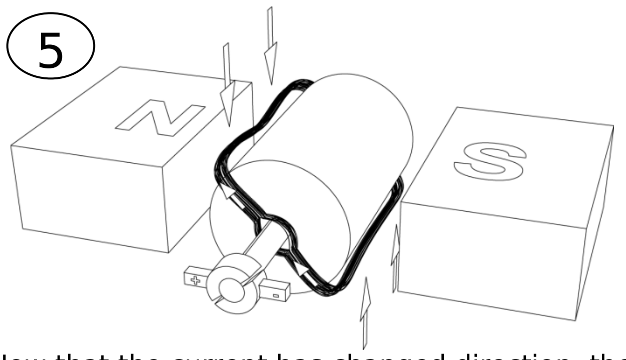
The torque is less than the frame before. This is because torque is force multiplied by the perpendicular distance. You can think of this as either the distance becoming less, or just taking the perpendicular component of the force, but either way the torque is less.



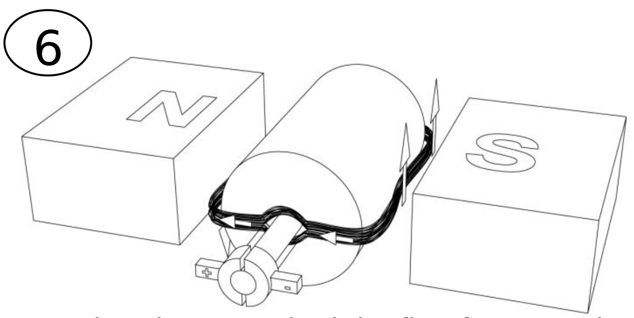
At this point the torque is zero, as the perpendicular distance is zero. Also at this point the current changes direction, which is shown in the next frame.



The current has changed direction. Now although the net force acting on the coil is zero, momentum keeps it turning past this point.



Now that the current has changed direction, the torque keeps the coil turning in the same direction.



… and we have reached the first frame again.

You will notice that the torque on the coil looks like this:

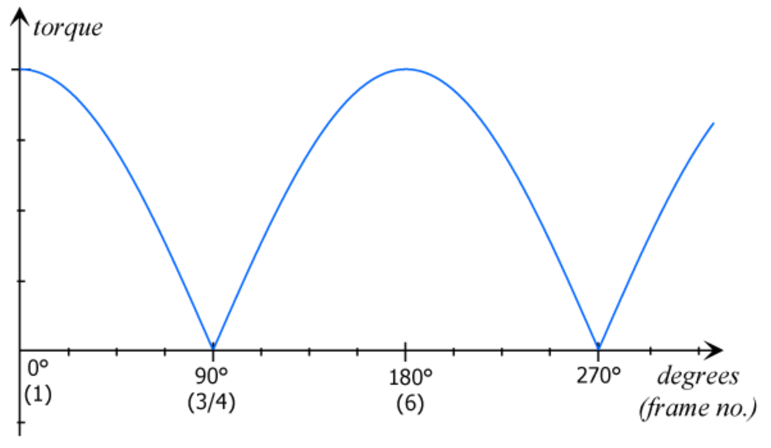


Fig. 54

6. describe the main features of a DC electric motor and the role of each feature

The DC electric motor uses the motor effect to create a continuous spinning motion. The main features of a DC electric motor are shown below.

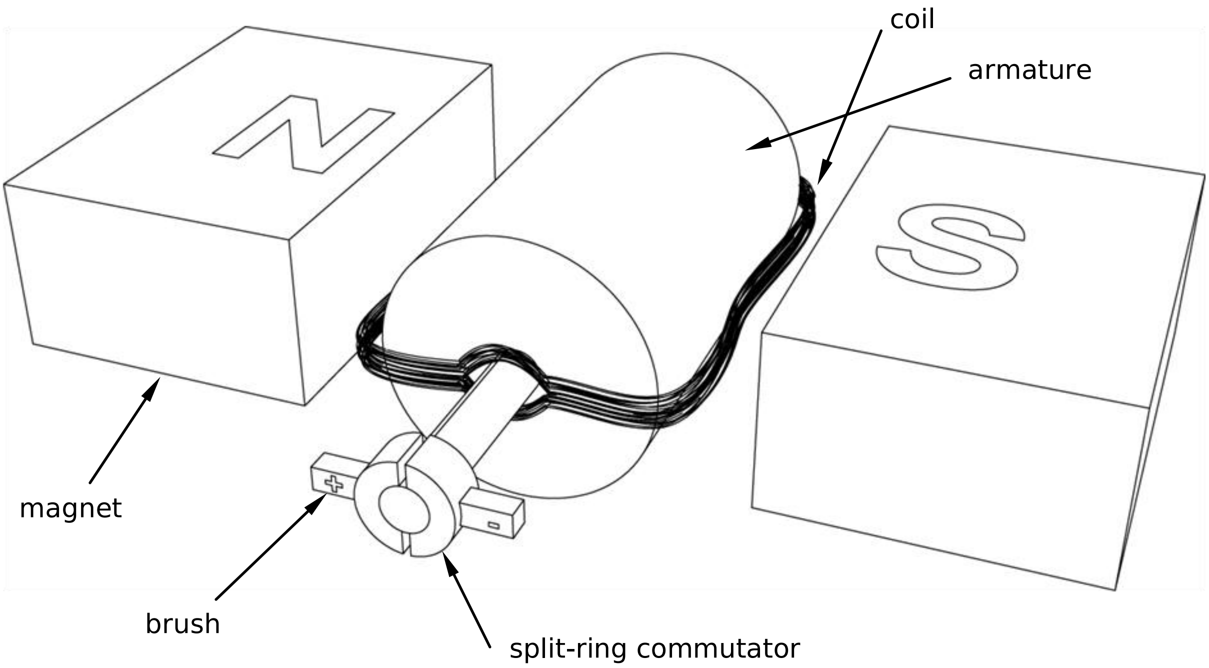


Fig. 55

A motor must have a magnetic field to work. This field is provided by either permanent **magnets** or electromagnets. Remember that magnetic field lines travel from north to south.

If you apply the right hand push rule to the two wires currents perpendicular to the magnetic field lines you will find that the two side push in opposite directions, which act together to rotate the coil. However the force will act in such a way that the plane of the coil is kept perpendicular to the magnetic field lines. So to prevent this, the **commutator** is used. By changing the direction of the current at the right time thus changing the direction of the force, and thus it will spin continuously. Momentum will move the coil past this point when it is perpendicular to the magnetic field, as at this point the forces cancel out and the coil will not spin.

The **brushes** just keep the current flowing into the commutator, without sparking. They allow a sliding contact with the commutator, allowing them to be stationary while the commutator is spinning.

The **armature** is the thing that the coil is wrapped around. This is usually iron. It gives the coils mass, resulting in momentum, and also holds the coils in place. Without the armature if the force is too great then the coil will bend and not turn the thing that the motor is trying to turn.

A **current** must also be present in the coil.

7. identify that the required magnetic fields in DC motors can be produced either by current-carrying coils or permanent magnets

The magnetic field in a DC motor can be produced using either a permanent magnet, or an electromagnet (made using a current-carrying coil and an iron core). If an electromagnet is used it is placed parallel to the commutator.

1. solve problems using:

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

Where,
F = Force (N)

l = Length of wire (m)
k = Magnetic force constant (on data sheet)
I_1 = Current in first wire (Amps)
I_2 = Current in second wire (Amps)
d = Distance separating wires (m)

2. perform a first-hand investigation to demonstrate the motor effect

The apparatus shown below is set up, where a wire is placed on an electronic balance. The wire is connected to a variable power source. Permanent magnets are placed on either side of the wire as shown. When no current is passed though the wire the electronic balance is zeroed. Now a current is passed though the coil, depending on the direction of the current the electronic balance will measure a positive or negative value. However the value has changed meaning the wire is experiencing a force. This shows the motor effect.

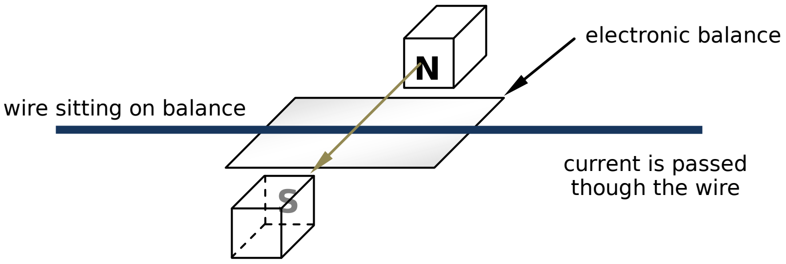


Fig. 56

3. solve problems and analyse information about the force on current-carrying conductors in magnetic fields using:

A current carrying conductor in a magnetic field creates a force.

$$F = BIl \sin\theta$$

Where,
F = Force (N)
B = Magnetic field strength (T)
I = Current in wire (Amps)
l = Length of wire (m)
θ = Angle between current and magnetic field (when using the right hand palm rule, this is the angle between the thumb and fingers.)

The direction of the force can be obtained by applying the *right hand palm/push rule*.

You should note that the formula $F = BIl\sin\theta$ is a simplification of $\boldsymbol{F} = I\boldsymbol{l} \times \boldsymbol{B}$.

4. solve problems and analyse information about simple motors using:

$$\tau = nBIA\cos\theta$$

Where,
τ = torque (Nm)
n = number of coils
B = magnetic field strength (T)
I = current (A)
A = area of coil (m^2)
θ = angle (angle between magnetic field lines and plane of coil)

We can easily derive this result. Take the diagram below as an example. The magnetic field will go from north to south, and from the result $F = BIl\sin\theta$ we know that only the parts of the wire of length l will experience a force, and that the magnitude of this force will be $F = BIl$. Each side will experience a torque given by $\tau = Fd$. We can replace F, however we only want the perpendicular component of F so we need to add a $\cos\theta$ to the end. This leads to $\tau = BIld\cos\theta$. Now this is the torque on one side, but both sides will have the same torque so the total torque will be given by $\tau = 2BIld\cos\theta$. Now we know that $2dl = A$, where A is the area, so $\tau = BIA\cos\theta$. This is for one loop, if we add more loops then the formula becomes $\tau = nBIA\cos\theta$.

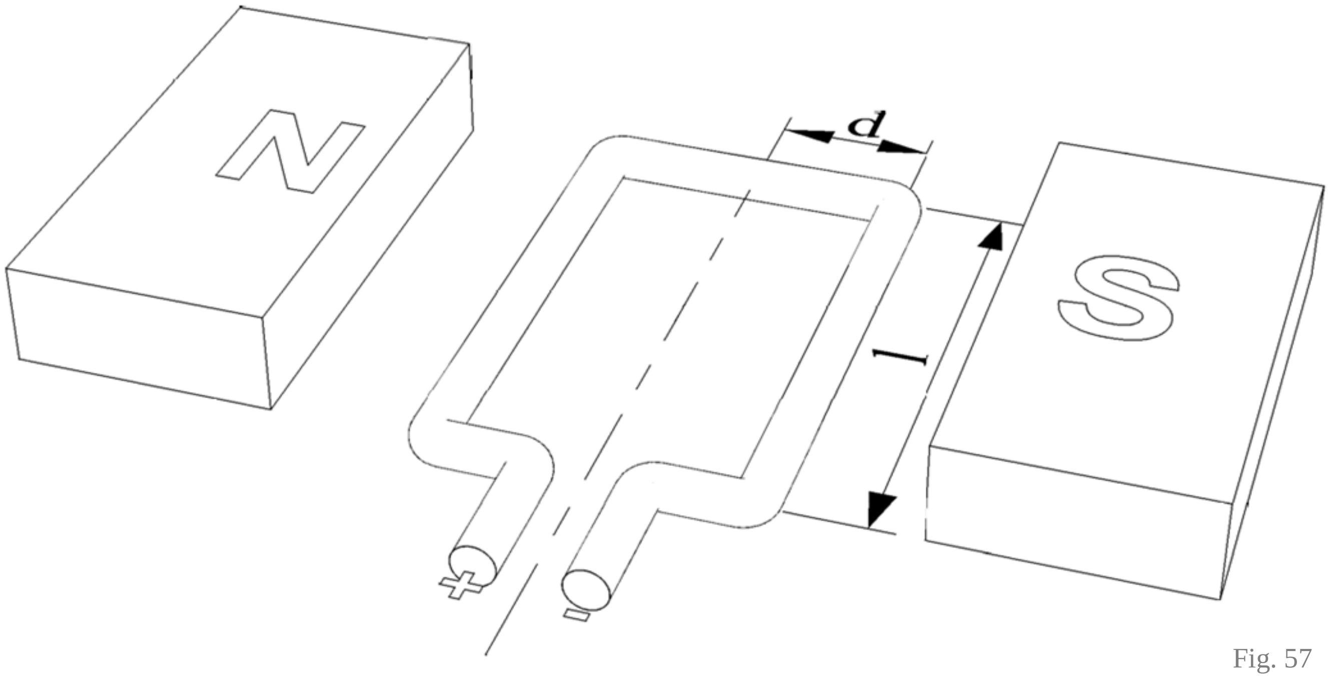
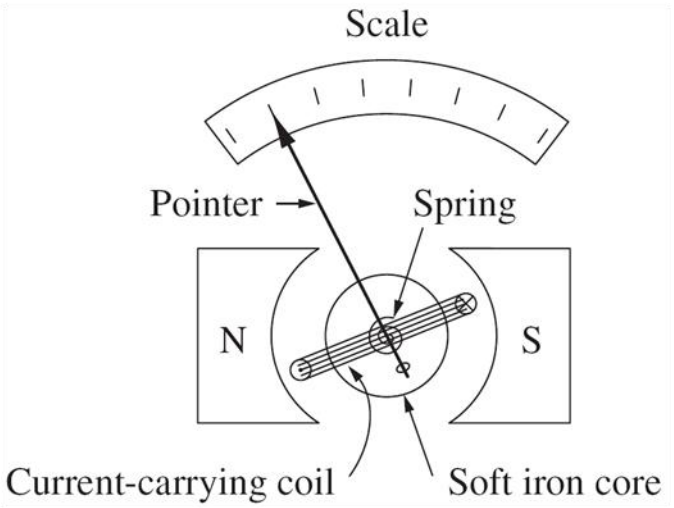


Fig. 57

5. identify data sources, gather and process information to qualitatively describe the application of the motor effect in:

– the galvanometer

A galvanometer is used to measure the magnitude and direction of direct current (**DC**). It uses the motor effect to do this.



Source: 2006 NSW HSC Physics Exam, © Board of Studies NSW 2006

Fig. 58

When a current is applied the pointer and coil will turn. It has a spring in it so that it will return to zero, and so that the force has something to push against. It can go both ways showing the direction of the current. The magnets used are shaped so that the field is perpendicular to the plane of the coil. This allows a uniform scale. The angle used in the force on a wire formula is constant as the sides of the coil are straight up and down. As the force on the coil = $BIl\sin\theta$, and as $\sin\theta$, l and B are constant, Force $\propto$ Current.

– the loudspeaker

Speakers create sound waves from electrical impulses. The motor effect in the speaker is used for movement in 1 dimension, not a spinning motion like the DC electric motor. When a current is present in the coil, and a magnetic field, the coil will have a force pushing it out. The spring brings it back in to normal position. This movement creates sound waves.

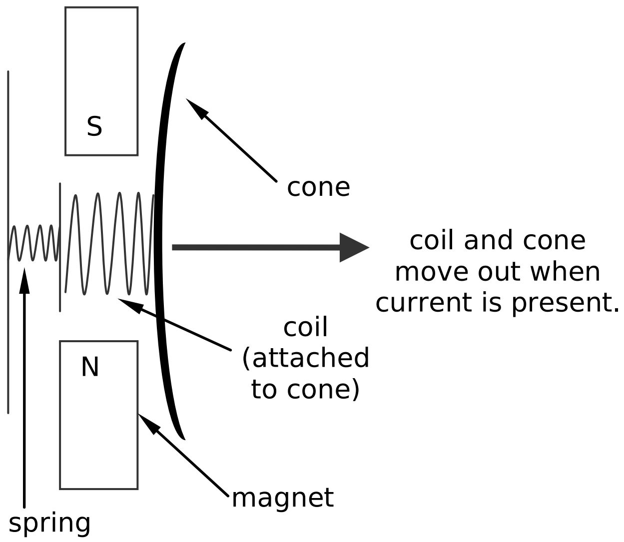


Fig. 59

2. The relative motion between a conductor and magnetic field is used to generate an electrical voltage

1. outline Michael Faraday's discovery of the generation of an electric current by a moving magnet

When a magnet is moved in and around a coil, an electric current will be generated in the coil. This is the opposite of the motor effect, and the process is known as induction, in which relative motion between a conductor and a magnetic field is supplied and a current is produced. The same formula is used as with the motor effect, ie. $F = BIl\sin\theta$.

Michael Faraday discovered this phenomenon by moving a magnet through a coil of wire. He noticed that when he moved the north end of a magnet towards the coil a current was induced and that when he pulled this north end back away from the coil a current in the opposite direction was induced. The same things happened with the south end of the magnet, but the current was in the opposite direction. He found that a current in the wire was induced to create a magnetic field to repel the magnets magnetic field.

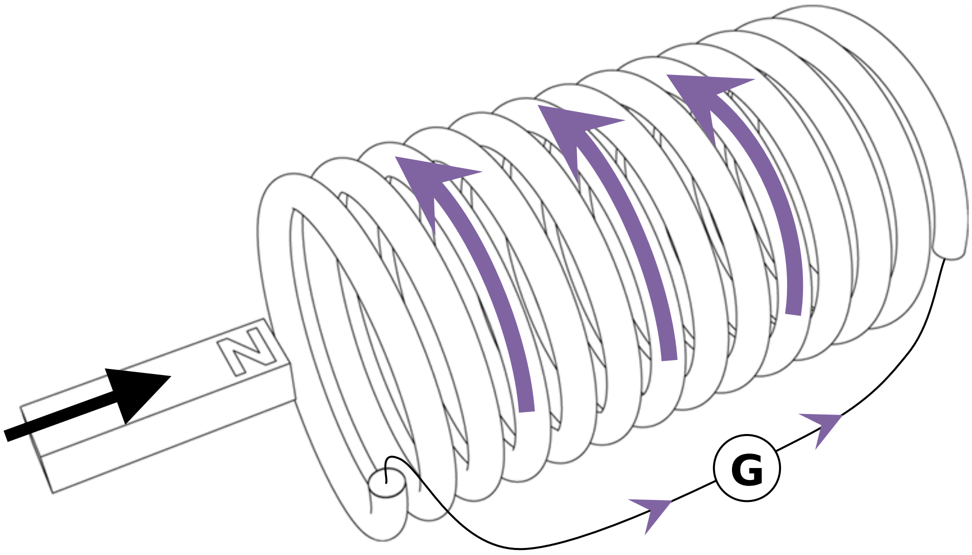


Fig. 60

See blue dot point 1 for an explanation of how to determine the direction of the induced current.

2. define magnetic field strength B as magnetic flux density

The B used in the following formulae,

$$F = BIl\sin\theta$$

$$\tau = nBIA\cos\theta$$

, is the magnetic field strength, which is also known as magnetic flux density. They are the same thing. B is measured in T (Telsa), or Weber per square metre (Wb m^{-2}).

When drawing magnetic fields, the higher the magnetic field strength (magnetic flux density) then the more closely the field lines are together, and vice verse. *(see next dot point)*

3. describe the concept of magnetic flux in terms of magnetic flux density and surface area

Magnetic Flux (measured in Wb) is the Magnetic Flux Density (measured in T OR Wb m^{-2}) for a given surface area.

Magnetic Flux Density deals with the strength of the overall field. And **Magnetic Flux deals with the strength of the magnetic field inside a given surface area**, this area is usually the area of a coil of wire.

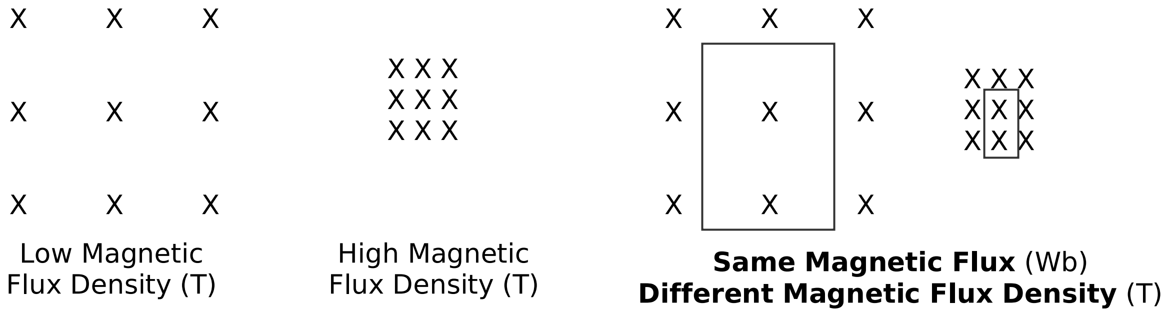


Fig. 61

So to calculate magnetic flux, multiply the normal magnetic flux density component by the area through which the magnetic field lines are passing.

$$\Phi_B = B_{\perp}A$$

4. describe generated potential difference as the rate of change of magnetic flux through a circuit

The induced emf (or generated voltage) is equal in magnitude to the rate at which the magnetic flux through the circuit is changing with time (commonly expressed as, the magnitude of the emf ε induced in a conducting loop is equal to the rate at which the magnetic flux through that loop changes with times). This is in the opposite direction as per Lenz's law, and indicated by the negative sign.

$$\text{generated potential difference} = -\frac{\text{change in magnetic flux}}{\text{time}} \times \text{number of turns}$$

$$\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}n$$

This result can be interpreted graphically as the generated voltage equals the negative of the slope of the tangent of the graph of a magnetic flux vs. time graph. For example in the magnetic flux vs. time graph below, the negative of the slope of the graph tells you the generated potential difference. So at $t = 1, 3, 5$ the voltage will be zero (because at these points the tangent to the curve has a gradient of zero), and at $t = 1, 4$ the voltage will be the greatest in a negative direction (the gradient is greatest and positive, but emf is the negative of the slope) and at $t = 2, 6$ the voltage will be the greatest in a positive direction.

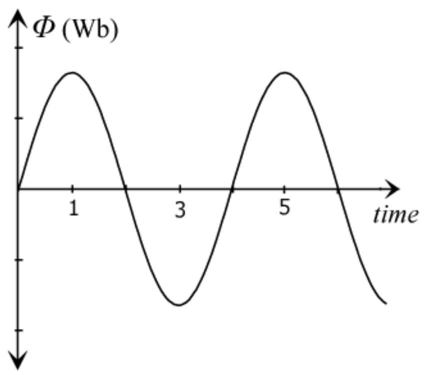


Fig. 62

5. account for Lenz's Law in terms of conservation of energy and relate it to the production of back emf in motors

Lenz's Law states that an induced current is always in a direction such that its magnetic field opposes the changing field that created it.

Lenz's Law is a result of conservation of energy. We know that energy cannot be created or destroyed and as you will soon see we need Lenz's Law for this to be true for induction. Suppose we have a changing magnetic field which produces a current, we know this will happen because of induction. But this current generated will also produce its own magnetic field. Now if this magnetic field from the current is in the same direction as the original changing magnetic field, then an even bigger magnetic field would be present and this larger magnetic field would in turn induce more current, which would in turn produce a larger magnetic field and so on. As you can see this would result in the current becoming larger and larger and larger, and the magnetic field becoming stronger and stronger and stronger. This would mean that you get all this energy from nothing.

As this cannot happen, the induced current must be in such a direction that the magnetic field produced by this induced current opposes the original magnetic field. This is what Lenz's Law states.

Let's take a closer look at the motor. In a motor, a current is supplied and this current in the presence of a magnetic field causes the coil of wire to spin. But because the coil is spinning we have relative motion between a conductor and a magnetic field and this will induce a current in the wire. Now if the current induced in the wire was in the same direction as that of the supplied current then the current would get larger and so the speed of the coil would get faster and so then the current would become even larger. This would result in the speed of the coil spinning and the current in the wire just getting larger and larger and larger. But again this means that you have got energy from nothing which is against the law of conservation of energy. And so the current induced in the coil due to the coil spinning in the presence of a magnetic field, which is known as back emf, will be in the opposite direction to the supply emf which means that energy of the system is conserved.

When the coil of a motor rotates, a back emf is induced in the coil due to its motion in the external magnetic field.

6. explain that, in electric motors, back emf opposes the supply emf

As explained above, in the coil of a motor, due to Lenz's law the supplied emf is resisted or opposed by induced emf or back emf.

Fig. 63

emf is voltage. In a motor as you have a changing magnetic field relative to a current carrying conductor, due to Lenz's law a back emf will be generated to oppose this changing magnetic field. As it will oppose a back emf will be generated.

If no back emf was present in a motor, then the motor will just keep getting faster and faster, this opposes the law of conservation of energy, and so thus an opposing emf, a back emf is produced.

The net emf equals the supplied emf minus the back emf,

$$\text{net emf} = \text{supplied emf} - \text{back emf}$$

In an ideal motor with no friction the motor will speed up until it has enough speed so that the generated back emf equals the supplied emf. At this point the net emf is zero and so as there is no current in the coil there are no forces acting on the coil. Now remembering that this is an ideal motor with no friction, if there is no force then the coil will just keep spinning at constant speed.

When the motion of the coil is resited, say by a load, then the coil will be spinning slower and so the back emf (which is induced due to the relative motion of a coil and a magnetic field) will be less. As the supplied emf is constant and as the back emf is less, the net emf will not be zero. It will be greater than zero. It is this non-zero net emf that allows for extra force (the greater the current then the greater the force ie. motor effect) to push against the load. If the load is too great then the motor slows and less back emf is generated and the net emf is too high. If this happens, the motor can overheat because the current is too high.

7. explain the production of eddy currents in terms of Lenz's Law

Eddy currents are produced by relative motion between a metal (not necessarily magnetic) and a magnetic field. They are small circular paths. Due to resistance eddy currents produce heat. These currents are produced to produce a magnetic field that, due to Lenz's law, opposes the original changing magnetic field.

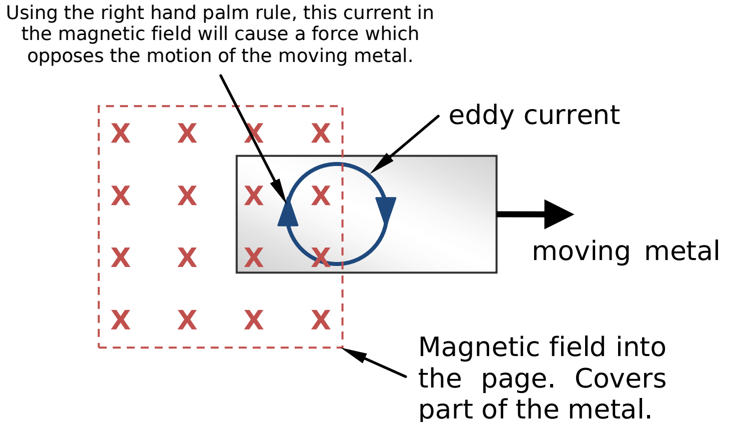


Fig. 64

An experiment can be done by dropping a magnet through a metal tube. The moving magnet induces eddy currents in the metal pipe. This is due to Lenz's Law. The eddy currents in the pipe create their own magnetic field to oppose the movement of the falling magnet. The diagram below shows a magnet falling though a metal tube. (part has been removed so we can see what's happening)

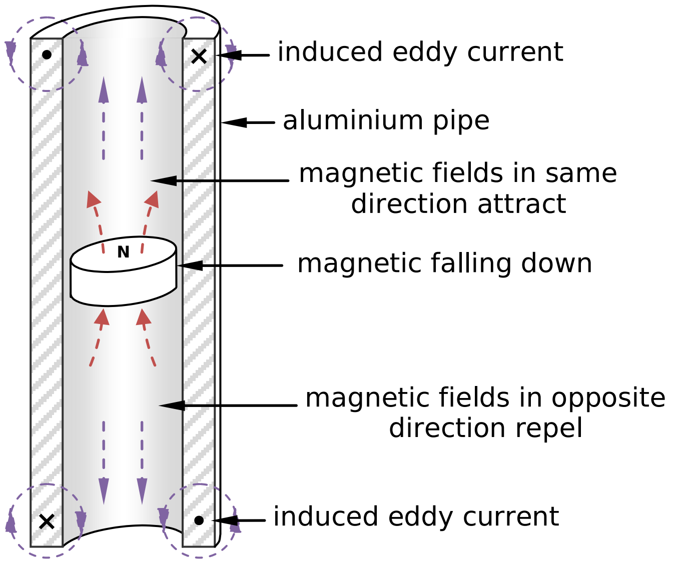
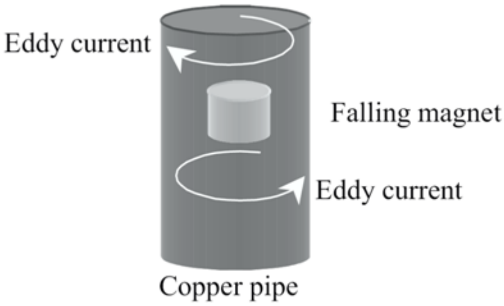


Fig. 65

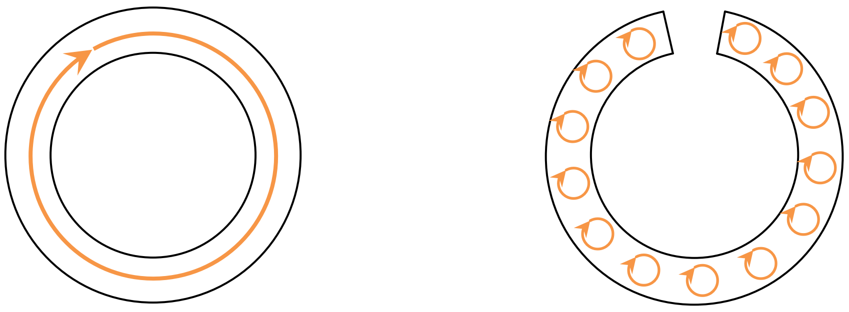
Another diagram that illustrates the production of eddy currents is below.



Motors and Generators, Joe Khachan and Chris Stewart
Science Teachers' Workshop 2002

Fig. 66

Another interesting experiment is when you compare a magnet falling though a metal tube and a metal tube with a slit in it. The diagram below show the top view of the tubes and the eddy currents induced.



Tube with no slit.
Big strong eddy currents
can be induced.

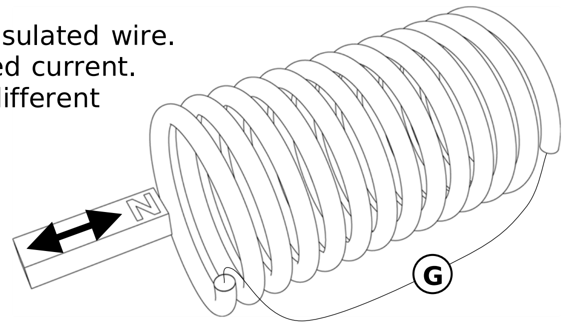
Tube with slit.
Only small eddy currents
can form, which are not as
strong as big eddy currents.

Fig. 67

The tube with no slit can generate big strong eddy currents which generate strong magnetic fields to oppose the motion of the falling magnet. However the tube with a slit cannot generate these big strong eddy currents. It can only produce small weak eddy currents, which do oppose the motion of the falling magnet, but not as much as the big strong eddy currents do.

1. perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet

A permanent magnet was moved in and out of a coil of insulated wire. The wire was connected to a galvanometer which measured current. This apparatus is shown to the right. The results of different situations are detailed below.



When the magnet was moved towards the coil as shown below, the coil generated a current to create its own magnetic field to oppose the changing magnetic field. That is it created a current which produced a magnetic field which repelled the approaching magnet.

Fig. 68

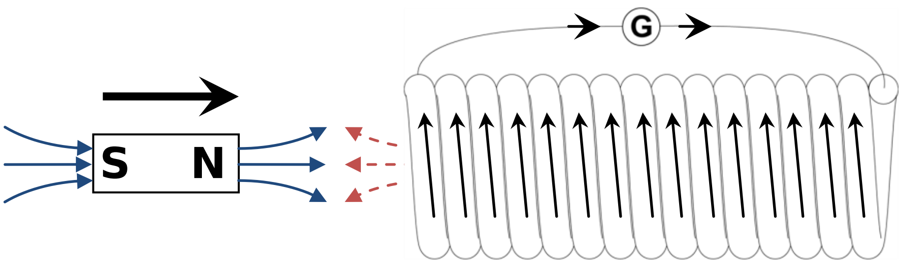


Fig. 69

When the magnet was in the middle of the coil (moving right), a current in the same direction as previously was induced, however a stronger current was measured as the magnetic flux is larger.

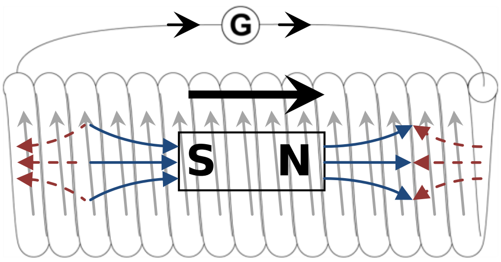


Fig. 70

Similarly, when the magnet left the coil, a current was induced in the same direction as previously. The strength of the induced current was the same as the first diagram.

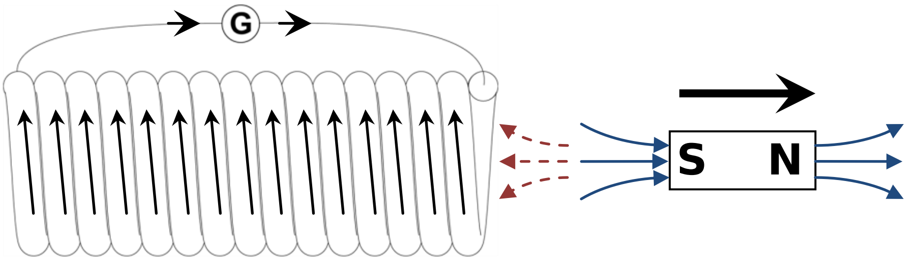


Fig. 71

It must also be noted that when the magnet was stationary, relative to the coil, no matter where it was there was no current generated. Also when the north and south poles were switched, the opposite happened. Also when the magnet shown in the diagrams above was moved from right to left (instead of left to right) (but with the same north-south orientation) the current induced was in the opposite direction.

Some factors that affected the strength of the induced current are:

- **Strength of the magnet.** The stronger the magnet, the greater the induced current.
- **Speed the magnet is moving.** The faster the magnet moves, the greater the induced current.

The direction of the induced current can be determined by using the right hand grip rule. From the preliminary course we know that when a current is present in a coil, a magnetic field will be present that goes through the middle of the coil. The direction of this magnetic field will be in the direction the right hand thumb is pointing when the curled fingers are pointing in the direction of the current (see diagram to the right). We also know that in a magnet the magnetic field goes out of the north end and into the south end. We now use the principle that the coil will induce a current to create a magnetic field that opposes the motion of the coil to work out which way the induced current will be.

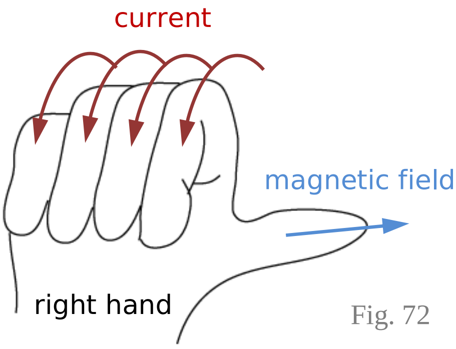


Fig. 72

2. plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when:

- the distance between the coil and magnet is varied

As the distance is increased the strength of the magnetic field decreases thus less current is induced.

- the strength of the magnet is varied

The stronger the magnet the greater the current induced.

- the relative motion between the coil and the magnet is varied

The greater the relative motion (ie. speed) the greater the current induced.

(the same experiment can be done as in blue dot point 1.)

3. gather, analyse and present information to explain how induction is used in cooktops in electric ranges

Induction cooktops use the fact that a conductor in the presence of a changing magnetic field will have induced eddy currents created to create a magnetic field to oppose the original changing magnetic field.

Induction cooktops have a coil below the cooktop. AC power is supplied through this coil which induced a changing magnetic field (DC power would not work as the magnetic field needs to be changing). The changing magnetic field from the coil induces eddy currents in the metallic pan/pot. Due to resistance, the eddy currents create heat which cooks the food. Because the heat is produced from the resistance from the eddy currents, it works best with metal pots/pans that are conductors (as larger eddy currents are induced).

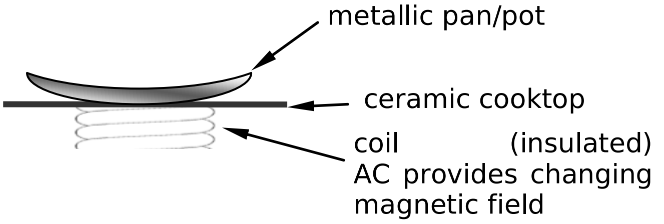


Fig. 73

Advantages of induction cooktops include:

- The cooktop itself does not get hot (only the pot/pan), so less danger of burns.
- As the heat is coming from the pan, less heat is lost, making it more efficient.

4. gather secondary information to identify how eddy currents have been utilised in electromagnetic braking

Eddy currents are used in electromagnetic breaking. The electromagnets will create a magnetic field that cuts the spinning disc. Now because of this relative motion between the magnetic field and the metal disc, by Lenz's Law the spinning disc will want to generate a current to produce its own magnetic field to oppose the magnets magnetic field. And so eddy currents will be created in the spinning disc which create their own magnetic field that opposes the original changing magnetic field. The repulsion of these two magnetic fields causes the spinning disc to slow.

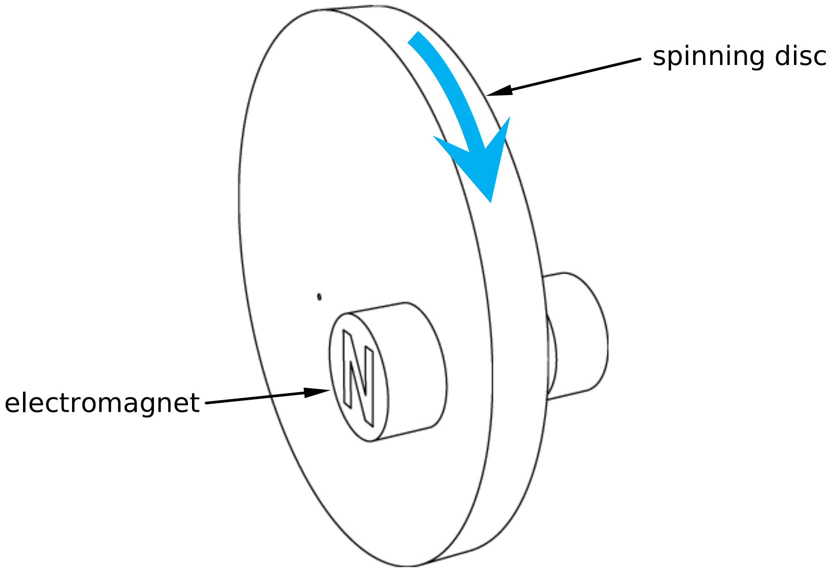


Fig. 74

Electromagnets are used because, unlike permanent magnets, they can be turned on and off. Also the strength of the magnetic field can be controlled by altering the current in the electromagnet, which allows for soft and hard breaking.

3. Generators are used to provide large scale power production

1. describe the main components of a generator

There are different types of generators and they each have slightly different components. There is the simple generator that is the same as the normal simple motor except that a turning motion is supplied and a current is generated. These generators have the same components as the motor.

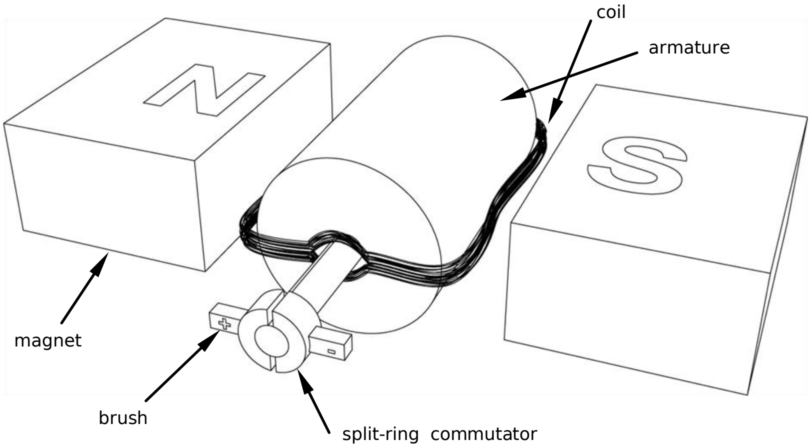


Fig. 75

The other main type of generator which is used in main power generators is detailed in the next dot point.

To determine the direction of the induced current in a wire, use palm rule, but using the left hand.

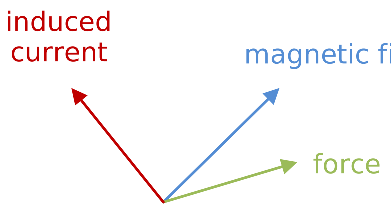


Fig. 76

The reason for this can be explained in terms of moving electrons in a magnetic field. Hence you can use the right hand, however you need to think of it in terms of moving electrons and force on those electrons.

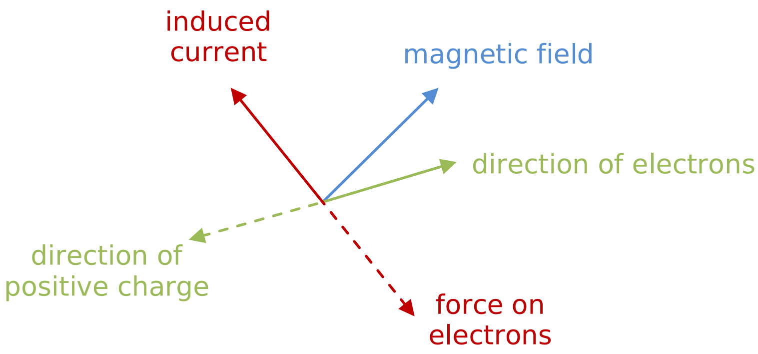


Fig. 77

2. compare the structure and function of a generator to an electric motor

A generator works in the opposite way to a motor. In a generator a moving coil (or moving magnetic field) is provided in the presence of each other which induces a current. In a motor a current is provided which creates a turning force, torque. The structure of motors and generators can be the same, however power station generators are different. A power station generator produces AC current. It has the magnetic field rotating inside a stationary coil.

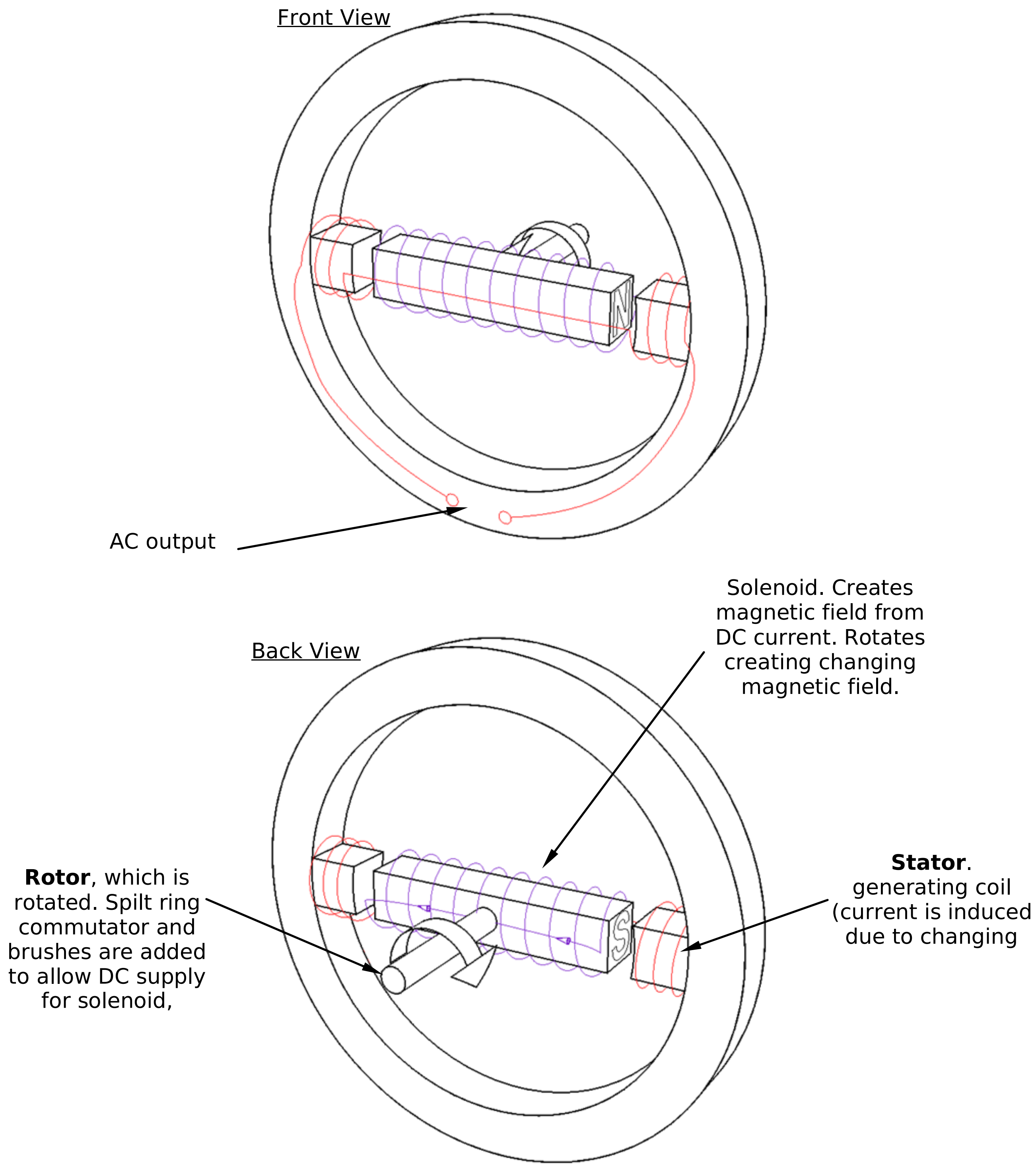


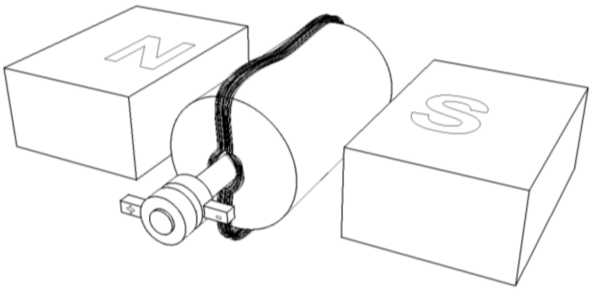
Fig. 78

To determine the direction of the current in a generator, the right hand push rule can be modified. Where fingers are the direction of magnetic field, thumb is the direction of turning motion and palm is the direction of the current in the wire.

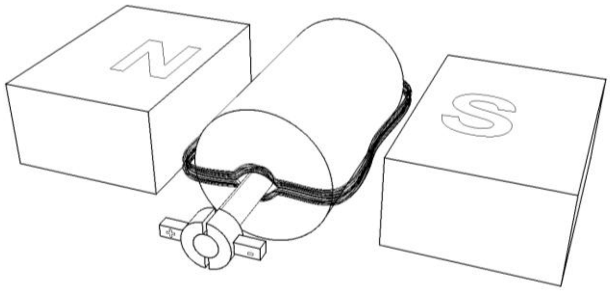
3. describe the differences between AC and DC generators

AC and DC generators produce different types of currents. Slip rings are used for AC generators, and split-ring commutators are used in DC generators. AC generators are preferred over DC generators because:

- Slip rings don't wear or break down as much as split ring commutators.
- Mains power is AC not change from DC to AC is needed.



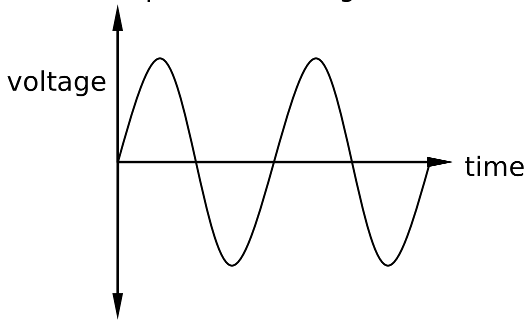
Basic AC Generator



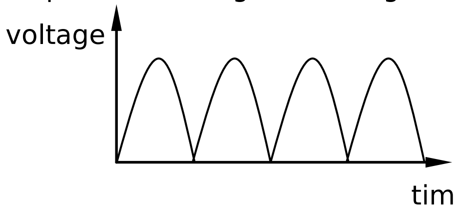
Basic DC Generator

Fig. 79

The output from a AC generator is:



The output from a single coil DC generator is:



The output from a multi coil (unrelated to number of coil loops) DC generator is (The graph is the sum of several loops out of phase added together):

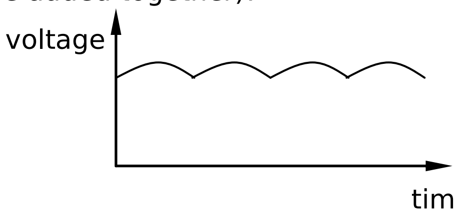


Fig. 80

4. discuss the energy losses that occur as energy is fed through transmission lines from the generator to the consumer

Electrical energy is lost through resistance of the wires. Because the wires are so long the resistance is huge. However the greater the voltage that the electricity is sent at, the less energy that is lost. That is why electricity in power lines is sent at such high voltages. $Power\ Loss = I^2 \times R$ Increasing voltage decreases current, thus less power is lost.

5. assess the effects of the development of AC generators on society and the environment

AC generators allow for the **production of AC electricity** which can be supplied to the public. This affects society greatly allowing for **lights** in houses and streets, and many other **electrical household appliances**. It has affected the environment because of the required **infrastructure** that has been built to support, generate and supply the electricity to homes. It has also affected the environment as the main source of the torque in AC generators comes from the **burning of fossil fuels** which contributes to the greenhouse effect. In contrast to that AC generators allow for production of energy from 'green' sources such as **hydroelectric and wind power** plants.

AC generators compared to DC generators have allowed for transformers to be used to change the voltage of electricity. This has allowed for different appliances to be used from the same source of electricity, making the use of electricity on a household level much simplified.

1. plan, choose equipment or resources for, and perform a first-hand investigation to demonstrate the production of an alternating current

An AC generator was used to produce alternating current. In which a coil was rotated in a magnetic field, and using slip rings the current induced will alternate every 360°.

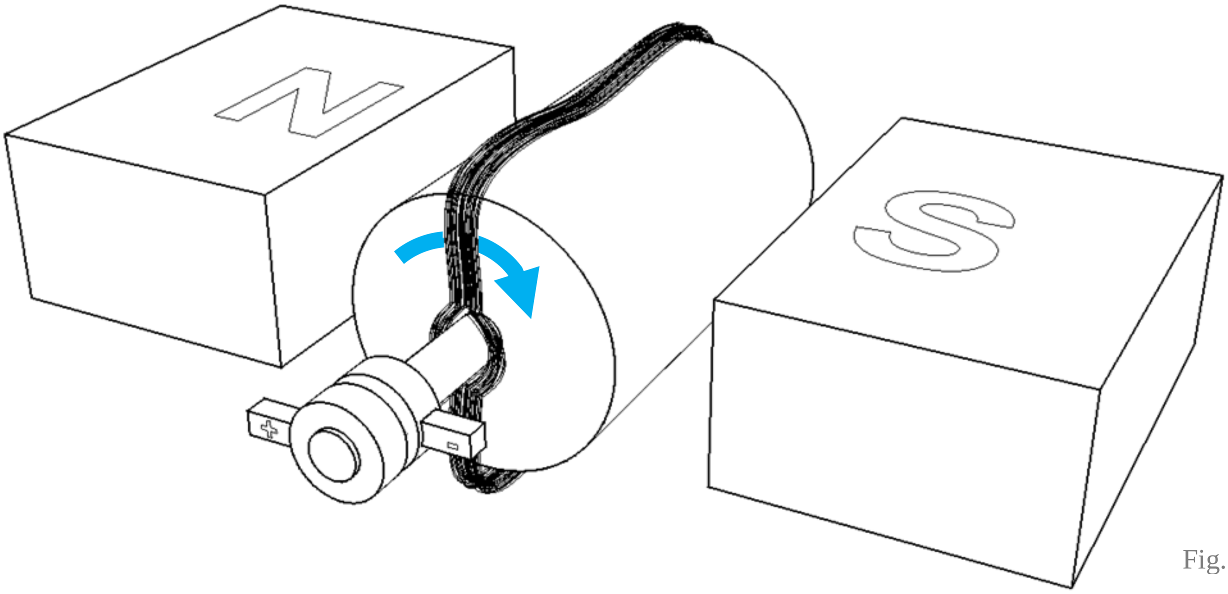


Fig. 81

In the school lab we used a generator shown below to produce an alternating current.

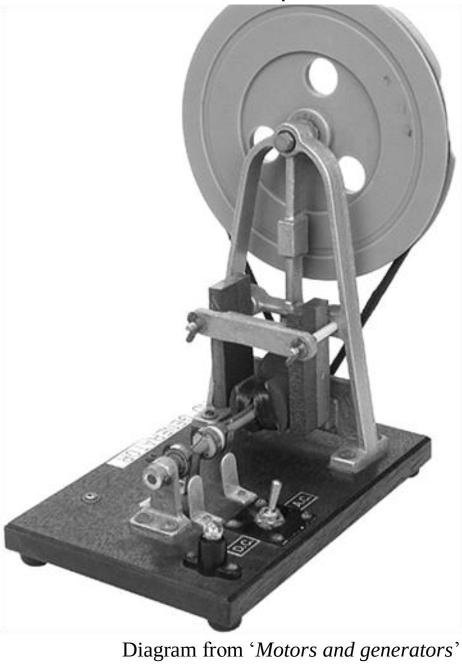


Fig. 82

Diagram from '*Motors and generators*' produced by Learning Materials Production, OTEN.

2. gather secondary information to discuss advantages/disadvantages of AC and DC generators and relate these to their use

AC Advantages

- Voltage can be stepped up and down.
- Can be transmitted at high voltage.
- Less energy loss in transmission.
- Simple slip rings are used.

AC Disadvantages

- Back emf opposes supplied emf.
- Emits EMR, so wires need insulation and shielding.
- Frequency must be sent to consumers at 50Hz. This has to be maintained and monitored.
- AC has a "skin-effect"; the electrons tend to travel at the edge of the conductor, which makes them slightly less efficient.

DC Advantages

- No shielding needed from EMR.
- Cheaper to produce cables.
- Magnetic field is stable so no back emf.
- Many appliances use DC.

DC Disadvantages

- Cannot be easily transformed (stepped up/down).
- Cannot be transmitted as easily.
- Split ring commutator needed in motors and generators, which wears more easily. Also it can spark.
- Discharge is more fatal.

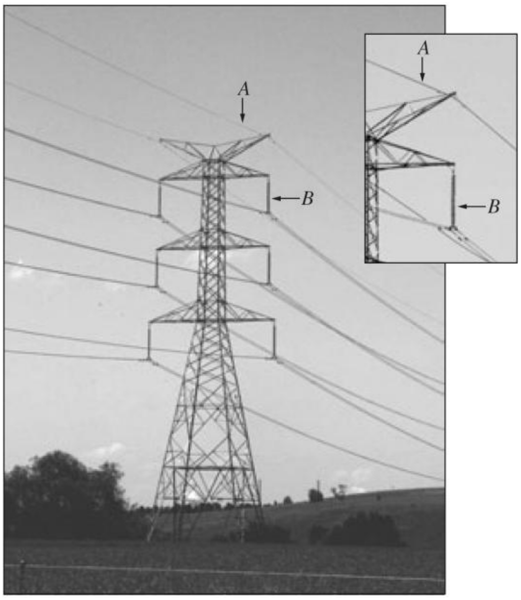
3. analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities

They each had different ideas as to what type of current would be delivered to the public.

- Edison → DC
- Westinghouse → AC

(See AC/DC advantages/disadvantages above)

4. gather and analyse information to identify how transmission lines are:



Source: 2004 NSW HSC Physics Exam
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Fig. 83

– insulated from supporting structures

As seen by B in the diagram, the transmission wires are separated from the tower by an insulator. Ceramic discs are mostly used.

– protected from lightning strikes

Sacrificial wires (A in diagram) hang above the transmission lines, if lightning strikes then the current from the lightning will pass through these wire and then down to earth at the next power pole. The actual transmission lines remain unaffected.

4. Transformers allow generated voltage to be either increased or decreased before it is used

1. describe the purpose of transformers in electrical circuits

Transformers are used in electrical appliances and circuits to change the voltage and current of the electricity. Voltage and current are directly related ($V = IR$), meaning if the voltage is increased the current decreases and vice versa.

2. compare step-up and step-down transformers

Transformers need alternating current (AC) to operate. This is because transformers need a changing magnetic field to work.

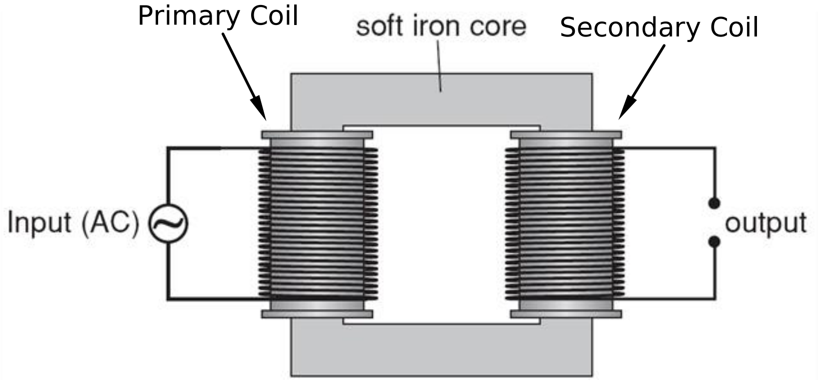


Fig. 84

Diagram adapted from '*Motors and generators*' produced by Learning Materials Production, OTEN.

As the AC power flows through the primary coil it will produce a changing magnetic field, provided by the alternating current. This field will be covering the secondary coil which due to Lenz's law will cause a current to flow in the secondary coil, to create its own magnetic field to oppose the original changing magnetic field. To change the voltage/current ratio the ratio of the number of loops in each coil is changed. This relationship can be seen in the next dot point. **Step-up transformers increase the voltage and step-down transformers decrease the voltage.** The soft iron core is used to intensify the magnetic field.

3. identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

Thus if there is more coil loops in the primary coil than the secondary, then the voltage in the secondary coil will be less than the primary.

As the power at the primary and secondary coil is the same. $P_p = P_s$, so $V_p I_p = V_s I_s$, so $\frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$.

4. explain why voltage transformations are related to conservation of energy

If you increase the voltage, the current decreases, and if you decrease the voltage, the current increases, this is because the total energy is conserved. This can be seen by the formula $Power = Voltage \times Current$. As power is just a rate of energy and as energy cannot be created or destroyed, the voltage to current ratio cannot change. And so an increase in voltage results in a decrease in current.

5. explain the role of transformers in electricity sub-stations

The greater the voltage that the electricity in transmission lines is, then the less power lost in transmission. So to avoid large loss of energy in the transmission lines, the voltage is sent out really high voltages from the power station. Because high voltage will mean low current, and $Power\ Loss = I^2R$. However these high voltages are much too large to be delivered straight to the consumer, so transformers in electrical sub-stations step down the voltage before it is delivered to the consumer. The larger the voltage the larger the transformer needed, so that is why there are many sub-stations, so that by the time the electricity gets to your local suburb only a small transformer is needed. It is also safer, as having high voltages in a local area poses a safety issue.

6. discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer

Mains power is 240V. For many appliances this voltage is too high or too low. So the appliance has a small transformer in it to change the voltage. eg. TV uses large voltages greater than 240V however an LCD screen needs only 12V.

7. discuss the impact of the development of transformers on society

Transformers have allowed **different voltage appliances** to exist. One of the main ways that this affects society is that many appliances can transform the mains 240V into much lower voltages and work fine, this affects society as it much **safer** for the person using the appliance. It also means that only one type of power point is needed and that a wider range of appliances can run of this same type of power point. Transformers have allowed **power stations to be further away** from the consumer, this means that precious city space is not taken up by power stations. This is because the electricity can be stepped up to high voltages to minimise power loss during transmission. Also as less power is lost in transmission, the electricity can be supplied more efficiently and the **cost to consumers is less**.

1. perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced

As the AC current flows through the primary coil, it will produce a changing magnetic field. This field will be covering the secondary coil which due to Lenz's law will cause a current to flow in the secondary coil. To change the voltage/current ratio the ratio of the number of loops in each coil is changed. This relationship can be seen in the next dot point. Step-up transformers increase the voltage, and step-down transformers decrease the voltage.

2. solve problems and analyse information about transformers using:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

This formula can also be extended to:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$$

3. gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome

Eddy currents are produced in the iron core in transformers. These eddy currents create heat due to resistance. To reduce the extent of heating,

- Transformers have **insulated layers (laminations)** in the iron core. This results in many smaller eddy currents forming instead of larger stronger eddy currents. These smaller eddy currents produce less heat than the larger eddy currents. Laminating the core will improve the efficiency of the transformer.

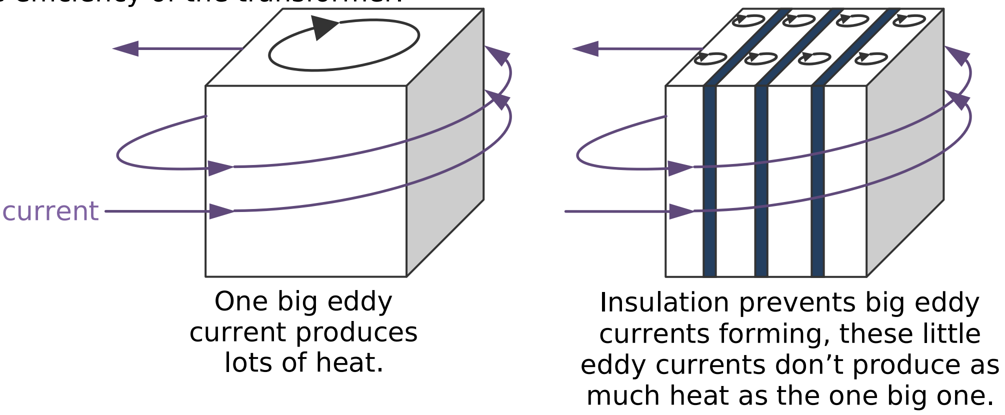


Fig. 85

- Transformers can use **ferrites** (iron ore (that is, iron with impurities in it)) in the core. Because these ferries are not good conductors of electricity, the eddy currents are smaller and produce less heat. Adding ferrites will improve the efficiency of the transformer.

- A **coolant** can be used, which will remove the heat produced. This does not minimise the amount of heat produced, hence the it does not affect the efficiency of the transformer, it does however prevent overheating of the transformer.

4. gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use

See students learn to: dot point 5.

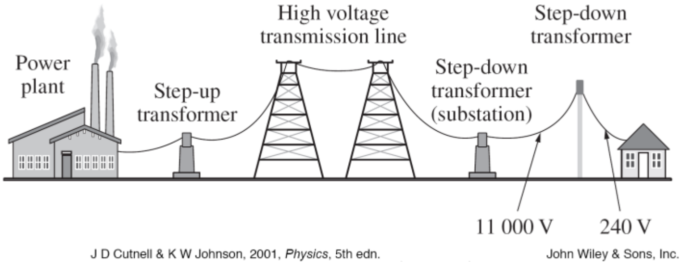


Fig. 86

5. Motors are used in industries and the home usually to convert electrical energy into more useful forms of energy

1. describe the main features of an AC electric motor

There are two main types of AC electric motors, the synchronous motors and induction motors. AC induction motors are the most common type of motor used.

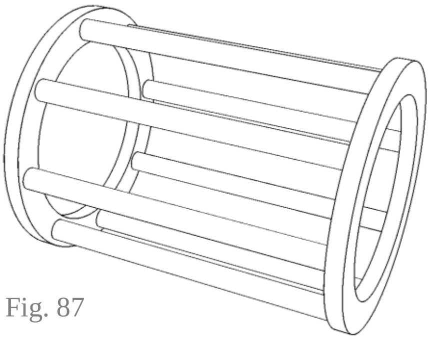


Fig. 87

The main features of an AC induction motor are the rotor (shown left) and the stator. There are no brushes or commutators. The stator is outside of the rotor. The stator uses AC supplied electromagnets to generate the changing magnetic field will induce a current in the rotor, and when a magnetic field and a current in the rotor is present, a force is applied to the rotor.

A synchronous electric motor is shown to the right and the features are the same as for the DC motor, with the exception that slip rings are used instead of a split ring commutator.

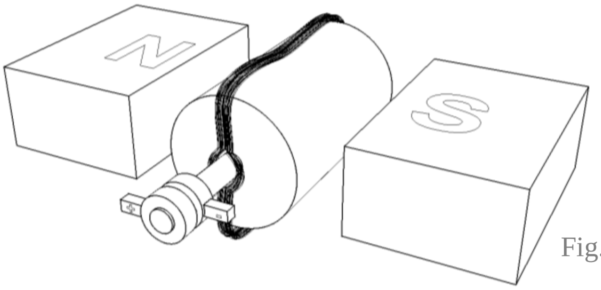
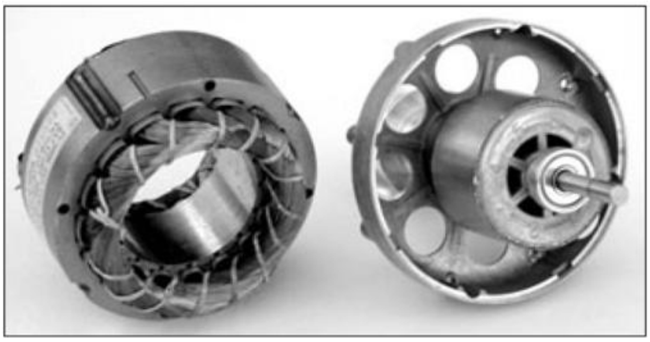


Fig. 88



Source: 2004 NSW HSC Physics Exam, p20, © Board of Studies NSW 2004

Fig. 89

1. perform an investigation to demonstrate the principle of an AC induction motor

A sheet of aluminium foil was placed on top of a pool of water. This allows the aluminium foil to move and spin. When a magnet above the foil is spun the aluminium sheet also spins. This is due to Lenz's Law, where the aluminium foil will induce eddy currents to create its own magnetic field which opposes the original changing magnetic field. The interaction of these two magnetic fields causes the aluminium foil to spin.

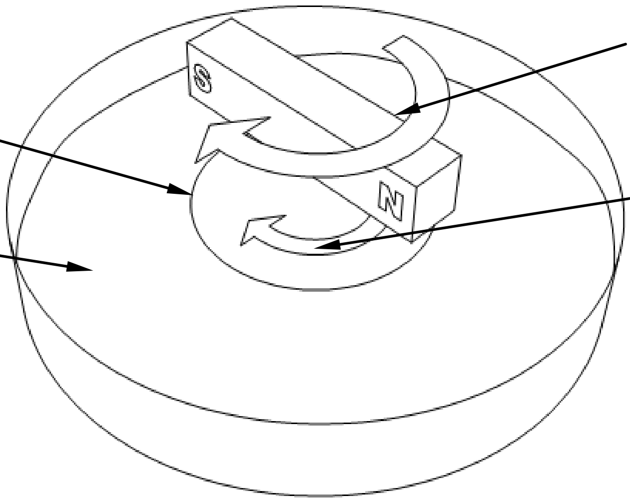


Fig. 90

2. gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry

Energy cannot be created of destroyed, it may only be changed from one form to another. For example in a hair dryer electrical energy is transformed into kinetic energy in the motor, heat energy in the thin heating wires, sound energy from the motor, light energy from the heating wires, and others. In industry electrical energy may be transformed into kinetic and sound energy in motors of power tools.

9.3 TOPIC REVIEW

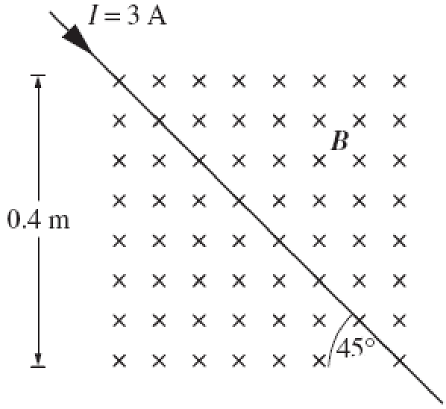
Summary

- A current-carrying conductor in a magnetic field will experience a force that is given by, $F = BIl\sin\theta$. This is known as the motor effect as this effect is how motors work. The direction of the force can be determined by using the right hand palm rule, there the fingers are the magnetic field, the thumb is the current and the palm is the force.
- Long parallel current-carrying conductors will experience a force given by, $\frac{F}{l} = k\frac{I_1 I_2}{d}$.
- Torque is a turning moment given by $\tau = Fd$ and $\tau = nBIA\cos\theta$ in a motor.
- In a current-carrying loop in a magnetic field, the two sides will experience a force in opposite direction which work together to turn the motor. The force on the coil will vary.
- A DC electric motor is made up of a coil of wire, permanent magnets or electromagnets, a slip ring commutator to change the direction of the current, brushes and an armature.
- The loudspeaker and galvanometer are applications of the motor effect.
- Faraday discovered induction, i.e. the generation of an electric current by moving a magnet around a coil of wire.
- Magnetic field strength is the magnetic flux density. This is different to magnetic flux which deals with the magnetic field inside the area of a coil (or a given surface area).
- A generated potential difference (or induced emf) is given by the rate of change of magnetic flux.
- Lenz's Law states that an induced current is always in a direction such that its magnetic field opposes the changing field that created it. The induced emf is known as back emf is induced due to conservation of energy. The same concept is responsible for the production of eddy currents.
- Induction is used in induction cooktops and eddy currents are used in electromagnetic breaking.
- A generator works the opposite to a motor. AC generators use slip rings and DC generators use split ring commutators.
- Energy is lost in transmission lines due to resistance in the wires and the generation of a back emf. These are reduced by sending electricity at high voltages.
- AC generators have affected society and the environment.
- Westinghouse wanted to supply AC power to cities, whereas Edison wanted to supply DC power.
- Transmission lines are insulated from supporting structures by ceramic discs and protected from lighting strikes by sacrificial wires.
- Transformers change the voltage and current of electricity. Step-up transformers increase the voltage and step-down transformers decrease the voltage. However energy is always conserved, and in an ideal transformer the power in equals the power out.
- Transformers are used in sub-stations to step down the voltage as it gets closer to the homes. Transformers have impacted society.
- Heating caused by eddy currents in transformers may be overcome by insulated layers (laminations), adding ferrites to the core and using a coolant.

- The principle of an AC induction motor can be demonstrated by a magnet and a piece of foil floating on water.
- Electrical energy can be transformed into other forms that are more useful in the home and industry.

Review Questions

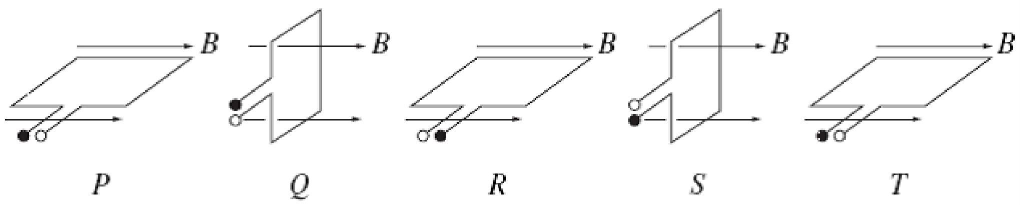
Q1. A current-carrying conductor passes through a square region of magnetic field, magnitude 0.5 T, as shown in the diagram. The magnetic field is directed into the page.



What is the magnitude of the magnetic force on the conductor?[1]

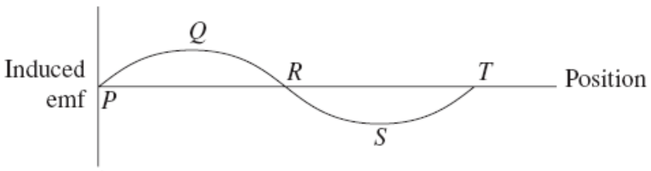
(A) 0.170 N
(B) 0.424 N
(C) 0.600 N
(D) 0.849 N

Q2. The coil of an AC generator rotates at a constant rate in a magnetic field as shown.

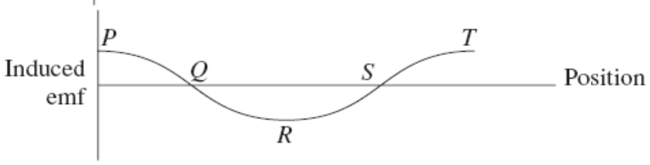


Which of the following diagrams represents the curve of induced emf against position?[2]

(A)

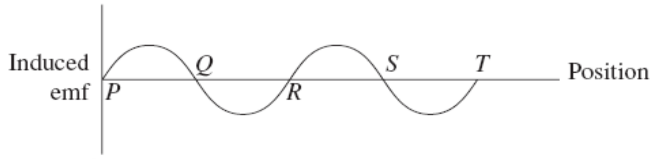


(B)

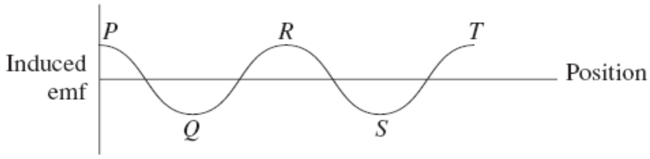


[1] From 2006 HSC Physics Exam. © Board of Studies NSW 2006.
[2] From 2002 HSC Physics Exam. © Board of Studies NSW 2002.

(C)



(D)



Q3. A 20 cm length of wire is suspended horizontally from a spring balance. The wire is hanging in a horizontal magnetic field that is perpendicular to the wire. A current flow of 25 A through the wire results in a reading of 0.12 N and when the current is reversed, the reading on the balance is 0.08 N.

What is the magnitude of the magnetic field?

(A) 4×10^{-3} T
(B) 8×10^{-3} T
(C) 4×10^{-1} T
(D) 8×10^{-1} T

Solutions on page 138.

Contextual Outline:

By the beginning of the twentieth century, many of the pieces of the physics puzzle seemed to be falling into place. The wave model of light had successfully explained interference and diffraction, and wavelengths at the extremes of the visible spectrum had been estimated. The invention of a pump that would evacuate tubes to 10-11 atmospheres allowed the investigation of cathode rays. X-rays would soon be confirmed as electromagnetic radiation and patterns in the Periodic Table appeared to be nearly complete. The nature of cathode rays was resolved with the measurement of the charge on the electron soon to follow. There was a small number of experimental observations still unexplained but this, apparently complete, understanding of the world of the atom was about to be challenged.

The exploration of the atom was well and truly inward bound by this time and, as access to greater amounts of energy became available, the journey of physics moved further and further into the study of subatomic particles. Careful observation, analysis, imagination and creativity throughout the early part of the twentieth century developed a more complete picture of the nature of electromagnetic radiation and matter. The journey taken into the world of the atom has not remained isolated in laboratories. The phenomena discovered by physicists have, with increasing speed, been channelled into technologies, such as computers, to which society has ever-increasing access. These technologies have, in turn, often assisted physicists in their search for further knowledge and understanding of natural phenomena at the sub-atomic level.

This module increases students' understanding of the history, nature and practice of physics and the applications and uses of physics, the implications of physics for society and the environment, and the current issues, research and developments in physics.

9.4 FROM IDEAS TO IMPLEMENTATION

1. Increased understandings of cathode rays led to the development of television

1. explain why the apparent inconsistent behaviour of cathode rays caused debate as to whether they were charged particles or electromagnetic waves

Observations suggesting cathode rays as **particles** are when they:

- move in straight lines (evidenced by sharp shadows of opaque objects)
- reflect at equal angles
- are deflected by a magnetic field
- are deflected by an electric field
- exert momentum (evidenced by turning the paddlewheel)
- travel slower than the speed of light or other electromagnetic waves
- move away from the cathode at right angles to cathode.

Observations suggesting cathode rays as **waves** as they:

- unaffected by gravity (actually they are but because of the low mass it is unnoticed), (see discharge tube containing a maltese cross experiment)
- did not appear to be deflected by electric fields (they in fact were, but too small to notice)
- could travel though certain thin sheets of metal (in fact the particles were so small that they passes though the crystal lattice of metals)
- move in straight lines (evidenced by sharp shadows of opaque objects)
- produce chemical changes, e.g. change the colour of silver salts
- produce fluorescence.

2. explain that cathode ray tubes allowed the manipulation of a stream of charged particles

Cathode ray tubes produce a stream of charged particles (electrons) through it. These are emitted from the cathode. An anode must be present to provide a potential difference, however as the particles travel so fast many do not travel back into the anode. Cathode ray tubes are near vacuums.

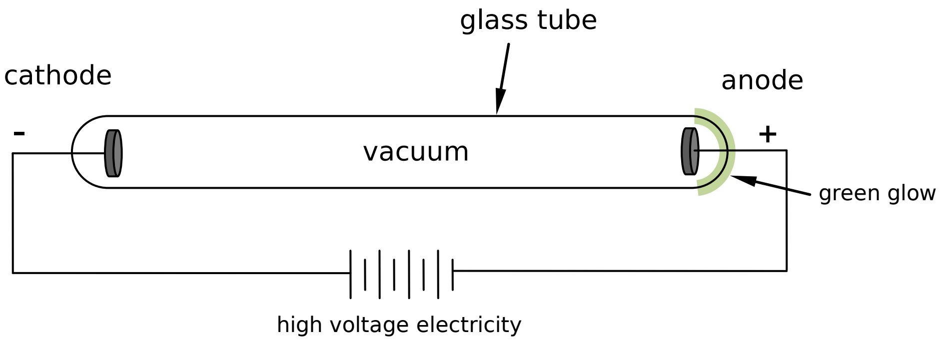


Fig. 91

3. identify that moving charged particles in a magnetic field experience a force

Just as a wire with a current in a magnetic field will experience a force (which is a result of this dot point), moving charged particles in a magnetic field also will experience a force. Remember that a current is just the flow of electrons which are charged particles.

4. identify that charged plates produce an electric field

Charged plates produce an electric field. This is shown below. The centre one is used for some experiments in this module.

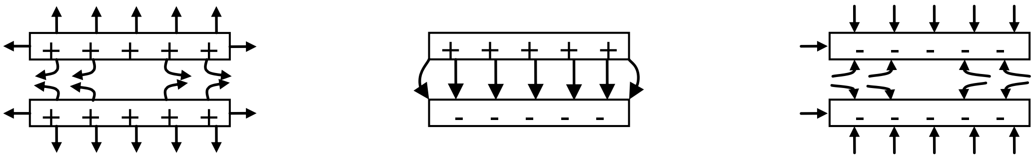


Fig. 92

5. describe quantitatively the force acting on a charge moving through a magnetic field

$F = qvB\sin\theta$

F = Force (N)
q = Charge on particle (C)
v = Velocity of particle (ms^{-1})
B = Magnetic Field Strength (T)
θ = Angle between direction of velocity and magnetic field lines. *It is probably safer to use $F = qvB$ and only use the component of v that is perpendicular to the magnetic field lines.

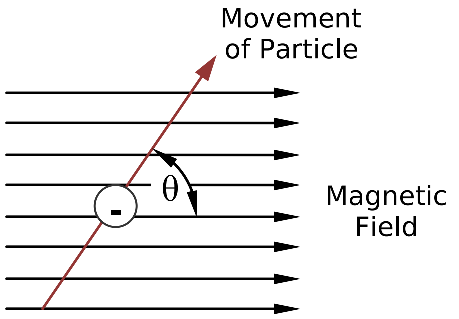


Fig. 93

The direction of the force will be normal to the magnetic field/movement of particle plane. The positive sense can be found using the right hand palm rule, where the fingers are the magnetic field, the thumb is the movement of the particle and the palm is the direction of the force experienced by the particle (remember that if the charge is negative, then the negative value of *q* will automatically adjust the direction by making *F* negative).

If this particle is moving in the same direction as the magnetic field, there will be no force acting on it, so only the component of the velocity which is perpendicular to the magnetic field contributes to the force which is why the formula has $\sin\theta$ on the end.

It should also be noted that when a force acts on this changed particle, the force will change the direction of the particle, and so the direction of the velocity will change, so the particle will move in a circular path.

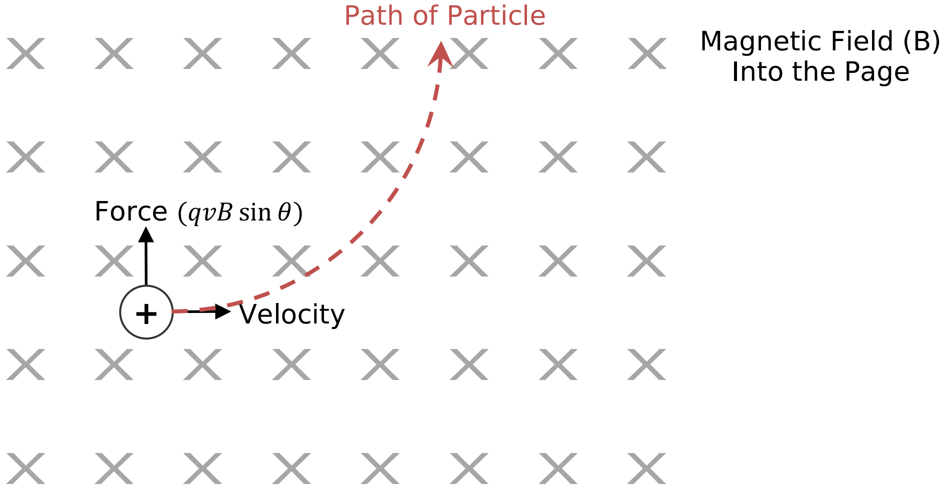


Fig. 94

6. discuss qualitatively the electric field strength due to a point charge, positive and negative charges and oppositely charged parallel plates

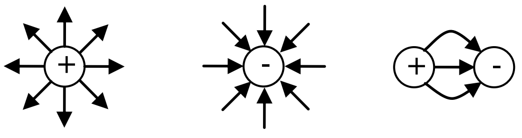


Fig. 95

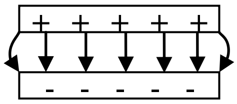


Fig. 96

The electric field extends radially from the point charge. The strength becomes less the further distance you are from the point charge. For parallel plates the electric field lines go from the positive plates, and the electric field strength is less when the distance is large, and less when the voltage is low,

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

7. describe quantitatively the electric field due to oppositely charged parallel plates

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

E = Electric Field Strength (Vm^{-1})
V = Voltage across plates (Volts)
d = Distance (m)

The force on a particle between these two plates can be calculated using,
$F = qE$
F = Force (N)
q = Charge on particle (C)
E = Electric Field Strength (NC^{-1})

8. outline Thomson's experiment to measure the charge/mass ratio of an electron

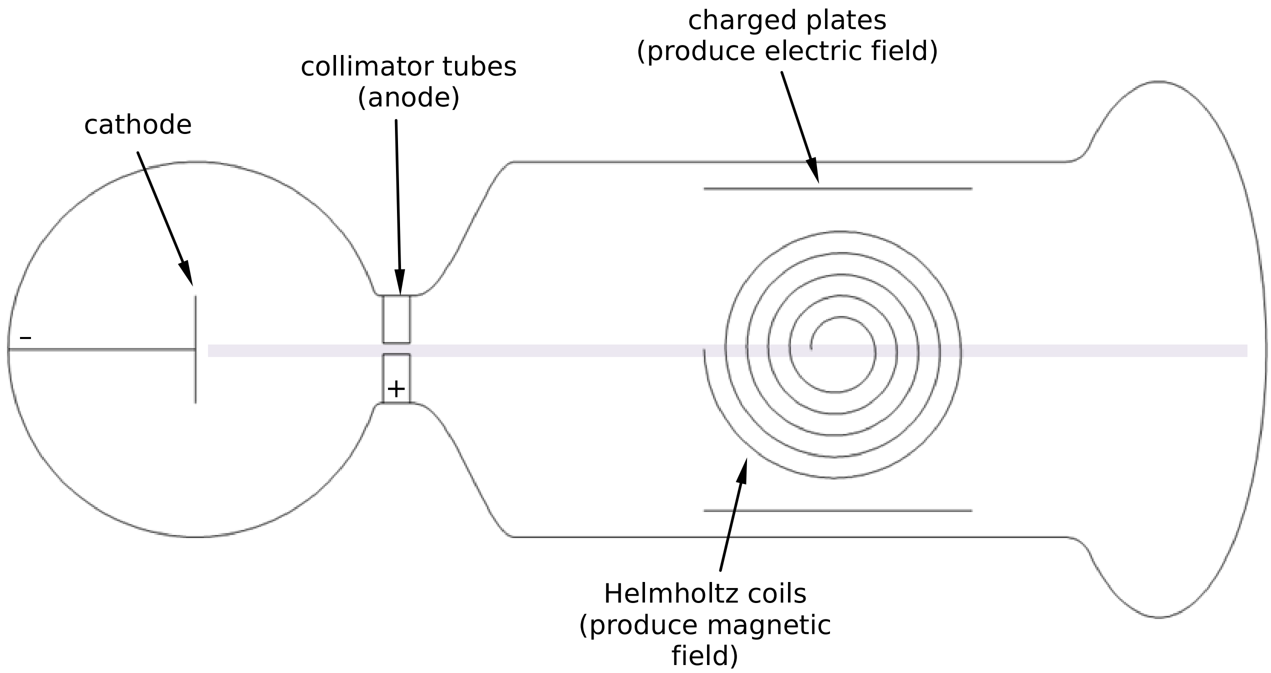


Fig. 97

The apparatus Thomson used to measure the charge/mass ratio of an electron is shown above. High voltages from an induction coil are supplied to the cathode and anode and the electrons are discharged from the cathode. They then travel at high speeds in the low pressure glass tube. They travel straight though to show up in the glass at the other end.

We know that the electrons (cathode rays) are affected by magnetic and electric fields. The force on the electron in a magnetic field is given by $F = qvB$, and the force on an electron in an electric field is given by $F = qE$. From the apparatus above the charged plates produce an electric field and the Helmholtz coils produce a magnetic field. From the equations we can see that if we change the electric or magnetic field strength then the force on the electron will change. In the apparatus the force on the electron due to the magnetic field is set up to be in the opposite direction to the force on the electron due to the electric field. Thus by changing the electric and magnetic field strengths so that the two forces cancel out then the electron (cathode ray) will travel in a straight path and this will be seen on the glass at the end of the tube.

So if force due to electric field equals force due to magnetic field,

$$qvB = qE$$

$$vB = E$$

$$v = \frac{E}{B}$$

As E (electric field strength) and B (magnetic field strength) are known the velocity of the electron can be calculated.

The magnetic field (in the diagram above) is directed out of/into the page, applying the right hand push rule with fingers in/out of the page and thumb directed towards the left (thumb is direction of current and electron flow is the opposite direction to current flow), this results in the force acting up/down. Just say the force from the magnetic field is acting down at first, once the force has bent the path of the electron the direction of the electron flow changes and by using the right hand push rule again the direction of the force changes. In a uniform magnetic field the electron will follow a circular path (only an arc of the circle sometimes not the whole circle). This means the centripetal force will be acting on the electron. We know that $F = \frac{mv^2}{r}$ so now by equating this force with the force due to magnetic field we get,

$$\frac{mv^2}{r} = qvB$$

$$qvBr = mv^2$$

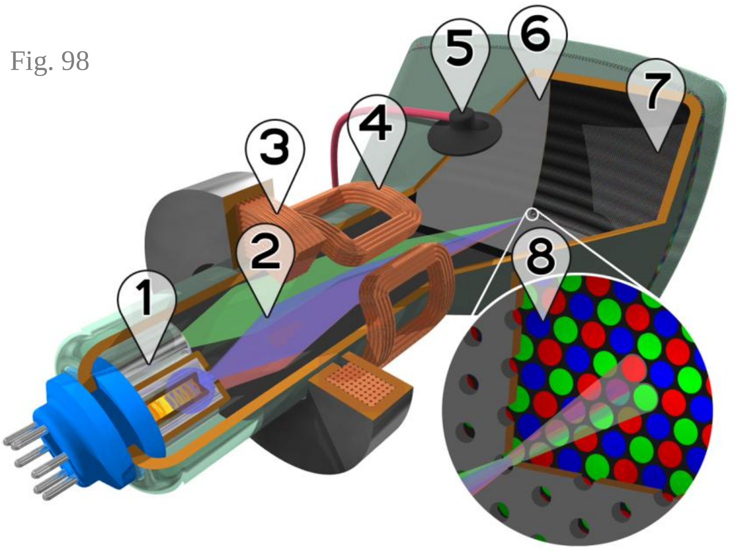
$$\frac{q}{m}vBr = v^2$$
$$\frac{q}{m} = \frac{v^2}{vBr}$$
$$\frac{q}{m} = \frac{v}{Br}$$

From above we know v, we also know B and r can be calculated from the displacement of the beam (visible inspection), hence we can calculate the charge (q) to mass (m) ratio.

9. outline the role of: in the cathode ray tube of conventional TV displays and oscilloscopes

Cathode Ray Tubes (CRT's) and Cathode Ray Oscilloscopes (CRO's) are two well known applications of cathode rays. Cathode ray tubes can be found in the old fashion televisions and computer monitors.

Fig. 98



1. Electron guns
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Shadow mask
7. Phosphors

CRT TV Display

Source: http://en.wikipedia.org/wiki/Image:CRT_color_enhanced.png
Reproduced under the terms of the GNU Free Documentation license, Version 1.2 or any later version published by the Free Software Foundation

Cathode ray oscilloscopes are those old things which show green curves. The difference is that in an oscilloscope the current is AC and thus the force on the electrons is alternating so the beam will travel back and forth, usually up and down. The main components of CRT's and CRO's are described below.

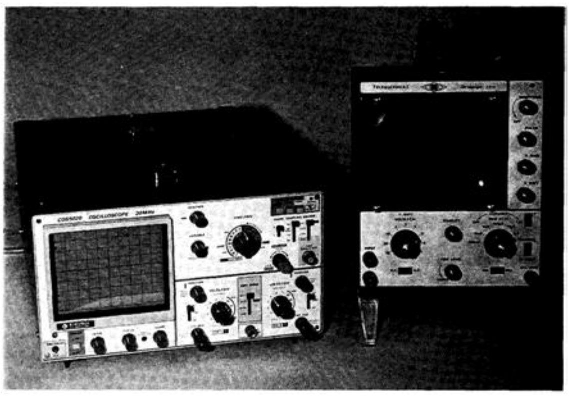


Fig. 99

Cathode Ray Oscilloscope

Hawkins, G., at el. (1996). *Getting it to Work: Physics Equipment for High Schools.* pg 6. NSW Department of School Education. http://www.schools.nsw.edu.au/media/downloads/schoolsscience/learning/yr11_12/science/physics/cathode.pdf

– electrodes in the electron gun

The electrodes (ie. the cathode and anode) allow for a **potential difference** and thus the **cathode rays (electrons) are emitted from the cathode**. However as the cathode rays are travelling at very high speeds only very few of these electrons go back into the anode, most keep travelling towards the screen.

– the deflection plates or coils

Either deflection plates or coils can be used, however they both do the same thing. They change the path of the cathode rays to direct them to certain parts of the screen. As cathode rays are charged their path can be altered by the presence of a magnetic or electric field. If electric plates are used then there are two sets, one set alters the x coordinate and the other the y coordinate. By varying the strength and direction of the current, the position of the cathode ray on the screen can be altered.

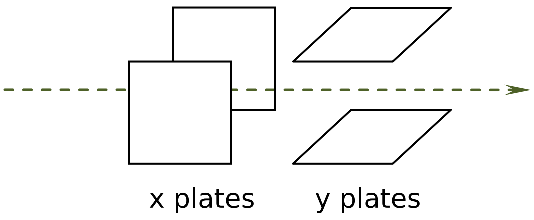


Fig. 100

Coils are used in a similar way except a magnetic field creates a force on the electrons rather than the electric field. Generally coils are used in TV's and plates are used in oscilloscopes.

– the fluorescent screen

The fluorescent screen is where the cathode rays hit and due to a phosphorus coating they emit a green light.

1. perform an investigation and gather firsthand information to observe the occurrence of different striation patterns for different pressures in discharge tubes

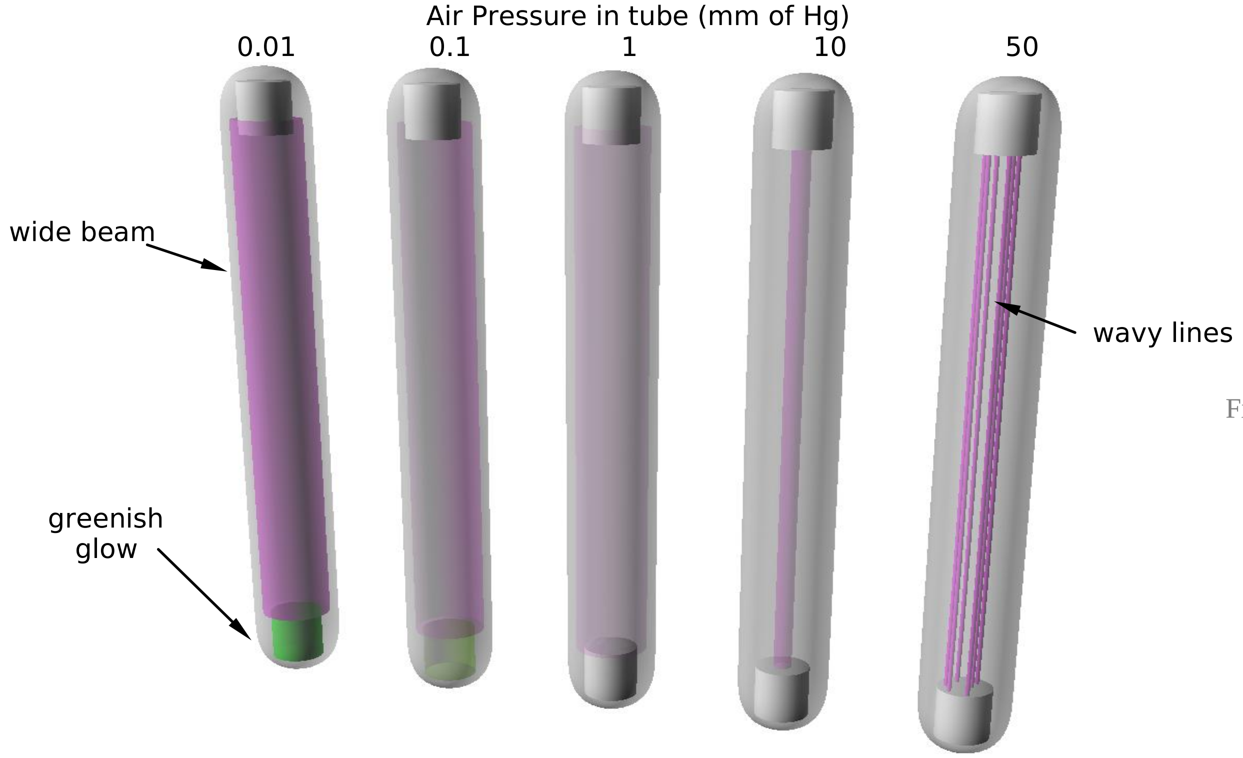


Fig. 101

We may conclude that the pressure of the discharge tube will affect how the cathode rays (electrons) travel. The different observed striation patterns is due to the different pressures of the discharge tubes. We used a transformer in order to get the high voltages that are needed for this experiment. As shown in the low pressure tubes it is seen that cathode rays (electrons) can travel through a vacuum, this fact lead to the further exploration of cathode rays.

The purple that is observed is known as striation patterns.

2. perform an investigation to demonstrate and identify properties of cathode rays using discharge tubes:

The use of discharge tubes poses potential risks/hazards. Discharge tubes require very large voltages which are usually produced by an induction coil. This large voltage can cause electric shock and so to minimise this risk, the apparatus should not be touched when in use. Also the induction coil produces x-rays, so you should not stand too close when it is operating.

– containing a maltese cross

In this experiment cathode rays were shone on a solid object. A shadow was produced behind the object. This suggested that cathode rays were waves as they were unaffected by gravity (actually they are but because of the low mass it is unnoticed) and they travelled in straight lines.

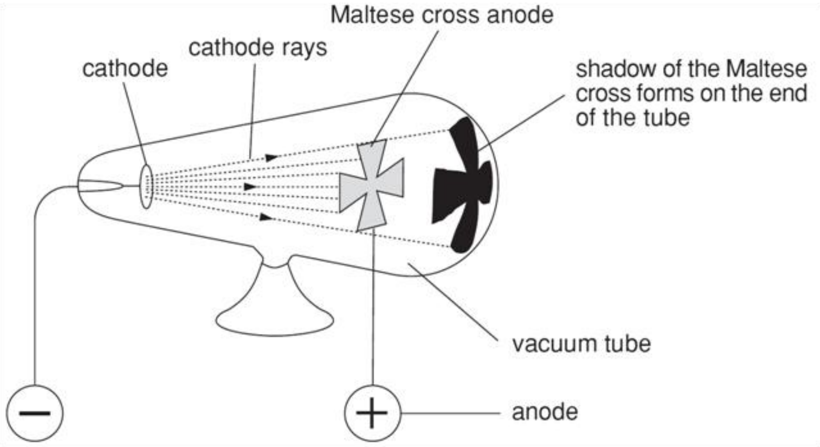


Fig. 102

Diagram from '*From ideas to implementation*' produced by Learning Materials Production, OTEN.

– containing electric plates

In this experiment cathode rays were shone though an electric field. It was observed that the cathode ray was attracted to the positive plate. This suggested that cathode rays were negatively charged particles as waves cannot be charged.

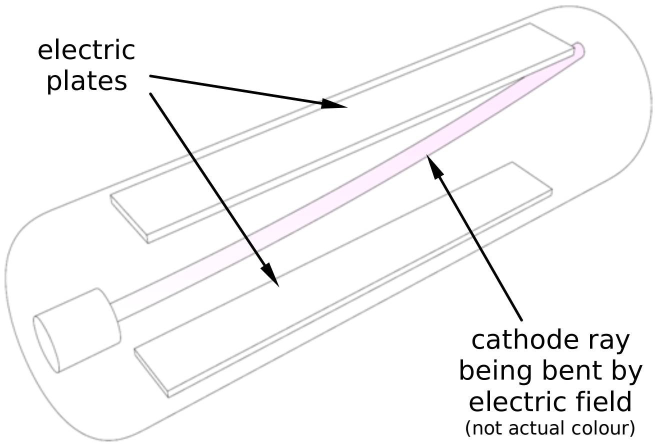


Fig. 103

– with a fluorescent display screen

In this experiment cathode rays were shone though a phosphorus screen. This allowed for their path to be observed. It was noticed that the path of the cathode rays was affected by a magnetic field, such as when magnets were placed near it.

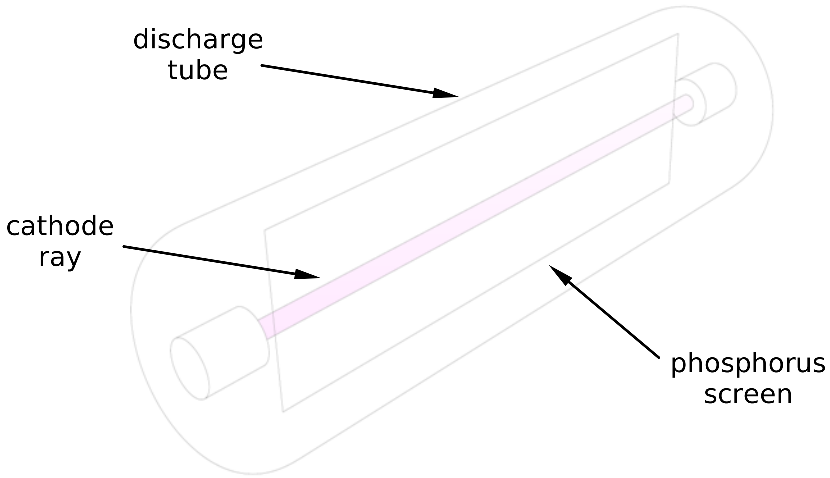


Fig. 104

– containing a glass wheel

In this experiment cathode rays were shone onto a glass wheel that was free to move. It was observed that the glass wheel moved. Meaning that the cathode rays must have mass (in order to have the momentum to make the wheel move), this meant that cathode rays must be particles as waves cannot have mass.

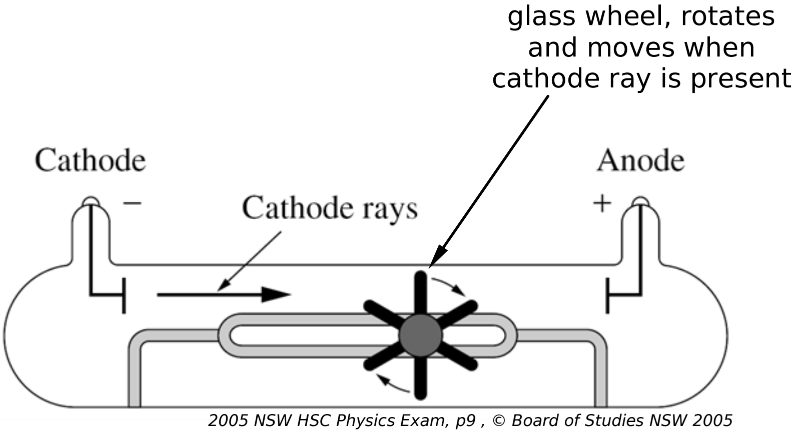


Fig. 105

– analyse the information gathered to determine the sign of the charge on cathode rays

When the cathode ray is travelling though an electric field, such as when two charged plates are present, the cathode ray tends towards the positive plate, meaning that the cathode rays must be negatively charged.

3. solve problem and analyse information using:

$$F = qvB\sin\theta$$

$$F = qE$$

and

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

2. The reconceptualisation of the model of light led to an understanding of the photoelectric effect and black body radiation

1. describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate

The photoelectric effect is when electrons are released from a metal surface exposed to electromagnetic radiation. This is because the quanta of energy from the electromagnetic radiation give the electrons the energy needed to escape from the metal. Hertz observed electrons (a spark) to be emitted from a receiver when electromagnetic waves were present. He observed the photoelectric effect but he failed to investigate it further.

In his original apparatus he used a metal ring as the receiver and a sparking wire producing a changing electric and magnetic field that propagates as an electromagnetic wave (the sparking wire produces electromagnetic waves, in particular, radio waves). These electromagnetic waves arrive at the receiving metal and emit electrons causing a spark.

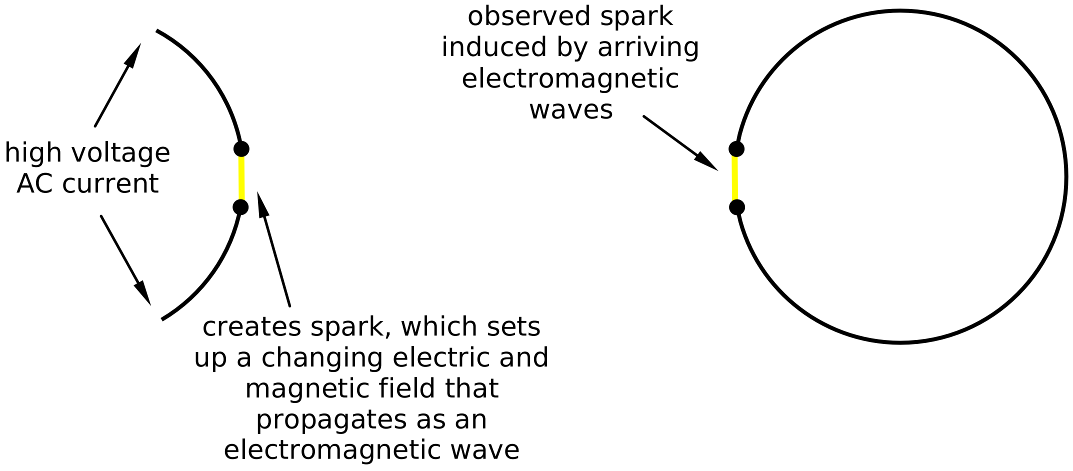


Fig. 106

Hertz also noted that if ultraviolet light was shone on the receiving loop then the gap could be made larger and a spark could still occur.

2. outline qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves

Hertz showed that these waves behaved like light. He showed that, like light, radio waves could reflect, refract, interfere, diffract, be polarized and travelled at the speed of light.

Hertz could determine the speed of radio waves by using the relationship that $c = f\lambda$. The frequency of the emitted waves was determined by the number of windings in the induction coil, and the voltage and current in the circuit. And the wavelength could be determined by using a double slit object which was placed in front of the radio waves (visible light spectrum may have been used from the light of the sparking), an interference pattern would occur and λ could be determined from this interference pattern.

3. identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised

A black body is a theoretical object that absorbs 100% of the radiation that hits it. Therefore it reflects no radiation and appears perfectly black. As all the radiation is absorbed, it heats the black body and it begins to radiate electromagnetic radiation. The black body is in equilibrium when the amount of incoming radiation equals that being radiated.

An example of a black body is a star, where all the electromagnetic radiation is absorbed and then radiated out again. However, in certain objects made with everyday materials that are shaped in a way that only allows energy to be trapped inside and radiated out and not reflected off the surface can also be considered black bodies.

Planck hypothesised that radiation emitted and absorbed by the walls of a black body is in discreet 'packets' or quanta of energy, i.e. it is not emitting continuously. It will emit in chunks of energy at a time (quanta of energy).

Two black body radiation curves are shown below. One is light as a wave and the other is light as discrete packets of energy. The latter is the experimental result.

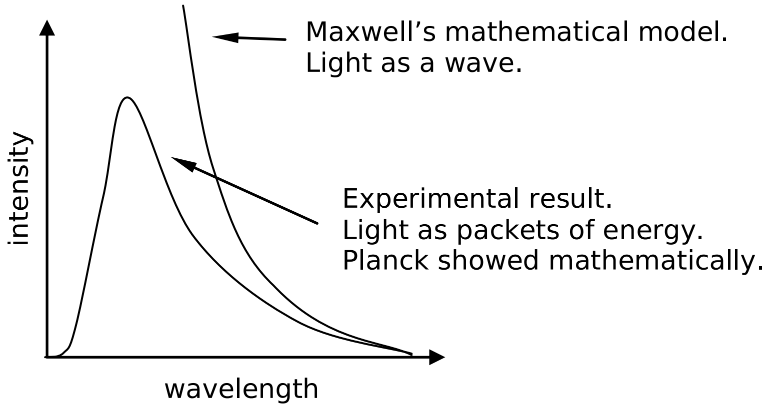


Fig. 107

The energy per each quantum (photon) of energy was directly proportional to the frequency. This is shown by the equation, $E = hf$ where,

E = energy of quantum (photon) (J)
h = Planck's Constant (6.626×10^{-34} Js)
f = frequency (m)

Also note that $1\text{eV} = 1.602 \times 10^{-19}$ J. (eV is electron volt)

The significance of Planck's constant is that light energy is made up of photons.

4. identify Einstein's contribution to quantum theory and its relation to black body radiation

Under the classical wave model of light, emission of electrons (from photoelectric effect) is independent of frequency, however the Quantum particle model of light said that emission was frequency dependent. Below a certain frequency (the critical or *threshold* or cut-off frequency) no electrons were emitted, regardless of the intensity of the light.

Einstein's contribution to quantum theory was that he used Planck's idea of quanta and named these packets of energy as photons. The use of this to explain the photoelectric effect meant that light could be considered to be both a wave or a particle (photon). Classical physics was unable to explain the photoelectric effect using the wave model of light. However Einstein explained the photoelectric effect by using Planck's idea of quanta. He assumed that light comes in little packets of energy he called **photons.** He explained the photoelectric effect with the particle model of light.

Einstein said the intensity of light depends on the amount of photons, not the energy of the photons.

Einstein's contributions lead to the start of quantum mechanics.

5. explain the particle model of light in terms of photons with particular energy and frequency

The particle model of light is that light travels in photons. A photon has a particular amount of energy ($E = hf$) and can either give all or none of its energy to an electron. A photon also has a particular frequency ($c = f\lambda$).

6. identify the relationships between photon energy, frequency, speed of light and wavelength:

$E = hf$
$c = f\lambda$

E = energy of photon (J)
h = Plank's constant (6.626×10^{-34} Js)
c = speed of light (3.00×10^{8} ms^{-1})
f = frequency (Hz)
λ = wavelength (m)

1. perform an investigation to demonstrate the production and reception of radio waves

If you place an induction coil near an AM radio, when the induction coil is turned on interference is heard when the spark jumps. This shows that the spark emits radio waves and that these radio waves are being received by the radio.

2. identify data sources, gather, process and analyse information and use available evidence to assess Einstein's contribution to quantum theory and its relation to black body radiation

3. identify data sources gather, process and present information to summarise the use of the photoelectric effect in photocells

Photocells produce a current when they are in the presence of light (or any electromagnetic radiation). They do this by using the photoelectric effect. As shown in the diagram below, the light gives the electrons in the cathode the energy to escape from the cathode (this is the photoelectric effect), as the electrons are negatively charged they travel to the anode. As the electrons flow from cathode to anode a potential difference between the cathode and anode is present and a current is measured on the ammeter.

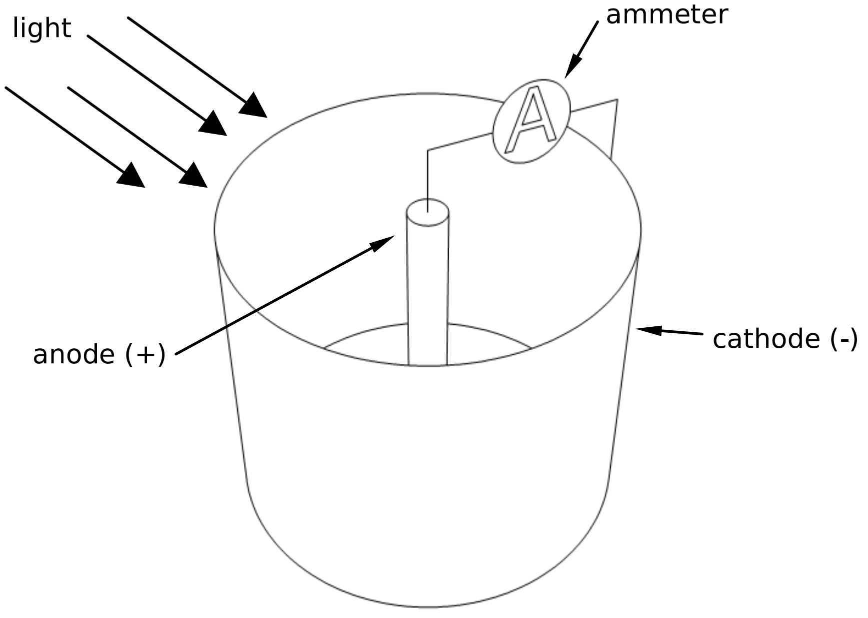


Fig. 108

4. solve problems and analyse information using:

$$E = hf$$

and

$$c = f\lambda$$

E = energy of photon/quanta (J)
h = Planck's Constant = 6.626×10^{-34} Js
f = frequency (Hz)
c = speed of light = 3.00×10^{8} ms^{-1}
λ = wavelength (m)

5. process information to discuss Einstein and Planck's differing views about whether science research is removed from social and political forces

- Einstein believed that scientific research should be removed from social and political forces; devoted to the pursuit of knowledge.
- Plank believed that the purpose of science was to support a social and political agenda.

I am lacking a reliable source on which to base my response to this dot point. If you find a source please let me know.

3. Limitations of past technologies and increased research into the structure of the atom resulted in the invention of transistors

1. identify that some electrons in solids are shared between atoms and move freely

In metallic bonding electrons are shared between atoms and can move freely. Because of this they can conduct electricity.

2. describe the difference between conductors, insulators and semiconductors in terms of band structures and relative electrical resistance

The valance band is the outermost shell with electrons in it. The valance band holds the valance electrons. The conduction band is above the valance band. No electrons are present in the conduction band, however the conduction band is where the electrons jump to and from when they conduct.

If an electron is in the conduction band and a potential difference is present, then current will flow. Electrons need to be in the conduction band for current to flow. Bands are energy levels, so to move an electron from the valance band to the conduction band energy must be given to the electron to allow it to be in the conduction band. This can be in the form of another electron hitting it, light, heat, etc.

In insulators there is a large gap between the valance band and the conduction band meaning that electrons need a lot of energy supplied to move then up an energy level and into the conduction band. With a semiconductor the gap is smaller meaning that the electrons need a bit of energy supplied to move then up an energy level and into the conduction band. In a conductor the valance band and conduction band are overlapping meaning that valance electrons are free to conduct as they are also in the conduction band

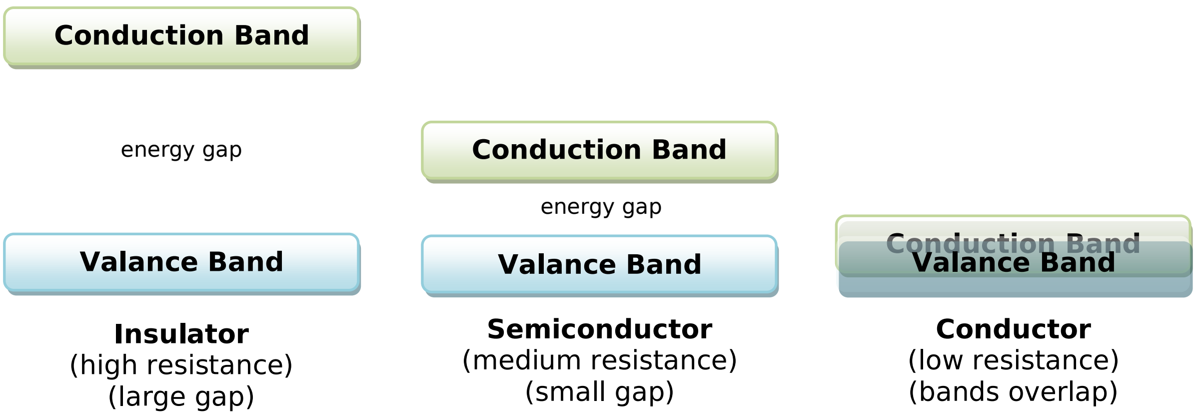
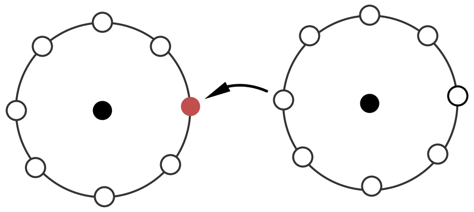


Fig. 109

3. identify absences of electrons in a nearly full band as holes, and recognise that both electrons and holes help to carry current

Take fluorine as an example. It has 2 electrons in the first shell and 7 valence electrons. It is one short of filling that shell. This gap where one electron could be placed to make the shell full is a hole. Because it has this hole, the atom has a slightly positive charge. So if a potential difference is applied to the material, in an atom next to this atom with a hole an electron will be removed and will go towards the positively charged atom with a hole to fill the shell. But now the second atom has a hole and so this continues. Electrons are now flowing through the material and a current is present.



Atom with a hole. So an electron from another atom fills the hole. And the process continues creating a current.

Fig. 110

4. compare qualitatively the relative number of free electrons that can drift from atom to atom in conductors, semiconductors and insulators

The number of free electrons that can drift from one atom to another in conductors is a large number, in semiconductors varies depending on conditions (but generally less than conductors) and in insulators is none.

5. identify that the use of germanium in early transistors is related to lack of ability to produce other materials of suitable purity

Transistors are made from semiconductor materials. Early transistors used germanium even though silicon is a better option. Germanium was used because the semiconductor needs to be very pure and in that time they could only purify germanium to the required purification. Silicon could not be obtained of suitable purity.

6. describe how 'doping' a semiconductor can change its electrical properties

Doping a semiconductor refers to adding impurities to the semiconductor. For example if a silicon semiconductor doped with arsenic then it is made up of mostly silicon atoms but small amounts of arsenic.

Doping can change the semiconductors electrical properties. Doping can change the number of holes present or the number of free electrons. This changes how well or poor a semiconductor conducts.

7. identify differences in p and n-type semiconductors in terms of the relative number of negative charge carriers and positive holes

To understand p and n-type semiconductors we will look at the structure of silicon, a common semiconductor. Silicon has 4 electrons in its valance shell. It covalently bonds with other silicon atoms to form a crystal lattice structure. Pure silicon has no excess electrons or holes. However when it is doped some free electrons (- charge) or holes (+ charge) may be present, this changes the charge and hence **p**ositive**-type** or **n**egative**-type** semiconductors may arise.

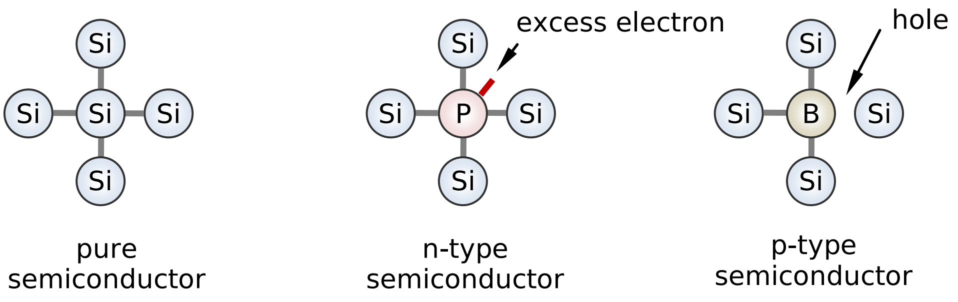


Fig. 111

If silicon is doped with phosphorus (5 valance electrons), the 5^{th} electron is not involved in bonding. It is converted into a free electron. This semiconductor is an n-type semiconductor because it has excess negative charges.

If silicon is doped with an atom that only has 3 electrons in its valance shell, such as boron, then the semiconductor has a hole in the silicon crystal lattice structure where the boron doping atom is. Semiconductors such as this are p-type semiconductors because they have a deficiency of negative charges.

8. describe differences between solid state and thermionic devices and discuss why solid state devices replaced thermionic devices

Solid state devices and thermionic devices do the same thing. They can control the direction of current flow and switch on/off current. However there are some differences between the two and these differences favour the use of solid state devices over thermionic devices.

- Solid state devices use **less electrical energy** to run than thermionic devices.
- Solid state devices **run faster** than thermionic devices.
- Solid state devices are much **lighter, smaller and cheaper** than thermionic devices.
- Thermionic devices take **time to start up** as they have to **warm up**. Solid state devices don't need to warm up.
- Solid state devices are much **more reliable** than thermionic devices.

- Solid state devices produce much **less heat** than thermionic devices.
- Thermionic devices are made from glass and hence are inherently **fragile**, whereas solid state devices are not.

Solid state devices include the solid state diode and transistor. Thermionic devices include values.

1. perform an investigation to model the behaviour of semiconductors, including the creation of a hole or positive charge on the atom that has lost the electron and the movement of electrons and holes in opposite directions when an electric field is applied across the semiconductor

The flow of electricity through a semiconductor can be modelled by using chairs and students. This is shown in the picture below (imagine the things they are standing on are chairs). In this model, the people represent electrons and the chairs represent holes. We start with a hole at the right (the hole means that the atom has a slightly positive charge), this positive charge will attract the person (electron) to the left of the hole and that person (electron) will move into that hole. This creates another hole where the electron came from and the process continues. The flow of the electrons is to the right and the position of the hole moves to the left.

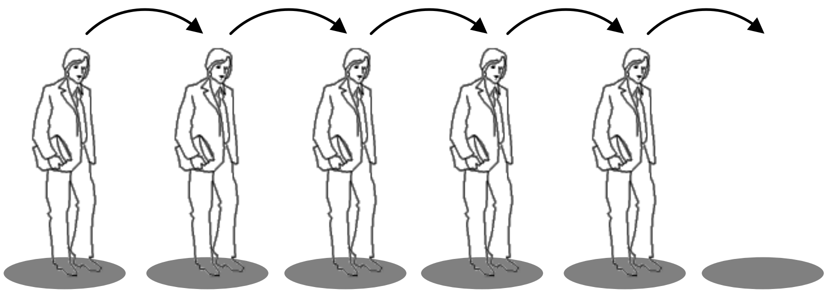


Fig. 112

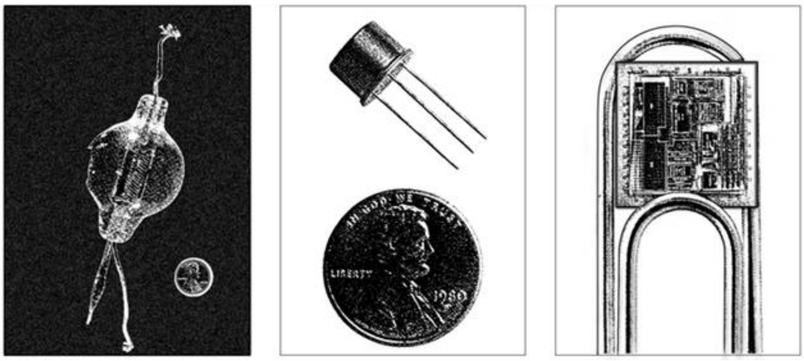
2. gather, process and present secondary information to discuss how shortcomings in available communication technology lead to an increased knowledge of the properties of materials with particular reference to the invention of the transistor

A transistor is an electronic switch that uses semiconductor material. There are two types of transistor, npn transistor and pnp transistor. Transistors were only discovered because it was observed that the output energy was greater than the input energy for a piece of germanium.

Before the use of semiconductors in solid state devices, thermionic devices (values) were the main means of radio communication. There are many problems with thermionic deceives (*see dot point 8*), so they needed better technology for radio communication. Through the study of semiconductors, it was found that solid state devices could replace thermionic devices. This also lead to the development of the transistor using germanium and silicon which worked much better than the thermionic devices.

3. identify data sources, gather, process, analyse information and use available evidence to assess the impact of the invention of transistors on society with particular reference to their use in microchips and microprocessors

The invention of the transistor has allowed for microchips and microprocessors to be developed. These have pushed society into the information age. They have allowed for small, light and cheap electronic devices, including computers and mobile phones.



thermionic device *transistor* *microchip*

Fig. 113

World Book Encyclopaedia, 1985, Vol.6, p.153

4. identify data sources, gather, process and present information to summarise the effect of light on semiconductors in solar cells

The effect of light on semiconductors in solar cells is the production of electricity. When light photons hit the semiconductor in solar cells, the photons knock the electrons from the valance band to the conduction band, allowing them to move freely. By placing metal contacts on the top and bottom of a solar cell, electricity can be obtained.

The composition of a solar cell is shown below. The light causes the electrons to move from the n-type silicon to the p-type silicon.

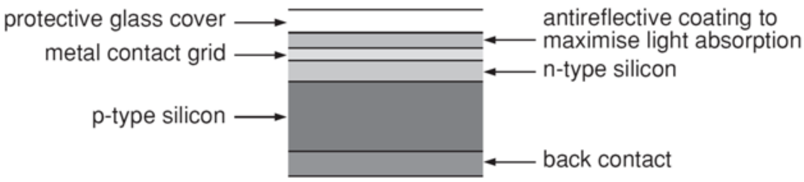


Fig. 114

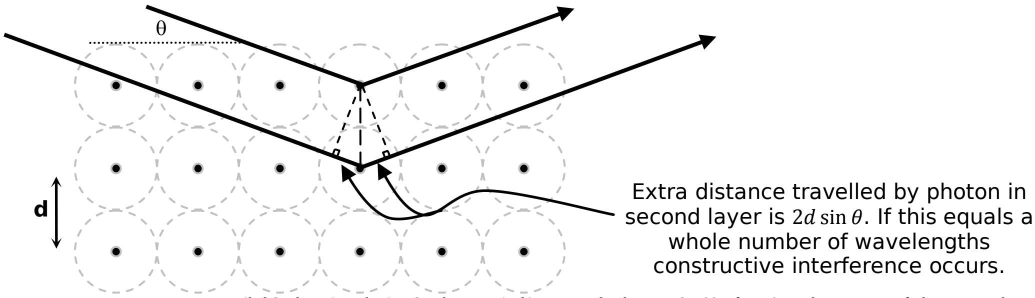
Diagram from '*From ideas to implementation*' produced by Learning Materials Production, OTEN.

4. Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications

1. outline the methods used by the Braggs to determine crystal structure

The Braggs used parallel beams of x-rays which were shone on the substance. The incident rays hit atoms and reflected scattered x-rays were observed and their interference pattern depended on the wavelength of the x-rays, the distance between the planes of atoms in the crystal and the angle of incidence of the x-rays on the crystal planes. This is because when the x-rays reflect of atoms of different layers, the x-rays travel a different distance, thus they are out of phase. The interference pattern was used to determine the atomic spacing and hence the crystal structure of materials. This process of scattering and interference is a form of diffraction, although it is unlike the diffraction of light travelling though a slit or past and edge.

Fig. 115



Detailed Study Unit 4 Physics, Synchrotron. (n.d.). Retrieved Feburary 26, 2007, from Australian Institute of Physics: VicPhysics: http://www.vicphysics.org/documents/teachers/synchrotron%20notes.doc

2. identify that metals possess a crystal lattice structure

Metals possess a crystal lattice structure. Depending on the metal, the lattice can be in different arrangements. The atoms form part of the crystal lattice and the electrons are in a *cloud* surrounding the atoms.

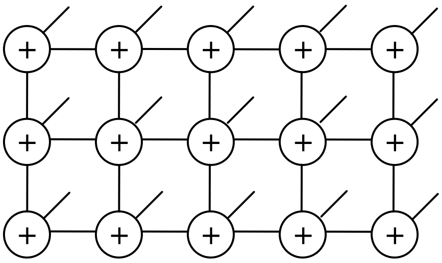


Fig. 116

3. describe conduction in metals as a free movement of electrons unimpeded by the lattice

Conduction in metals is when the electrons in the lattice structure flow through the metal, unimpeded by the lattice.

4. identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations

When a material becomes hotter, the atoms in the lattice vibrate more. The more the atoms vibrate, the more likely the electrons flowing through as electricity are going to be impeded and scattered in different directions. Also impurities in the metal are often found inside the lattice and these are likely to impede electron flow.

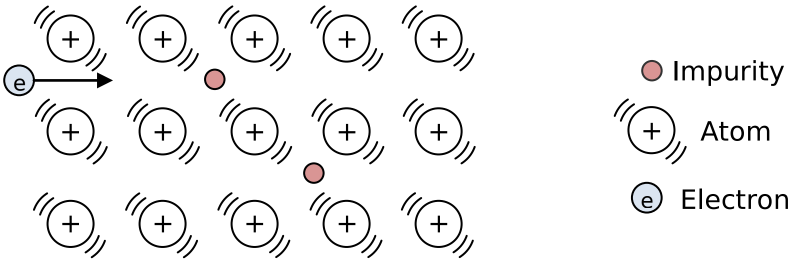


Fig. 117

An electron is more likely to be impeded when the atoms are vibrating lots. Similarly, impurities can impede electron flow.

5. describe the occurrence in superconductors below their critical temperature of a population of electron pairs unaffected by electrical resistance

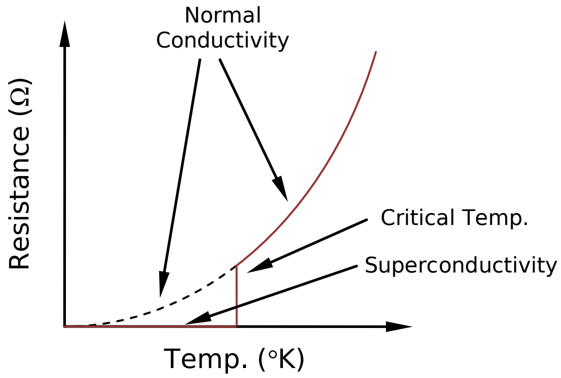


Fig. 118

As explained by BCS theory, below the critical temperature of a superconductor, electron pairs (cooper pairs) are formed, which are unaffected by electrical resistance. They travel at the speed of light.

6. discuss the BCS theory

Atoms in a crystal lattice are constantly vibrating. Because they are all connected, these vibrating atoms create waves throughout the metal. These waves are called phonons. The more the atoms are vibrating (ie. the hotter the material), the larger the phonons. In superconductors (at low temperatures) the phonons are small, and any distortion caused by the electrons is reflected in phonons. These phonons can attract electrons to form cooper pairs.

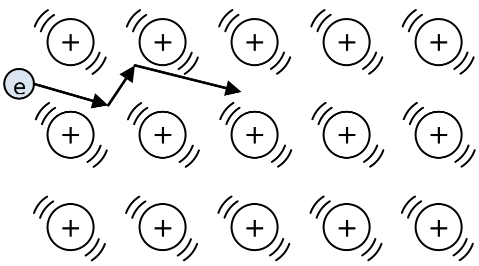


Fig. 119

In a normal conductor, electrons collide with each other and the lattice. This produces resistance that results in heating that in turn encourages resistance.

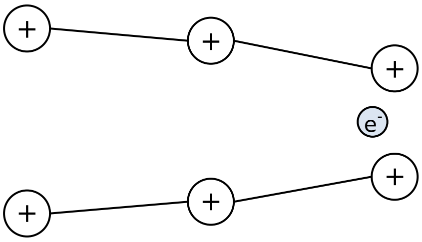


Fig. 120

In the superconducting state, as negatively charged electrons pass between the rows of the positively charged nuclei they are attracted towards the electron.

As shown above the moving electron causes the lattice to distort and an increased positive charged density is formed near the electron. To counter-act this, a second electron is attracted towards the electron (even though the two electrons repel). This pair of electrons are called a Cooper pair, which move easily through the material. This is because their strong negative charge will repel any positive atoms that it gets close to, thus no collisions occur and electron flow is not resisted.

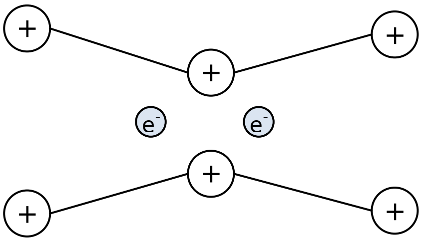


Fig. 121

Cooper pair of electrons.

7. discuss the advantages of using superconductors and identify limitations to their use

One of the biggest limitations to the practical use of superconductors is that at best they currently only have a critical temperature of 1°K to 133°K (-270°C to -140°C). Also they are difficult to manufacture as many are ceramics and they are often brittle.

The advantage of superconductors is that because they have zero resistance, no heat is produced.

1. process information to identify some of the metals, metal alloys and compounds that have been identified as exhibiting the property of superconductivity and their critical temperatures

	Material	**Critical Temperature (°K)**
Metals	Aluminium	1.20
	Tin	3.73
Metal Alloys	Tin-niobium alloy	18
	Ni-Al-Ge alloy	21
Compounds	$YBa_2Cu_3O_7$	90
	$HgBa_2Ca_2Cu_2O_8$	133

2. perform an investigation to demonstrate magnetic levitation

Grab a superconductor and cool it to below its critical temperature (possibly with liquid nitrogen). Next place a magnet above the superconductor and it should hover above. This is magnetic levitation. As the superconductor heats to above the critical temperature, the magnet should fall and sit on the superconductor. The stronger the magnet, the higher it will hover.

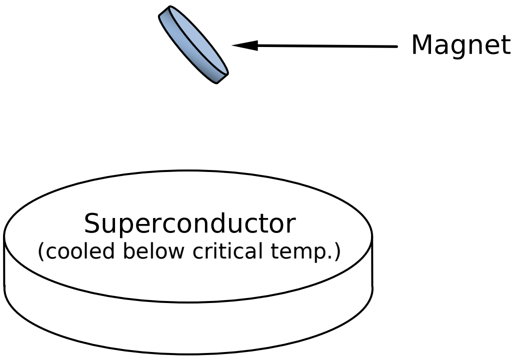
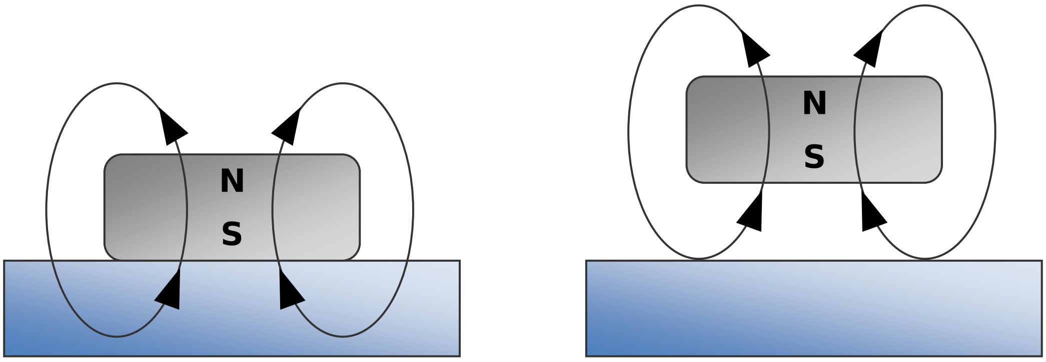


Fig. 122

Fig. 123

3. analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting



Superconductor above Critical Temp. *Superconductor below Critical Temp.*

Fig. 124

A magnet will hover above a superconductor that is cooler than its critical temperature because of the Meissner effect. When in the superconducting state and the magnetic field from the magnet is cutting the superconductor, currents inside the superconductor are set up, which create a magnetic field that repel the magnet.

4. gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train

Superconductors are used to levitate the train. Permanent and electromagnets are used to propel the train forward.

Superconductors (cooled to below their critical temperature) are on the train, due to the Meissner effect these are repelled from the permanent magnets on the track. This levitates the train (this eliminates friction with the track, thus much faster speeds can be attained).

The train is propelled by permanent magnets on the track and electromagnets on the train.

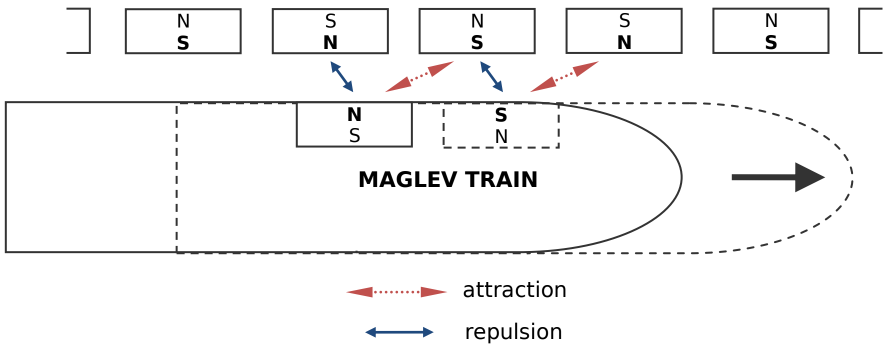


Fig. 125

The track has permanent magnets which each have polarity opposite to the next. The train has electromagnets which, by the use of AC electricity, change polarity in phase with the changing tracks permanent magnets. That means that the magnet on the train will always repel the magnet on the track adjacent to it. It also means that the magnet on the track ahead of the adjacent magnet will always attract to the trains magnet. This attraction pulls the train forward, similarly the adjacent magnet on the track will push the train forward. For this to work thought, the train must have forward momentum, which is initially provided by the standard wheel propulsion used by normal trains.

5. process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors and transmission of electricity through power grids

- **Computer chips:** Currently computer chips cannot be made smaller because of the heat generated from resistance. With superconductors no heat is produced and so wires and transistors on a computer chip could be packed much more closely together and with no heat produced, making computing power much more faster.

- **Generators and motors:** The use of superconductors in generators and motors would mean super strong magnets and no energy loss in the coils of the motor or generator. This means that the generator or motor would be 100% efficient. This has not yet been achieved.

- **Transmission of electricity through power grids:** When electricity is transmitted through power lines, energy is lost in heat due to resistance in the wires. If superconductor materials were used for the wires, there would be no heat lost from transmission.

9.4 TOPIC REVIEW

Summary

- Cathode rays are a stream of electrons. However when cathode rays were first investigated in cathode ray tubes it was debated as to whether they were waves or particles.
- A moving charged particle in a magnetic field will experience a force, $F = qvB\sin\theta$. The direction of this force is given by the right hand palm rule.
- Charged plates will produce an electric field, $E = \frac{V}{d}$.
- Thomson's experiment measured the charge/mass ratio of an electron.
- Cathode ray tubes in TV's and oscilloscopes comprise of electrodes in the electron gun, deflection plates or coils and a fluorescent screen.
- The striation patterns will vary depending on the pressure in discharge tubes.
- The properties of cathode rays were determined by performing experiments of discharge tubes containing a Maltese cross, electric plates, a fluorescent screen and a glass wheel.
- The photoelectric effect is when electrons are released from a metal surface exposed to electromagnetic radiation.
- Planck's hypothesised that radiation emitted and absorbed by the walls of a black body cavity is quantised.
- Einstein said the intensity of light depends on the amount of photons, not the energy of the photons.
- Einstein and Planck had differing views about whether science research is removed from social and political forces.
- The difference of conductivity of conductors, semiconductors and insulators is due to the energy gap between the valance band and the conduction band.
- Holes are where an electron is missing. Both free electrons and holes help to carry current.
- Germanium was originally used in semiconductors, but now silicon is used. However it is often doped with other elements to improve conductivity. Semiconductors can be n-type or p-type.
- Solid state devices and thermionic devices do the same thing, however the solid state devices has many advantages.
- The invention of the transistor has had a huge impact on society as it has allowed from microchips and microprocessors.
- Braggs used x-rays to determine the crystal structure of elements. It was found that metals posses a crystal lattice structure.
- Conduction in metals is the free movement of electrons unimpeded by the lattice. However impurities and lattice vibrations hinder electron flow and create resistance.
- In superconductors, at their critical temperature the electrical resistance becomes zero, this is because the electrons form cooper pairs. However superconductors are brittle and only become superconducting at low temperatures.
- Magnets are able to hover above a superconductor due to the Meissner effect. This has been used to develop a maglev train.

- Superconductors have potential applications in computer chips, motors and generators and transmission of electricity in power grids.

Contextual Outline:

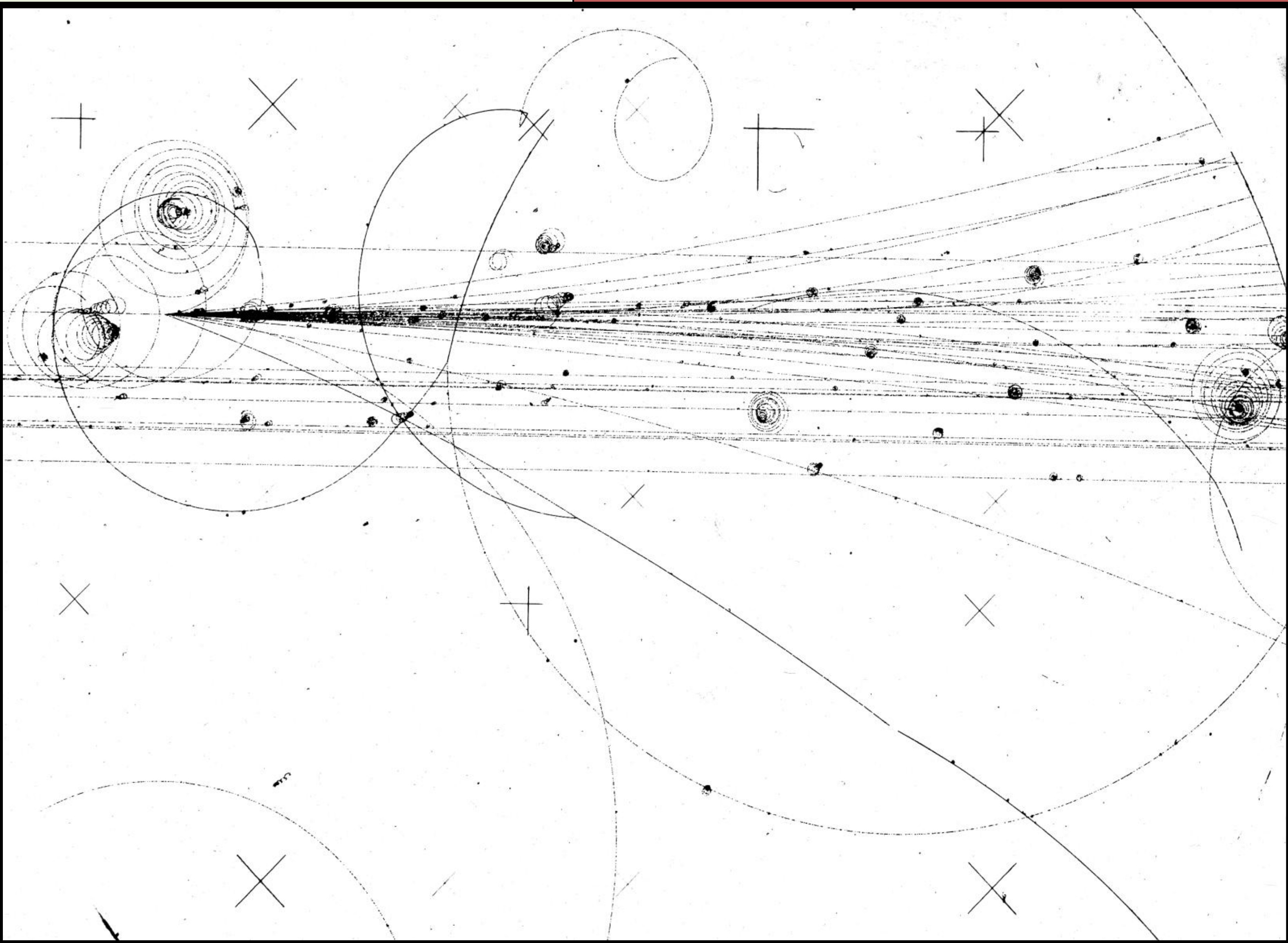
Geophysics is the application of physical theories and measurement to the investigation of the planet we inhabit. Geophysical studies may involve large-scale problems such as the Earth's structure and behaviour (solid earth geophysics) and problems associated with the exploration of the crust for minerals and for engineering purposes (exploration geophysics).

Both solid earth geophysics and exploration geophysics use similar instrumentation and methods to study phenomena such as gravitation, the Earth's magnetic field, radioactivity and the behaviour of seismic waves. Using an understanding of its material properties, geophysicists explore the Earth in ways that human senses cannot.

Geophysical investigations provide society with such benefits as improved location of energy resources, minerals, hazard minimisation and an understanding of the complex planet we inhabit.

This module increases students' understanding of the history of physics and the implications of physics for society and the environment.

9.8 OPTION – FROM QUANTA TO QUARKS



1. Problems with the Rutherford model of the atom led to the search for a model that would better explain the observed phenomena

1. discuss the structure of the Rutherford model of the atom, the existence of the nucleus and electron orbits

The Rutherford model of the atom has a central nucleus with electrons orbiting around it. In the Rutherford model, most of the mass of the atom is in the nucleus, yet Rutherford did not know what the nucleus was made up of.

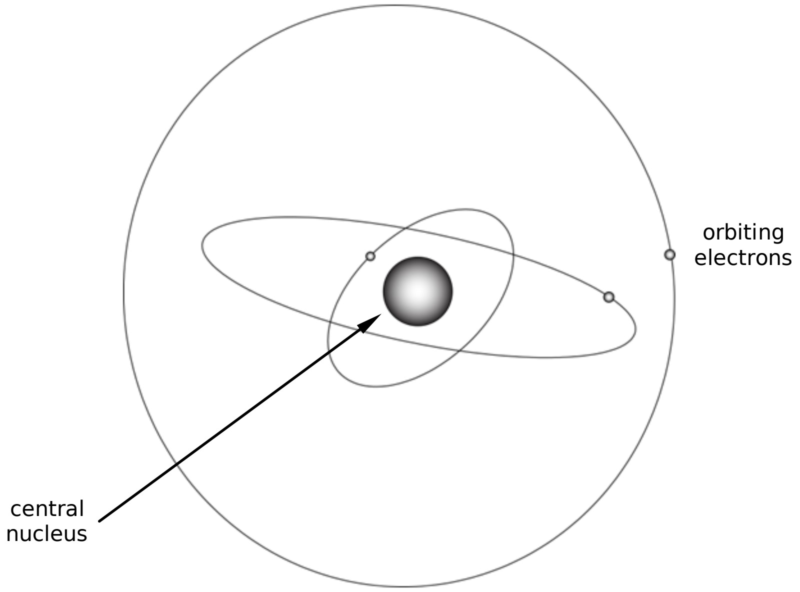


Fig. 126

2. analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom

Bohr's model of the atom had the orbiting electrons in energy levels. They are at **quantised energy levels** (i.e. discreet radii) and they **can move between levels by absorbing or emitting energy** (see diagram).[1] These energy levels are the principal quantum number, n, which is equal to 1, 2, 3 .... In Bohr's model of the atom, electrons can only be in these integer number shells, ie. an electron cannot be somewhere between shell 1 and 2. The development of Bohr's model of the atom was due to the hydrogen spectrum. "He reasoned that since the energy emitted was of characteristic amounts and never in amounts in between, that the stable shells were of specific distances from the nucleus and that electrons could only exist stably at those fixed distances from the nucleus."[2]

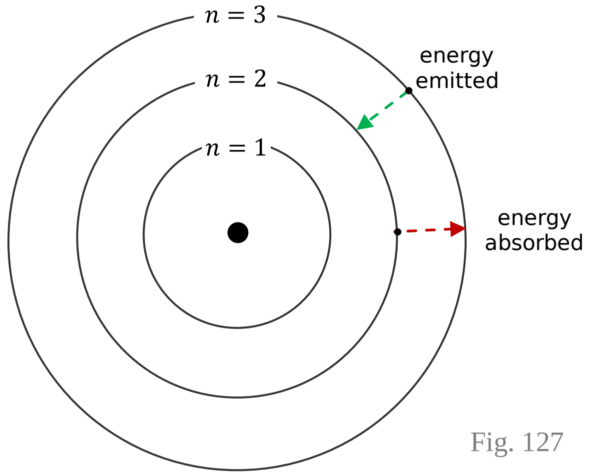


Fig. 127

3. define Bohr's postulates

1. Despite the nucleus (positively charged) and electron (negatively changed) being oppositely charged they do not attract and collapse together. The **electrons are stable** in their shells and are not pulled towards the nucleus. This violates classical physics. Also an electron that is stable and doesn't change energy level will not radiate energy.

[1] Board of Studies NSW. (2004). *2003 HSC Notes from the Marking Centre Physics*. Board of Studies NSW. Pg. 37

[2] Charles Sturt University. (n.d.). *Physics 9.8 Option- From Quanta to Quarks: 1. Rutherford and Bohr*. Retrieved from HSC Online: http://www.hsc.csu.edu.au/physics/options/quanta_quarks/phy981.html#a2

2. If an electron moves down a shell/energy level then quantised energy in the form of a photon will be emitted. Similarly if an electron moves to a higher energy level then the atom must absorb some quanta of energy. This explains the existence of spectral lines.
3. $mvr = n\frac{h}{2\pi}$, where n is a positive integer. This means that mvr (angular momentum) can only take on certain values and is quantised.

4. discuss Planck's contribution to the concept of quantised energy

Planck said that energy was quantised in discreet packets of energy. This is given by the formula, $E = hf$, where h is Planck's constant. This means that the energy is a multiple of h and therefore quantised. This differs from classical physics where energy was thought to be a continuous wave. This concept of quantised energy was initially brought up for an explanation of black body radiation.

5. describe how Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

We have the equation, $E = hf$ and from Bohr's second postulate we have $E = E_f - E_i$.
So;

$hf = E_f - E_i$

As, $E_f = \frac{1}{n_f^2}E_1$ and $E_i = \frac{1}{n_i^2}E_1$

$$hf = \frac{1}{n_f^2}E_1 - \frac{1}{n_i^2}E_1$$

$$hf = E_1\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

As, $c = f\lambda$

$$f = \frac{c}{\lambda}$$

$$h\frac{c}{\lambda} = E_1\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\frac{1}{\lambda} = \frac{E_1}{hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Hence Bohr's postulate lead to the mathematical model below which predicts the hydrogen spectrum.

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

6. discuss the limitations of the Bohr model of the hydrogen atom

The limitations of the Bohr model of the hydrogen atom were:

- It worked for hydrogen but not for larger atoms.
- It could not explain the relative intensity of spectral lines.
- It could not account for the hyperfine spectral lines.
- It could not explain the Zeeman effect.

(See blue dot point 4.)

1. perform a first-hand investigation to observe the visible components of the hydrogen spectrum

A hydrogen discharge tube was connected to high voltage electricity. The discharge tube was observed with a spectroscope. Spectral lines were observed. This process is shown in the diagram below.

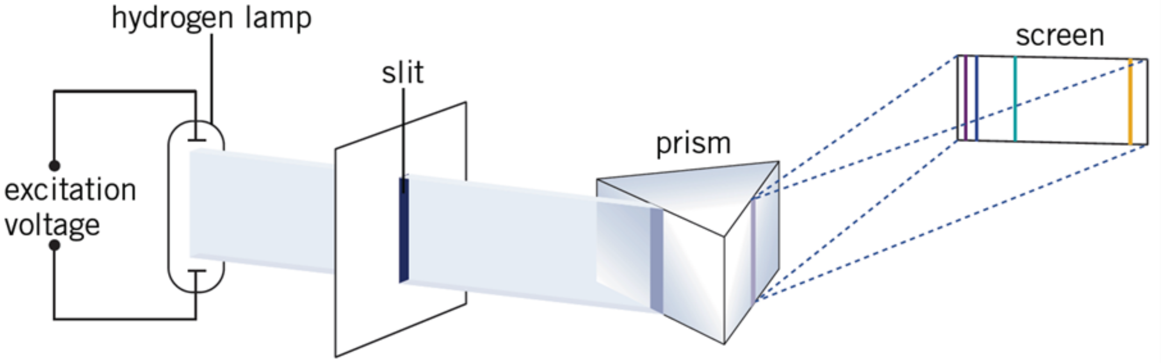


Fig. 128

Irwin, D., Farrelly, R., Vitlin, D., & Garnett, P. (2002). *Chemistry Contexts 2 Solutions & Modules 7 & 8 (CD).* Longman Sciences, Pearson Education Australia Pty Limited. pg. 70

The colours and wavelengths of the visible spectrum of hydrogen is shown below.

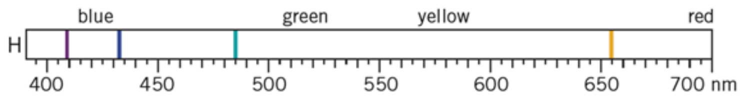


Fig. 129

Irwin, D., Farrelly, R., Vitlin, D., & Garnett, P. (2002). *Chemistry Contexts 2 Solutions & Modules 7 & 8 (CD).* Longman Sciences, Pearson Education Australia Pty Limited. pg. 70

2. process and present diagrammatic information to illustrate Bohr's explanation of the Balmer series

Bohr's explanation of the Balmer series was that if an electron fell from a higher shell down to shell 2, the spectrum emitted was known as the Balmer series. The Balmer series was in the visible spectrum. There are names given to the spectra when electrons fall from higher shells down to each of the shells. For example, when electrons fall to the first shell the spectrum emitted is known as the Lyman series which is in the ultraviolet spectrum.

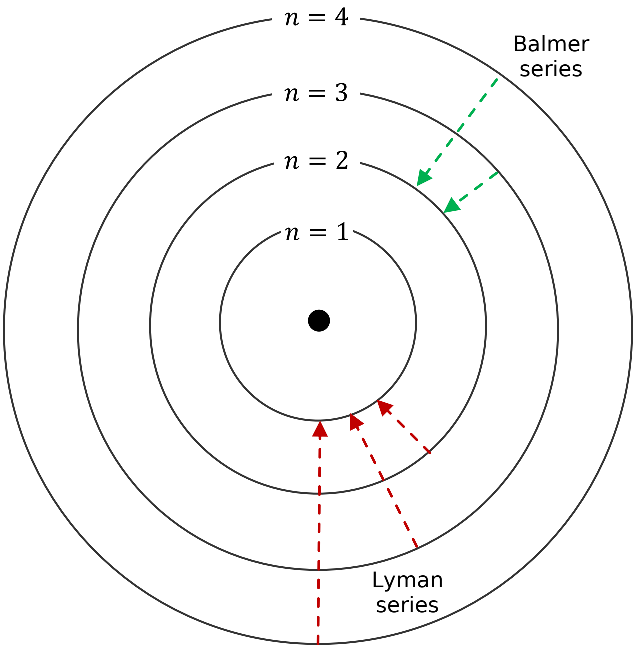


Fig. 130

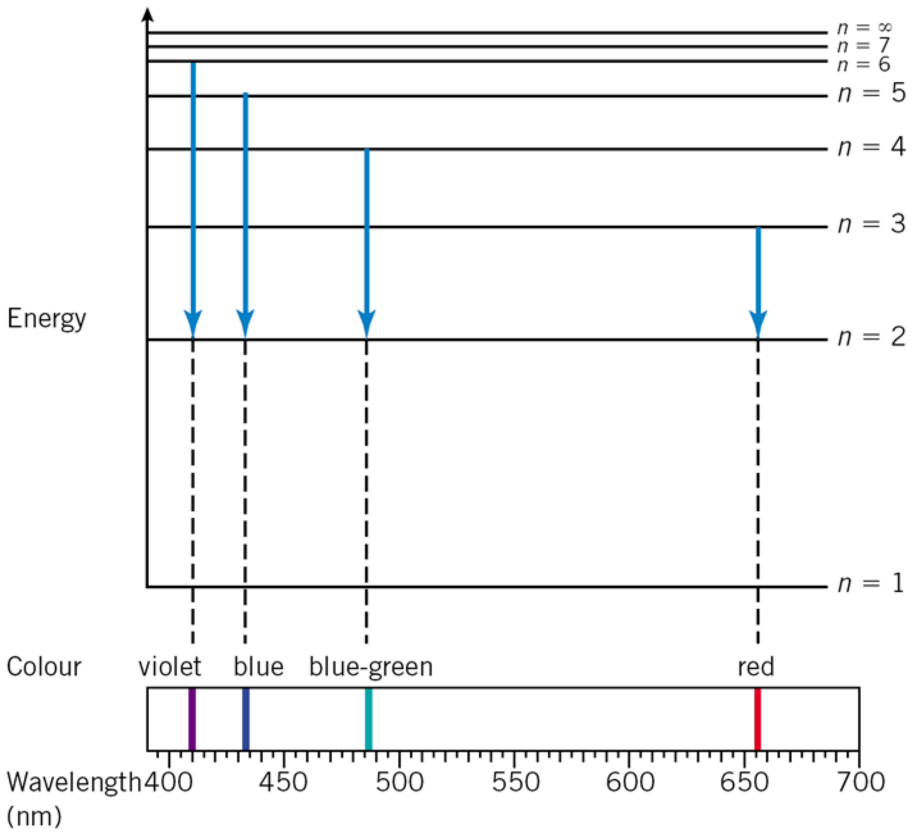


Fig. 131

Irwin, D., Farrelly, R., Vitlin, D., & Garnett, P. (2002). *Chemistry Contexts 2 Solutions & Modules 7 & 8 (CD).* Longman Sciences, Pearson Education Australia Pty Limited. pg. 71

3. solve problems and analyse information using:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

This equation defines the wavelengths of the hydrogen spectrum.

Where:
λ = Wavelength (m)
R = Rydberg's constant
n_f = Final shell
n_i = Initial shell

4. analyse secondary information to identify the difficulties with the Rutherford-Bohr model, including its inability to completely explain:

– the spectra of larger atoms

The Rutherford-Bohr model only worked for hydrogen. It did not work for atoms with more than one electron.

– the relative intensity of spectral lines

Different spectral lines were different intensities. This could not be explained by the Rutherford-Bohr model.

– the existence of hyperfine spectral lines

It was found that some spectral lines consisted of much finer lines that when viewed at a low zoom appeared as one. The cause of these hyperfine spectral lines could not be explained by the Rutherford-Bohr model.

– the Zeeman effect

The Zeeman effect (the splitting of spectral lines when the sample was placed in a magnetic field) could not be explained by the Rutherford-Bohr model.

2. The limitations of classical physics gave birth to quantum physics

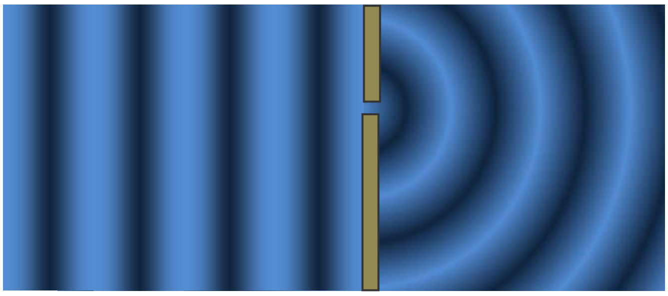
1. describe the impact of de Broglie's proposal that any kind of particle has both wave and particle properties

de Broglie proposed that if light, which travels in waves, can be viewed as little packets of energy then particles such as electrons could travel as waves.

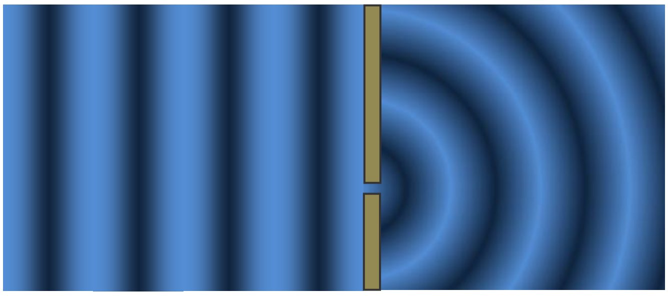
The de Broglie wavelength of a particle was given by, $\lambda = \frac{h}{mv}$.

2. define diffraction and identify that interference occurs between waves that have been diffracted

Diffraction (which only occurs in waves, it does not occur in particles) is when a wave passes through a small split and the wave spreads out.



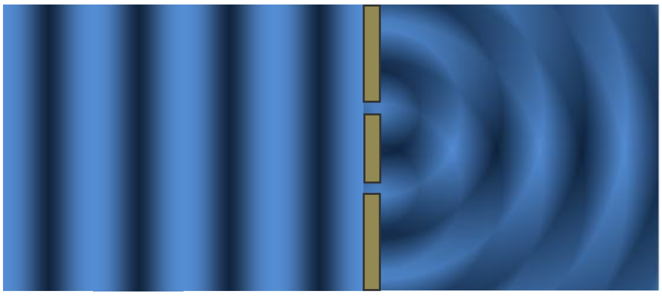
diffraction pattern
(slit A open)



diffraction pattern
(slit B open)

Fig. 132

If two slits are open at the same time then the two waves will interfere (the interference is possible because of the diffraction pattern). The wave will be heightened in some places and cancelled out in other places.



diffraction patterns interfere when
both slits are open

Fig. 133

3. describe the confirmation of de Broglie's proposal by Davisson and Germer

Davisson and Germer confirmed de Broglie's proposal that electrons can be both a wave and a particle. They did this by showing that electrons produced an interference pattern from diffraction just like X-rays (a wave) did.

During their experiments an accident occurred and air entered the vacuum chamber. This caused an oxide layer to form on the metal surface. To try to remove this, Davisson and Germer heated the metal, however doing so created large crystal regions in the material, where the crystal lattice was large enough for electrons to pass through. Now when they subjected electrons to the materials, they were observed to diffract as they passed though the crystal lattice. As diffraction is a wave property and does not happen with particles, electrons must have a wave nature as well as a particle nature.

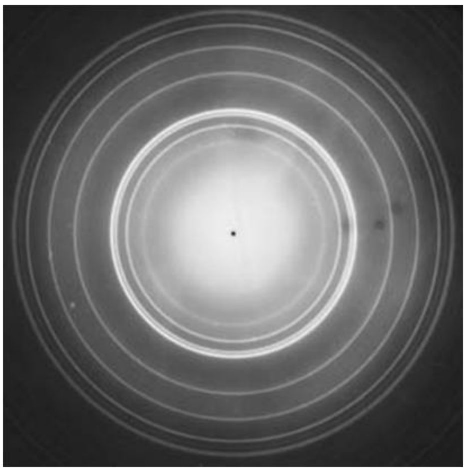


Fig. 134

Electron diffraction: Electron diffraction pattern. [Photograph]. Retrieved September 11, 2007, from Encyclopædia Britannica Online: http://www.britannica.com/eb/art-92144

The diagram to the right shows the observed diffraction pattern, which is the same as the x-ray diffraction pattern.

4. explain the stability of the electron orbits in the Bohr atom using de Broglie's hypothesis

Using de Broglie's hypothesis of the wave nature of particles we can explain why electrons can only exist in specific energy levels. Because these orbiting electrons can be thought of as waves, where the shell number relates to the number of waves, if you have non integer number of waves then the wave will not join and will collapse. So electrons can only exist where a whole number of waves is possible. This coincided with the specific orbits that Bohr had postulated. Since the electron could exist as a wave it was in a non-radiating energy level as also postulated by Bohr.

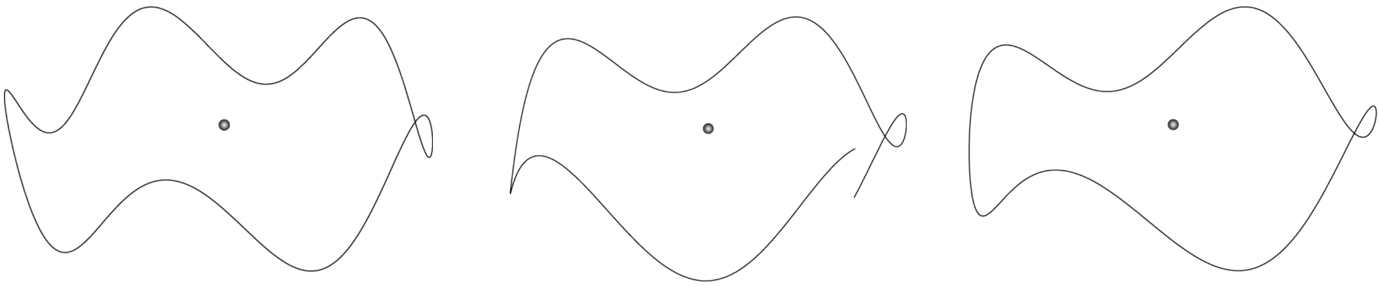


Fig. 135

1. solve problems and analyse information using:

$$\lambda = \frac{h}{mv}$$

Where:
λ = de Broglie wavelength (m)
h = Planck constant (6.626×10^{-34} Js)
m = mass of particle (kg)
v = velocity of particle (ms^{-1})

2. gather, process, analyse and present information and use available evidence to assess the contributions made by Heisenberg and Pauli to the development of atomic theory

Heisenberg:
Heisenberg's contribution to the development of atomic theory was the **Uncertainty Principle**, which states that both the position and the momentum of a subatomic particle cannot be accurately determined simultaneously. The more you know about the momentum of the particle, the less you know about its position. And the more you know about the particles position the less you know about its momentum. This can be expressed mathematically,

$$\text{uncertainty of momentum} \times \text{uncertainty of position} \geq \frac{h}{2\pi}$$

This is because the best methods we have to determine the position of a particle will change its momentum, and the methods used to determine momentum change the position. For example to see the position of the particle, we need to shine light on it to see it. However when photons are shown on the particle they collide and the momentum and path of the particle is changed by this collision.

Pauli:
Pauli's contribution to the development of atomic theory was the **Pauli Exclusion Principle**, which states that no two electrons in an atom can have the same set of quantum numbers. Pauli's Exclusion Principle provides reason why electrons in atom are arranged in shells. An electron in an atom has four such quantum numbers. They define the energy of the electron in terms of the

distance of its orbit from the nucleus, the orbit's shape, the orientation of the axis of the orbit, and the electron's spin on its own axis.

Pauli also predicted the existence of the neutrino.

3. The work of Chadwick and Fermi in producing artificial transmutations led to practical applications of nuclear physics

1. define the components of the nucleus (protons and neutrons) as nucleons and contrast their properties

The nucleus of an atom is made up of protons, neutrons and other sub-atomic particles, known as nucleons. Protons have a positive charge and neutrons have no charge. The mass of the proton is slightly less than that of a neutron.

	Symbol	Charge (C)	Mass (kg)
Proton	${}^{1}_{1}\mathrm{p}$	1.602×10^{-19}	1.673×10^{-27}
Neutron	${}^{1}_{0}\mathrm{n}$	0	1.675×10^{-27}

2. discuss the importance of conservation laws to Chadwick's discovery of the neutron

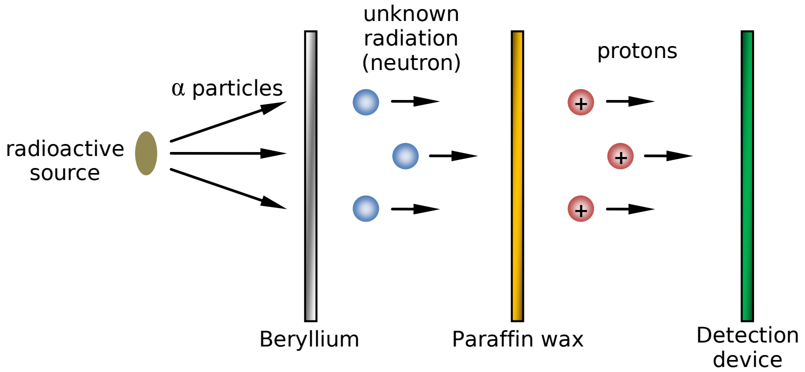


Fig. 136

When beryllium was exposed to alpha particles (helium nucleus, i.e. ${}^{4}_{2}\mathrm{He}$), neutrons are emitted from the beryllium,

$${}^{9}_{4}\mathrm{Be} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$

Although they could not directly detect the neutrons, Chadwick knew something had to be there, as protons were detected as coming from a paraffin wax placed after the beryllium and the conservation laws (i.e. **conservation of energy** and **conservation of momentum**) had to hold. Due to the conservation laws Chadwick knew that this unknown particle (neutron) had about the same mass of the proton.

The neutrons could not be detected directly as they caused little or no ionisation.

3. define the term 'transmutation'

Transmutation is the changing of one element into another by nuclear reactions, remembering that the number of protons in the nucleus of an atom determines the type of element.

4. describe nuclear transmutations due to natural radioactivity

Large unstable elements naturally decay into smaller elements in an aim to become more stable. During nuclear transmutations three forms of radiation can be emitted.

Alpha Particle	proton / helium nucleus	${}^{4}_{2}He$
Beta Particle	electron	${}^{0}_{-1}\mathrm{e}$
Gamma Ray	electromagnetic radiation	${}^{0}_{0}\gamma$

For example, radium is naturally unstable and will decay producing radon-222 and an alpha particle, and so due to the natural radioactivity of radium a new element radon has been created. So a nuclear transmutation has occurred.

$$^{226}_{88}Ra \rightarrow \, ^{222}_{86}Rn + \, ^{4}_{2}He$$

The natural nuclear radioactive decay of uranium-238 is shown below.

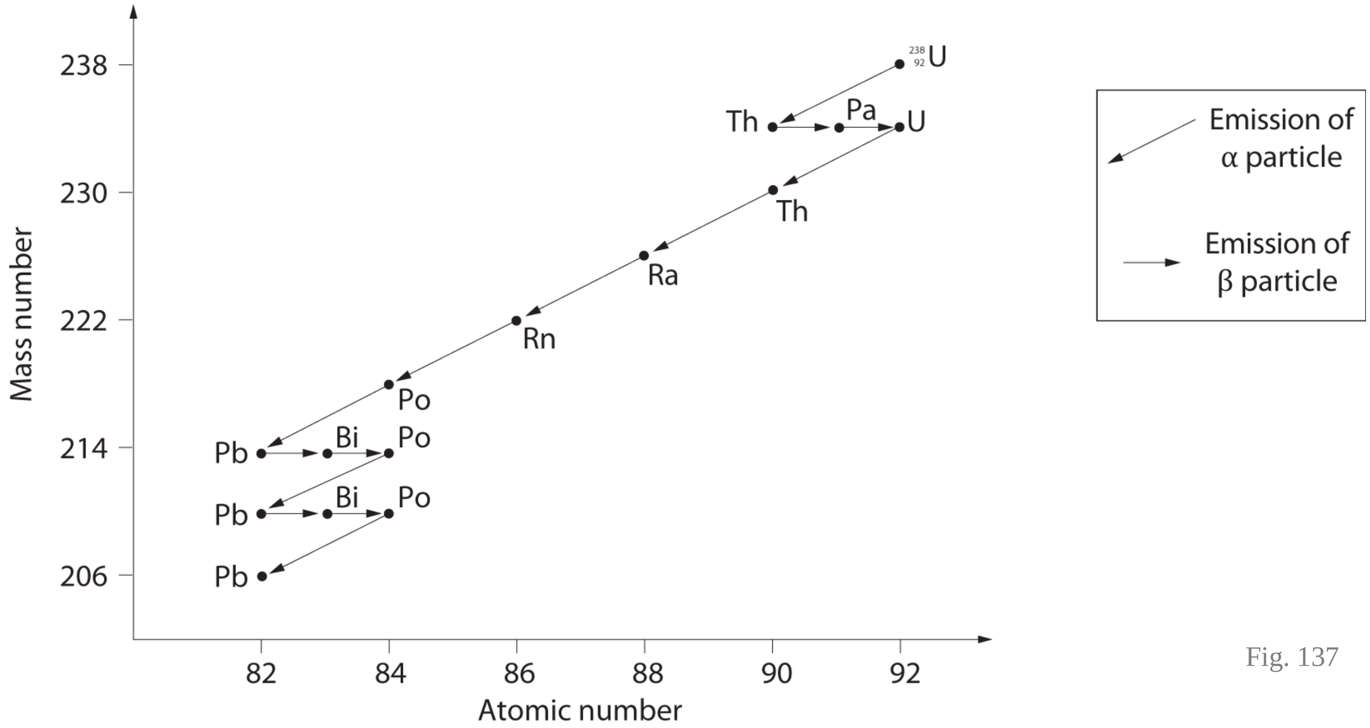


Fig. 137

5. describe Fermi's initial experimental observation of nuclear fission

Nuclear fission is the splitting of an atom into other smaller element atoms. Fermi bombarded elements with neutrons (he found that slow neutrons were more effective at initiating nuclear reaction than fast neutrons). He bombarded U-235 with neutrons. The uranium atoms absorbed the neutrons and became unstable producing Kr-92 and Ba-141. He observed that these two lighter elements had been produced, hence nuclear fission had occurred. It was also observed that more neutrons had been emitted than were absorbed.

$$^{235}_{92}\mathrm{U} + \, ^{1}_{0}\mathrm{n} \rightarrow \, ^{236}_{92}\mathrm{U}$$

$$^{236}_{92}\mathrm{U} \rightarrow \, ^{92}_{36}\mathrm{Kr} + \, ^{141}_{56}\mathrm{Ba} + 3 \, ^{1}_{0}\mathrm{n}$$

6. discuss Pauli's suggestion of the existence of neutrino and relate it to the need to account for the energy distribution of electrons emitted in β-decay

It was found that beta decay electrons had varying kinetic energies. That is, when a material radioactively decayed to emit electrons (beta decay), these emitted electrons had different kinetic energies. We would expect that all the emitted electrons would have the same kinetic energy, and that kinetic energy would be of a given value. This can be explained with the example below.

$$^{210}_{83}\mathrm{Bi} \rightarrow \, ^{210}_{84}\mathrm{Po} + \, ^{0}_{-1}\mathrm{e} + \, ^{0}_{0}\bar{\nu}$$

Bismuth undergoes beta decay to produced Polonium and beta decay electrons. Now given that the mass of Bi-210 is 209.93857 amu, the mass of Po-210 is 209.93678 amu and the mass of an electron is 0.00055 amu, we can calculate the mass defect to be 0.00124 amu. This mass defect is converted to energy in the form of the kinetic energy of the beta decay electron. So from $E = mc^2$ we can gather that the ejected electrons should have a kinetic energy of $0.00124 \times 931.5 = 1.15506\,\mathrm{MeV}$. However this was not what was observed. Instead the electrons had kinetic energies lower than this, as shown in the diagram below.

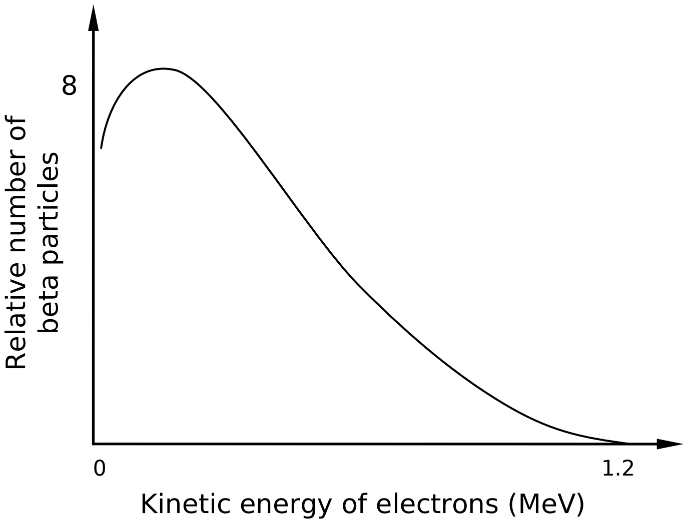


Fig. 138

Pauli noted that the total energy during the beta decay of some atom was not conserved. This incorporated the energy due to mass (i.e. $E = mc^2$) and the mass defect. As the conservation laws must hold, some other particle with energy must have also been emitted, which Pauli named the neutrino. The neutrino has zero or extremely small mass with zero charge.

7. evaluate the relative contributions of electrostatic and gravitational forces between nucleons

Nucleons are protons and neutrons. Protons are positively charged and so their force of electrostatic repulsion is repelling them. This force is quite large. The other force acting on protons is the force of gravity. But this force is very weak because the mass of a proton is very small.

Two protons in a nucleus are about 10^{-15} m apart, and so the force of gravity between these two protons will be about 1.9×10^{-34} N, of attraction. But the electrostatic force is about 230 N, of repulsion. This means that the force of gravity is nowhere near large enough to hold these protons together in the nucleus.

Neutrons have the force of gravity as attraction but this again is extremely weak. Neutrons have no electrostatic force because they are neutrally charged.

8. account for the need for the strong nuclear force and describe its properties

So how can protons exist together in the nuclear with such a strong force of electrostatic repulsion? Well this is where the strong nuclear force comes in. It is this strong nuclear force that holds these protons together in the nucleus. This strong nuclear force acts on both protons and neutrons[1].

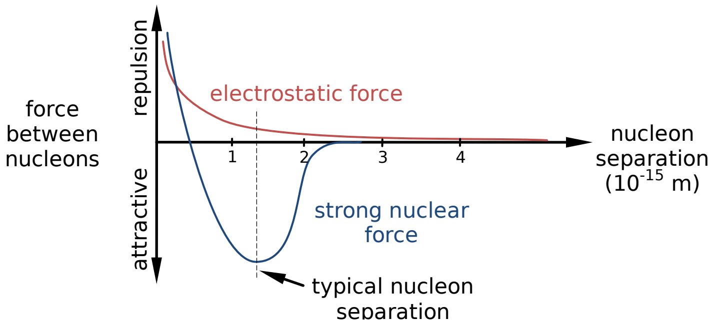


Fig. 139

As seen in the graph above the attractive force of the strong nuclear force is far greater (about 10^4 N) than the repulsive electrostatic force (230 N) at the typical nucleon separation distance. You will also

[1] It should be noted that the strong nuclear force does not act on all particles. The particles that the strong nuclear force acts on are called hadrons and the particles it does not act on are called leptons. Electrons, muons and neutrinos are examples of leptons.

notice that the strong force is only attractive at small distances, i.e. 10^{-15} m. And also that this strong force becomes repulsive at very small distances, i.e. less than the diameter of a nucleon.

9. explain the concept of a mass defect using Einstein's equivalence between mass and energy

The mass of protons and neutrons can be measured to be 1.673×10^{-27} kg and 1.675×10^{-27} kg respectively. The mass of a nucleus of an atom can also be measured. Take helium as an example, it is made up of two protons and two neutrons in the nucleus and its atomic mass is 4.003 amu. However when we add the mass of two protons, two neutrons and two electrons we get a mass of 4.031 amu. This is slightly greater than the measured mass of the atom. The difference in these two masses is known as the mass defect, i.e. mass defect helium is 0.028 amu.

We know that the conservation of mass must hold, so where does this mass go? Well it is converted into energy ($E = mc^2$) called the binding energy which holds the atom together. The graph below shows the binding energy per nucleon graphed against mass number.

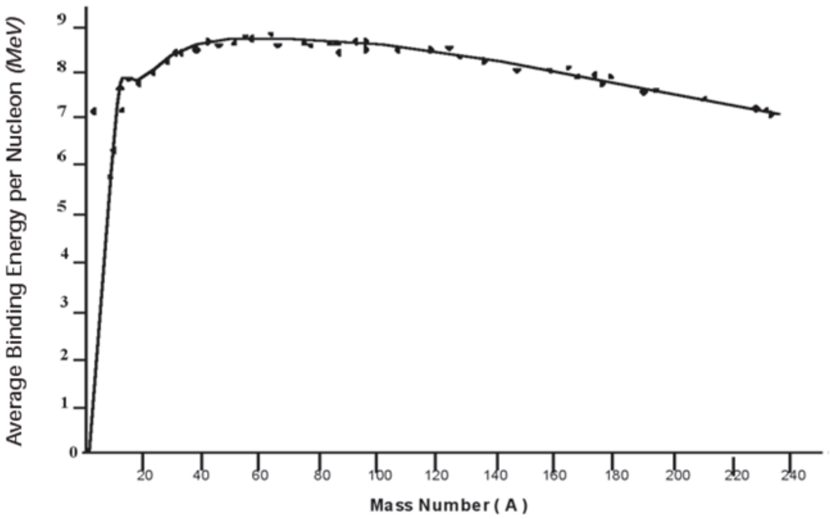


Fig. 140

10. describe Fermi's demonstration of a controlled nuclear chain reaction in 1942

In 1942 Fermi managed to attain a controlled nuclear chain reaction in a squash court at the University of Chicago. He used the entire nation's supply of uranium to do this. Control rods were known to be neutron absorbers and were inserted amongst the uranium. This was done to prevent the reaction from becoming uncontrollable and unstoppable. Geiger counters were used to detect the radiation emitted from the nuclear fission. Neutrons were shot at the uranium and it was noticed that by placing control rods in between the uranium, the detected radiation stabilised and continued at this stable rate. Fermi had achieved a controlled nuclear chain reaction.

11. compare requirements for controlled and uncontrolled nuclear chain reactions

In an uncontrolled nuclear chain reaction, the neutrons produced by the fission of one uranium atom will go on to cause fission to other uranium atoms. This causes an uncontrollable nuclear chain reaction and is what happens in a nuclear bomb.

The requirement for a reaction of this type is sufficient U-235 and a source of initial neutrons.

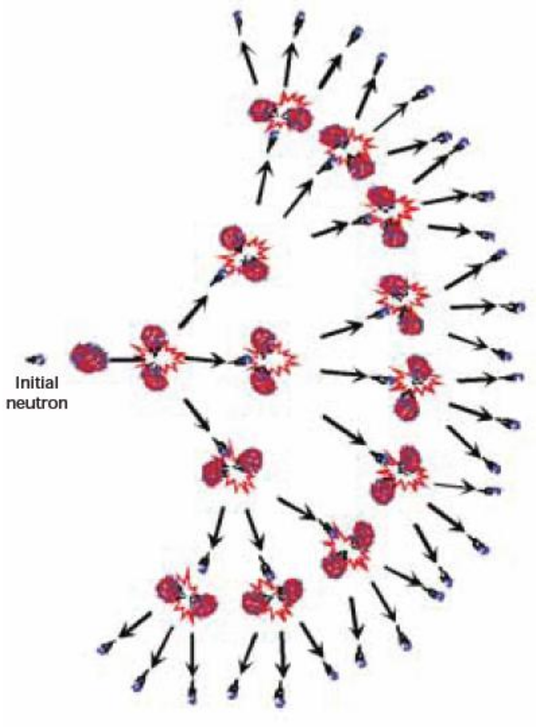


Fig. 141

Roberson, P. L. (2007, June 29). Physics Teacher and Student Workbook. *Physics Excursion Notes and Workbook* , pg17. ANSTO. http://www.ansto.gov.au/__data/assets/pdf_file/0007/8863/PhysicsLR.pdf.

The energy released from an uncontrolled nuclear chain reaction is exponential.

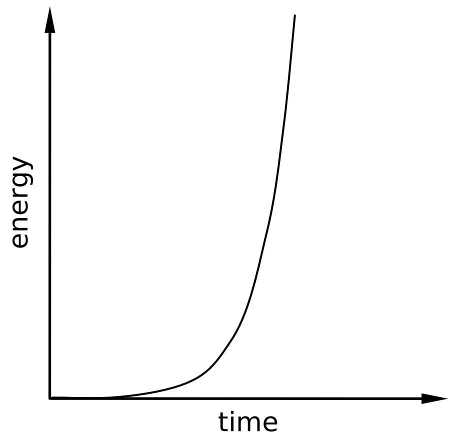


Fig. 142

In a controlled nuclear chain reaction control rods and a moderator are present. The control rods (usually cadmium) absorb extra neutrons (this reduces the amount of fission), and the moderator (usually graphite) slows down the neutrons. This is the type of reaction that occurs in nuclear power plants.

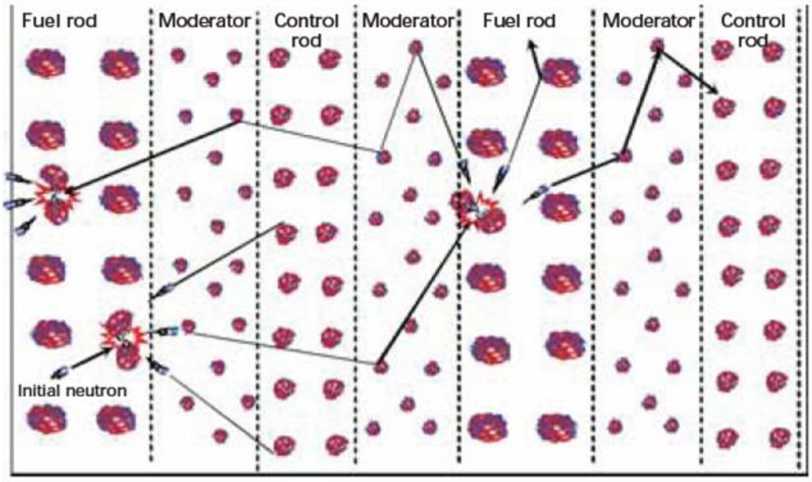


Fig. 143

Roberson, P. L. (2007, June 29). Physics Teacher and Student Workbook. *Physics Excursion Notes and Workbook* , pg17. ANSTO. http://www.ansto.gov.au/__data/assets/pdf_file/0007/8863/PhysicsLR.pdf.

The energy released from a controlled nuclear chain reaction is exponential but quickly flattens out due to the presence of the control rods.

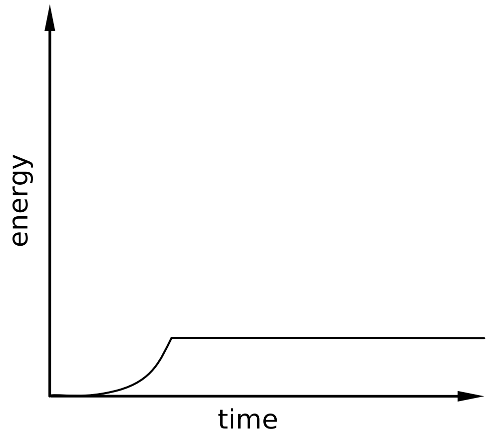


Fig. 144

1. perform a first-hand investigation or gather secondary information to observe radiation emitted from a nucleus using Wilson Cloud Chamber or similar detection device

A Wilson Cloud Chamber contains a radioactive source and a gas vapour. Alpha, beta and gamma radiation can be detected and the path can be observed by observing the ionisation of the vapour that is caused by the radiation. Although it is particularly good at detecting alpha particles.

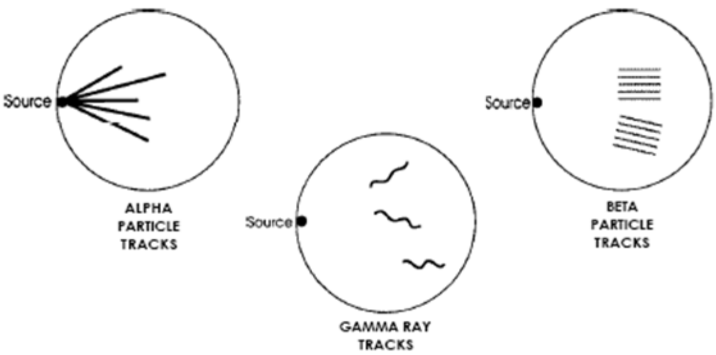


Fig. 145

Hawkins, G., at el. (1996). *Getting it to Work: Physics Equipment for High Schools.* pg 11. NSW Department of School Education. http://www.schools.nsw.edu.au/media/downloads/schoolsscience/learning/yr11_12/science/physics/cloud.pdf

2. solve problems and analyse information to calculate the mass defect and energy released in natural transmutation and fission reactions

When calculating the mass defect and energy released in natural transmutation and fission reactions there are many different units that may be used and you need to be aware of.

Atomic mass unit (amu) is used to measure masses on the atomic level.

$$\begin{aligned} 1\ \text{amu} &= 1.661 \times 10^{-27}\ \text{kg} \\ &= 931.5\ \text{MeV}/c^2 \end{aligned}$$

Also another unit of energy is electron volt (eV).

$$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$$

Mass defect can be given by,

$$\text{mass defect} = \text{predicted mass of components} - \text{atomic mass of atom}$$

To calculate the binding energy just use $E = mc^2$, where m is the mass defect and E is the binding energy.

4. An understanding of the nucleus has led to large science projects and many applications

1. explain the basic principles of a fission reactor

Nuclear fission reactors release nuclear energy by breaking apart large unstable isotopes. In a fission reactor a controlled chain reaction occurs and to facilitate this control rods are used. The energy released by this fission is used to heat water and produce steam which turns a turbine to produce electricity. The main components of a fission reactor are:

Fuel Rods – The fuel rods consist of enriched uranium (U-238, with a high concentration of U-235). It is within the fuel rods that fission occurs.

Moderator – The moderator slows the neutrons produced by the fission of uranium. This gives the neutrons a much greater chance of being captured into other uranium nuclei and causing fission to occur again. Fermi used graphite as a moderator while modern reactors use heavy water.

Control Rods – The control rods regulate the number of neutrons available to produce fission. They do this by absorbing neutrons, thus making less free neutrons available to cause fission. Control rods allow the rate of fission reactors to be controlled. Control rods are usually made from substances such as cadmium or boron.

Heat Exchanger – The heat exchanger is used to extract the energy produced from the fission reactions. It also cools the core to prevent overheating.

The diagram below shows the basic principles of a fission reactor. The heated water that comes out is passed through other water, which turns to steam which turns a turbine.

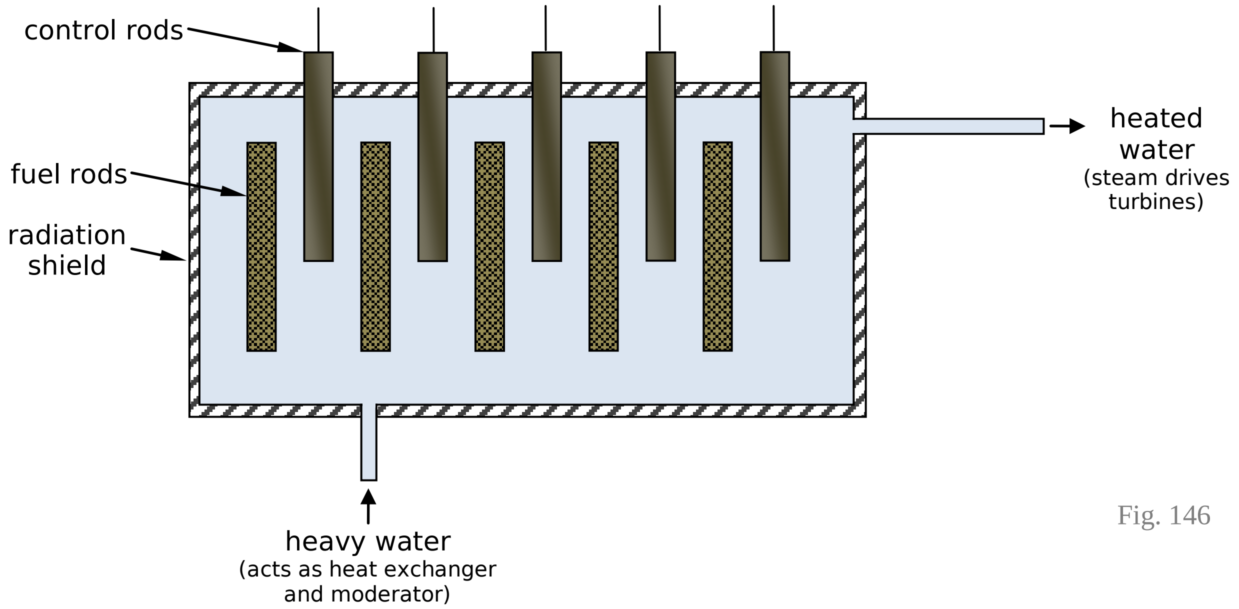


Fig. 146

2. describe some medical and industrial applications of radio-isotopes

Radio-isotopes are unstable elements that emit radiation.

Medical applications of radio-isotopes include:

- **Detecting Cancers** – **Tc-99m** (Metastable Technetium-99) is a radio-isotope used in medicine as a tracer to detect abnormal cell growths (ie. cancer) and blood flow abnormalities. Tc-99m is used as it has a short half life of several hours, attaches to biological carriers and is easily excreted. It is injected into the patient's blood stream and is observed by the gamma radiation that it emits.

$$^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + \gamma$$

- **Kill Cancers** – Radiation from the radio-isotopes is used to kill the cancerous cells. **Cobalt-60** can be implanted into the tumour and over time the release of gamma radiation will kill the nearby cancerous cells. Alternatively, gamma radiation from the radioactive decay of cobalt-60 may be directed at the cancer from outside the body.

- **Sterilise Equipment** – Gamma radiation emitted by cobolt-60 can be used to kill viruses and bacteria on surgical equipment.

Industrial applications of radio-isotopes include:

- **Thickness Control** – The thickness of materials can be measured by detecting how much radiation that is exposed to the material, penetrates it. The amount of radiation that makes it through will tell you how thick the material is. This is used in the manufacture of metal, plastic, glass, paper, etc.

- **Smoke Detectors** – Smoke detectors are used industrially as a safety measures in factories. Fire Alarms contain **Americium-241** which radioactively decays producing alpha particles.

$$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ^{4}_{2}He$$

When no smoke is present, the alpha particles ($^{4}_{2}He$) emitted from the Am ionise nitrogen and oxygen in the air in the detector. However when smoke is present, it absorbs the alpha particles so the rate of ionisation drops and this sets off the alarm.

- **Electricity Production** – Heat produced by the decay of **Plutonium-238** can be converted into electricity.

3. describe how neutron scattering is used as a probe by referring to the properties of neutrons

Neutron scattering refers to firing many neutrons at a sample. The neutrons then scatter and statistical analysis on this scattering pattern can be used to determine the structure of matter.

Because neutrons have a **neutral charge** they can enter the nucleus of atoms much easier than protons.

Also neutrons have a **de-Broglie wavelength** about that of the spacing between atoms in crystal lattices and their energy is similar to that of the lattice vibrations. This makes them especially useful for investigating the structure of matter. They also have great penetrating ability.

“Even though they pose no electrical charge, neutrons are like little flying magnets. This is because they exhibit a **'magnetic moment'**. This comes about because the neutron's zero charge is actually made up of a positive charge and a negative charge that cancel each other out. The distribution of the positive and negative charges is different, so a spinning neutron acts like a spinning cloud of charge (or a magnetic field) that interacts with any unpaired electron in an atom. Thus neutrons can not only reveal the internal physical structure of a substance, but they can expose the normally invisible lines of magnetic flux as well.”

4. identify ways by which physicists continue to develop their understanding of matter, using accelerators as a probe to investigate the structure of matter[1]

As seen in the study of the standard model of matter, there are many subatomic particles. These are investigated by particle accelerators, in which charged particles are sped up to high speeds/energies and collided with other particles and atoms. Beams of very high-energy particles are produced which can be used to probe the structure of matter.

The main types of particle accelerators in use are linear accelerators, cyclotrons and synchrotrons.

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[1] This dot point requires you to “*identity* the methods”, so to me all you need to do is no know of linear accelerators, cyclotrons, synchrotrons, etc. And as these are never named specifically and you are never asked to *describe*, then I would presume that just knowing the names of these particle accelerators would be enough. Nonetheless, in the 2006 HSC Physics Exam, you were required to “*explain* the physical principles involved in the design of the cyclotron,” and so I have included a little more information here than I initially presumed was required.

In **linear accelerators**, protons or electrons are passed through evacuated drift tubes. These drift tubes have alternating charge, and alternating polarity with the frequency of the AC current. For the process to work, the tubes must get longer as the particle gets faster. The most famous linear accelerator in existence is the Stanford Linear Accelerator which can accelerate electrons up to 99.99% of the speed of light.

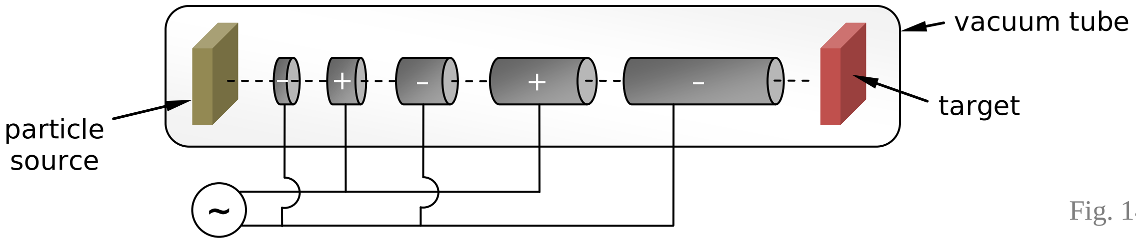


Fig. 147

The **cyclotron**, shown below from the top view, consists of two D-shaped objects with open edges. The dees form an alternating potential difference provided by the oscillator. The dees are also in a magnetic field and are in a vacuum. "The charged particle enters near the centre of the cyclotron and is accelerated across the gap by the potential difference between the chambers. The magnetic field then deflects the charged particle in a semi-circular path inside the chamber until it again reaches the gap between the chambers. While the particle is in the chamber the polarity of the AC current between the chambers changes so that the charged particle is always accelerated between the gaps. It accelerates across the gap twice with each revolution and after many revolutions it emerges with a very high energy."[1]

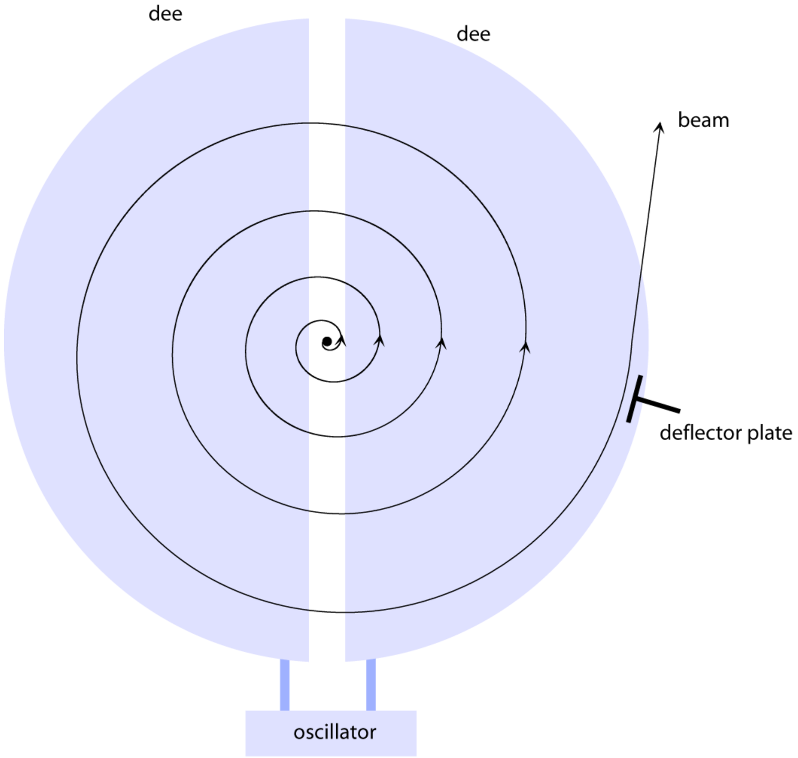
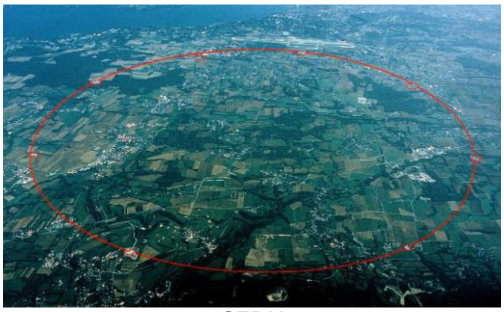


Fig. 148

The **synchrotron accelerator**, consists of a single circular evacuated tube. This is the accelerator used at Fermilab and at CERN.

[1] Retrieved from Caresa Education Services, *From Quanta to Quarks*, http://www.caresa.com.au/quantadp.htm, (Retrieved August 2007).

Fermilab



CERN

Fig. 149

5. discuss the key features and components of the standard model of matter, including quarks and leptons

According to the standard model of matter, **quarks** and **leptons** are the fundamental building blocks of the universe. First generation quarks and leptons are the most common particles, however higher generation particles and first generation antiparticles are only really seen in particle accelerators, etc. (with the exception of the positron and the neutrino.)

The standard model is made up of 24 particles (all fermions). There are 12 leptons/anti-leptons in 3 generations and 12 quarks/anti-quarks, which come in 6 flavours and in 3 generations. The table below shows the organisation of these fermions (each also has their anti counterpart which is denoted by the symbol with a bar on top, with the exception of the anti-leptons, e^+, μ^+, τ^+, which have a $^+$ rather than a bar, $\bar{\ }$).

	Generation 1			Generation 2			Generation 3		
Quarks	Up	u	$+\frac{2}{3}e$	Charm	c	$+\frac{2}{3}e$	Top	t	$+\frac{2}{3}e$
	Down	d	$-\frac{1}{3}e$	Strange	s	$-\frac{1}{3}e$	Bottom	b	$-\frac{1}{3}e$
Leptons	Electron Neutrino	v_e	0	Muon Neutrino	v_μ	0	Tau Neutrino	v_τ	0
	Electron	e	-1	Muon	μ	-1	Tau	τ	-1

Hadrons (particles that contain quarks) come in two kinds, mesons and baryons. Mesons are made up of a quark and an anti-quark, and baryons are made up of three quarks (or three anti-quarks).

Therefore, protons and neutrons are baryons. **Protons** are uud (two up quarks and one down quark) and **neutrons** are udd (one up quark and two down quarks).

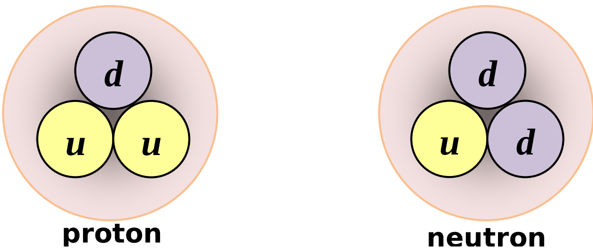


Fig. 150

The other component of the standard model, apart from the particles, is the interactions, i.e. the forces. There are four kinds of forces, those being the, gravity force, electromagnetic force, weak force and fundamental strong force. Each of these forces has an exchange boson.

Force	Exchange Boson
Gravity	graviton
Electromagnetic	photon
Weak	W^+, W^-, Z^0
Fundamental Strong	gluon

1. gather, process and analyse information to assess the significance of the Manhattan Project to society

The Manhattan Project was the project that developed the atomic bomb during World War II.

"The most profound effect on society was the **death of several hundred thousand people** in Hiroshima and Nagasaki as the result of the atomic bomb dropped on each and the massive destruction that resulted. However, some argue that dropping the bomb **shortened the war** and resulted in less people being killed than if the war had continued.

The Manhattan Project led to the **increased knowledge and understanding of nuclear processes**. This has enabled the technology to be used for peaceful purposes such as the **production of electricity** by nuclear power stations but with this comes the danger of nuclear **accidents** such as that at **Chernobyl** and the problem of disposing of **nuclear wastes**. It has also facilitated the development of **nuclear isotopes used in medicine, industry and agriculture**."[1]

2. identify data sources, and gather, process, and analyse information to describe the use of:

- a named isotope in medicine

See medical above.

- a named isotope in agriculture

In agriculture, food is often irradiated to prevent foods such as fruit and vegetables from going off. The food is sprayed with **cobolt-60**. As this is a radio-isotope it produces, gamma radiation which kills bacteria.

- a named isotope in engineering

In engineering radio-isotopes are used to assess the integrity of metal objects. Gamma rays have a shorter wavelength than x-rays and as such they are more penetrating. A radio-isotope that emits gamma radiation, such as **iridium-192** can be shielded on the outside, but still allow gamma rays out in one direction, a detector such as photographic film could be placed on the other side of the metal and an image will develop on the film. This allows metals and welds to be examined for holes, cracks, or other abnormalities that may decrease the strength of the material.

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1 *From Quanta to Quarks*, Retrieved from Caresa Education Services: http://www.caresa.com.au/quantadp.htm

9.8 TOPIC REVIEW

Summary

- The Rutherford model of the atom has a central nucleus with electrons orbiting around it. Bohr's model of the atom had the orbiting electrons in energy levels. They are at quantised energy levels (i.e. discreet radii) and they can move between levels by absorbing or emitting energy.
- Bohr's postulates are that the electrons are stable in their shells; electrons can move between shells by absorbing/emitting energy in discreet packets; and angular momentum of orbiting electrons is quantised.
- Planck said that energy was quantised in discreet packets of energy. This is given by the formula, $E = hf$.
- Bohr's postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum.
- However the Bohr model had limitations.
- The Balmer series is when the emission spectra when electrons fall down to shell two. It is in the visible spectrum.
- de Broglie's proposed that any kind of particle has both wave and particle properties. This hypothesis was confirmed by Davission and Germer, who observed electrons to diffract (a property of waves).
- de Broglie's hypothesis explains the stability of the electron orbits, as waves at in between shells will collapse.
- Heisenberg's is known for the Heisenberg Uncertainty Principle, and Pauli is known for the Pauli Exclusion Principle and his prediction of the neutrino.
- Protons and neutrons are found in the nucleus of atoms and are known as nucleons.
- Chadwick discovered the neutron. The conservation of energy and conservation of momentum laws resulted in the discovery.
- Transmutation is the changing of one element into another by nuclear reactions. Large unstable elements naturally decay into smaller elements in an aim to become more stable.
- Fermi was the first to observe nuclear fission.
- Pauli suggested the existence of the neutrino. The suggestion was due to the need to account for the energy distribution of electrons emitted in β-decay.
- The strong nuclear force is needed to hold the nucleons together.
- The mass defect of an atom is due to the binding energy needed to hold it together.
- Fermi demonstrated a controlled nuclear chain reaction in 1942 in a squash court.
- A Wilson Cloud Chamber can be used to detect radiation.
- A fission reactor contains fuel rods, a moderator, control rods and a heat exchanger.
- Medical applications of radio-isotopes include detecting and killing cancers and sterilising equipment. Industrial applications include thickness control, smoke detectors and electricity production.

- Neutron scattering is used as a probe due to their neutral charge, suitable de-Broglie wavelength and magnetic moment.
- Particle accelerations such as the linear accelerator, cyclotron and synchrotron are used to accelerate charged particles to high speeds to probe the structure of matter.
- Under the standard model of matter, quarks and leptons are the fundamental particles. They come in six different flavours and combine to form baryons (such as protons and neutrons) and mesons. The standard model of matter also describes the four fundamental forces in terms of their exchange boson.
- The Manhattan Project was the project that developed the atomic bomb during World War II. It had a huge impact on society.
- Cobolt-60 is used to irradiate food in agriculture and iridium-192 is used in engineering to inspect materials for damage.

GLOSSARY OF KEY WORDS

Account	Account for: state reasons for, report on. Give an account of: narrate a series of events or transactions
Analyse	Identify components and the relationship between them; draw out and relate implications
Apply	Use, utilise, employ in a particular situation
Appreciate	Make a judgement about the value of
Assess	**Make a judgment** of value, quality, outcomes, results or size
Calculate	Ascertain/determine from given facts, figures or information
Clarify	Make clear or plain
Classify	Arrange or include in classes/categories
Compare	Show how things are **similar or different**
Construct	Make; build; put together items or arguments
Contrast	Show how things are different or opposite
Critically (analyse/ evaluate)	Add a degree or level of accuracy depth, knowledge and understanding, logic, questioning, reflection and quality to (analysis/evaluation)
Deduce	Draw conclusions
Define	**State meaning** and **identify essential qualities**
Demonstrate	Show by example
Describe	Provide **characteristics** and **features**
Discuss	Identify issues and provide points **for and/or against**
Distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
Evaluate	**Make a judgement** based on criteria; determine the value of
Examine	Inquire into
Explain	Relate **cause and effect**; make the relationships between things evident; provide why and/or how
Extract	Choose relevant and/or appropriate details
Extrapolate	Infer from what is known

Identify	Recognise and name
Interpret	Draw meaning from
Investigate	Plan, inquire into and draw conclusions about
Justify	**Support an argument or conclusion**
Outline	Sketch in general terms; indicate the main features of
Predict	Suggest what may happen based on available information
Propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
Recall	Present remembered ideas, facts or experiences
Recommend	Provide reasons in favour
Recount	Retell a series of events
Summarise	Express, concisely, the relevant details
Synthesise	Putting together various elements to make a whole

Board of Studies NSW. (2007, July 27). *A Glossary of Key Words (HSC)*. Retrieved from Board of Studies NSW: http://www.boardofstudies.nsw.edu.au/syllabus_hsc/glossary_keywords.html

SAMPLE INDEPENDENT INVESTIGATION

Practical experiences are an essential component of both the Preliminary and HSC courses. Students will complete 80 indicative hours of practical/field work across both the Preliminary and HSC courses with no less than 35 indicative hours of practical experiences in the HSC course. Practical experiences have been designed to utilise and further develop students' expertise in each of the following skill areas:

• planning investigations
This involves increasing students' skills in planning and organising activities, effectively using time and resources, selecting appropriate techniques, materials, specimens and equipment to complete activities, establishing priorities between tasks and identifying ways of reducing risks when using laboratory and field equipment.

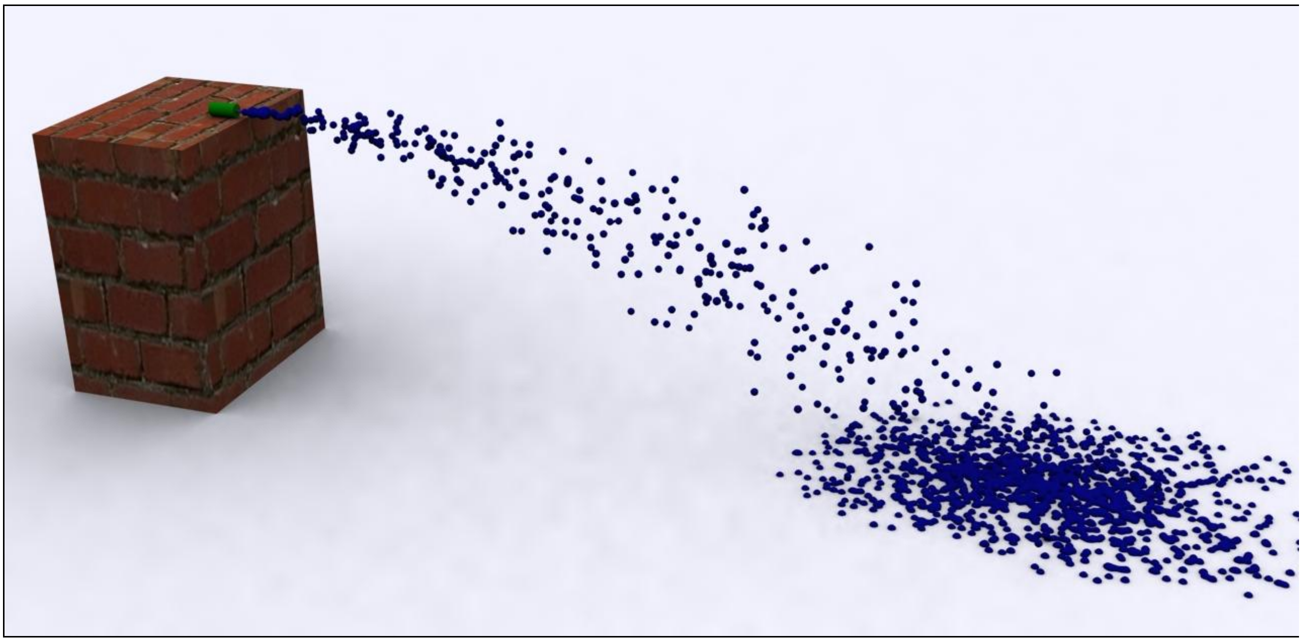
• conducting investigations
This involves increasing students' skills in locating and gathering information for a planned investigation. It includes increasing students' skills in performing first-hand investigations, gathering first-hand data and accessing and collecting information relevant to physics from secondary sources using a variety of technologies.

• communicating information and understanding
This involves increasing students' skills in processing and presenting information. It includes increasing students' skills in speaking, writing and using nonverbal communication, such as diagrams, graphs and symbols to convey physical information and understandings. Throughout the course, students become increasingly efficient and competent in the use of both technical terminology and the form and style required for written and oral communication in physics.

• developing scientific thinking and problem-solving techniques
This involves further increasing students' skills in clarifying issues and problems relevant to physics, framing a possible problem-solving process, developing creative solutions, anticipating issues that may arise, devising appropriate strategies to deal with those issues and working through the issues in a logical and coherent way.

• working individually and in teams
This involves further increasing students' skills in identifying a collective goal, defining and allocating roles and assuming an increasing variety of roles in working as an effective member of a team within the agreed time frame to achieve the goal. Throughout the course, students will be provided with further opportunities to improve their ability to communicate and relate effectively with each other in a team.

Determining the Average Muzzle Velocity of a Water Pistol



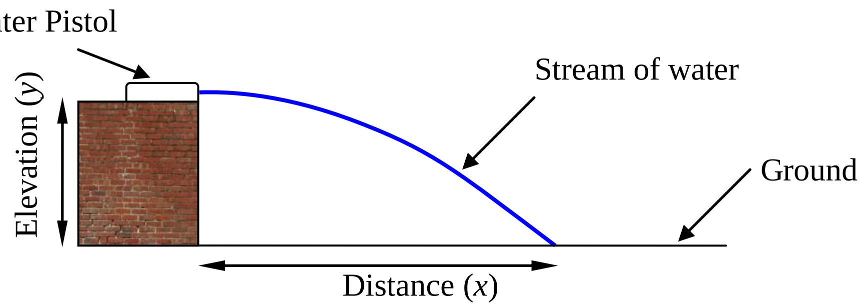
Andrew Harvey
12 PHYSICS

Aim:
To determine the average muzzle velocity of a water pistol.

Variables:

Independent (Change)	**Dependent (Measure)**	**Control (Same/Constant)**
Nothing.	Distance (horizontal)	Value of *g* (ie. mass of earth and radius of earth + elevation) Water Pistol Amount of water in the water pistol Substance be fired from the water pistol (water) Elevation of water pistol Angle of water pistol Air density Flow of air around experiment (Do indoors where there is less wind) Velocity of frame of reference (earth) Altitude of ground (flat surface) Elevation of water pistol (vertical height) Force on trigger

Apparatus:



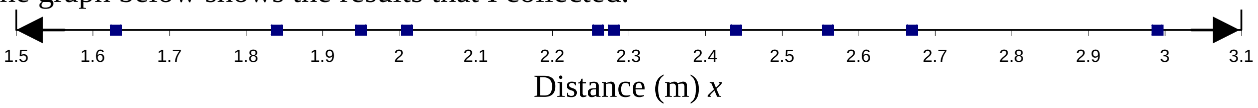
Procedure:

1. Fix the *water pistol* at an angle of 0° to the horizontal, at a constant elevation.
2. Place a ruler along the line of action of the *water pistol*, placing 0 directly below the *water pistol muzzle*, keeping the ruler horizontal.
3. Fire the *water pistol*, by slowly applying a constant force on the trigger.
4. Measure the approximate average distance (x) the water traveled.
5. Repeat step 3 and 4 multiple times. Each time keep the things in the same/constant column the same.
6. Record results.
7. Calculate average.

Data Recorded/Data:

Fire Number	Distance (m) x	Elevation (m) y	Initial Velocity (ms^{-1})
1	2.28	0.455	7.482
2	2.99	0.455	9.812
3	1.63	0.455	5.349
4	2.44	0.455	8.007
5	2.56	0.455	8.401
6	1.95	0.455	6.399
7	2.26	0.455	7.417
8	2.67	0.455	8.762
9	2.01	0.455	6.596
10	1.84	0.455	6.038

The graph below shows the results that I collected.



Calculations:

Process

Use $v_y^{\ 2} = u_y^{\ 2} + 2a_y\Delta y$ to find v_y ($u_y = 0$, $a = 9.8$, $\Delta y =$ elevation)

Then use $v = u + at$ to find t ($v = v_y$, $u = 0$, $a = 9.8$)

Then use $\Delta x = u_x t$ to find u_x ($\Delta x =$ horizontal distance)

u_x will equal $\left|\vec{u}\right|$ because the water is launched horizontally, thus there is no vertical motion at the beginning. The direction of u_x will always be along the line of action of the water pistol.

Actual Calculations

①

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.28 \times 9.8}{\sqrt{19.6 \times 0.455}} = 7.482ms^{-1}$$

②

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.99 \times 9.8}{\sqrt{19.6 \times 0.455}} = 9.812ms^{-1}$$

③

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{1.63 \times 9.8}{\sqrt{19.6 \times 0.455}} = 5.349ms^{-1}$$

④

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.44 \times 9.8}{\sqrt{19.6 \times 0.455}} = 8.007ms^{-1}$$

⑤

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.56 \times 9.8}{\sqrt{19.6 \times 0.455}} = 8.401ms^{-1}$$

⑥

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{1.95 \times 9.8}{\sqrt{19.6 \times 0.455}} = 6.399ms^{-1}$$

⑦

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.26 \times 9.8}{\sqrt{19.6 \times 0.455}} = 7.417ms^{-1}$$

⑧

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.67 \times 9.8}{\sqrt{19.6 \times 0.455}} = 8.762ms^{-1}$$

⑨

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{2.01 \times 9.8}{\sqrt{19.6 \times 0.455}} = 6.596ms^{-1}$$

⑩

$$u = \frac{x \times 9.8}{\sqrt{19.6 \times y}} = \frac{1.84 \times 9.8}{\sqrt{19.6 \times 0.455}} = 6.038ms^{-1}$$

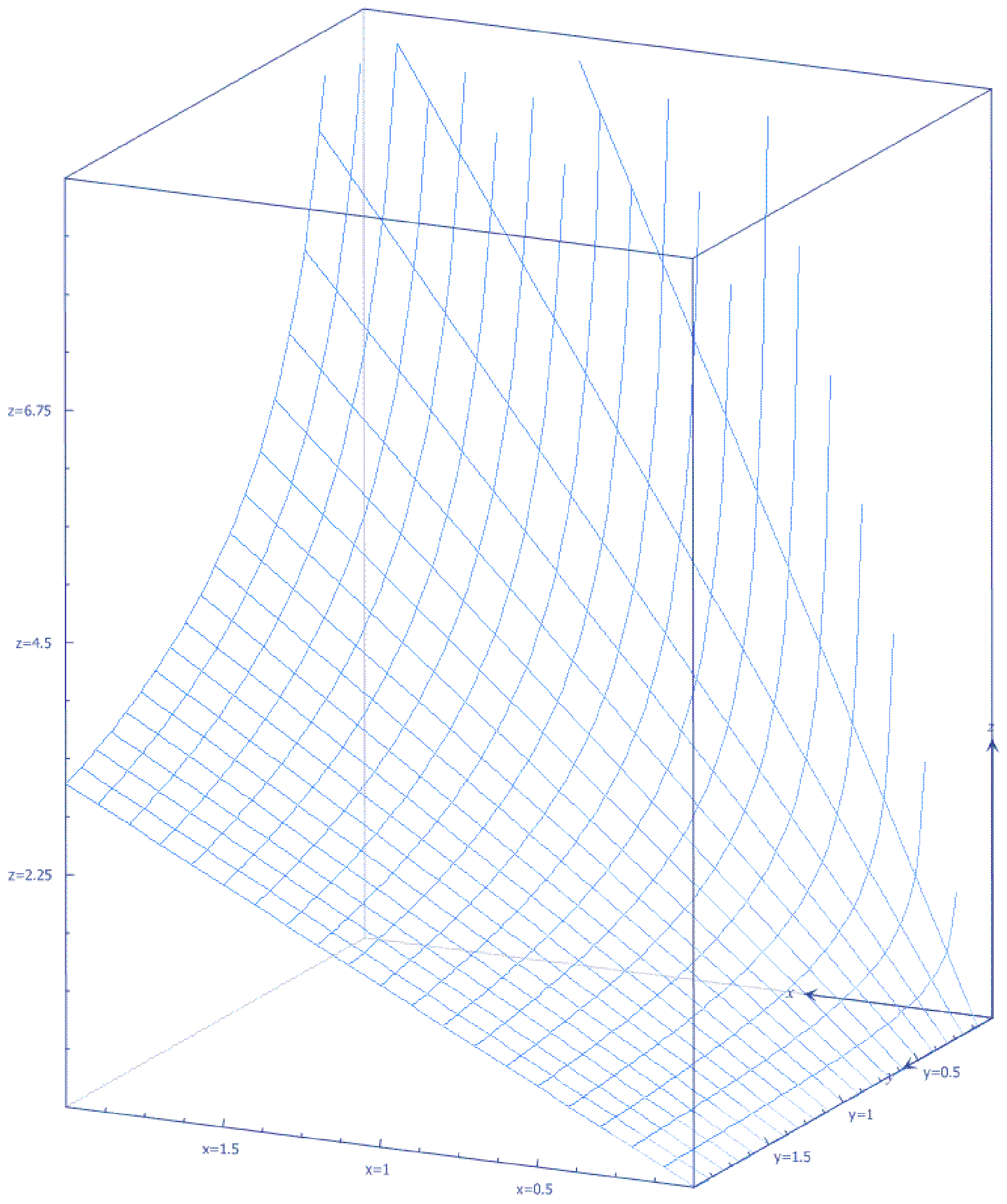
The Function

The relationship between horizontal distance, vertical height, and initial velocity can be determined, and is given by:

$$u = \frac{7x}{5} \cdot \sqrt{\frac{\left(\frac{5}{2}\right)}{y}} \qquad \textbf{OR} \qquad u = \frac{x \times 9.8}{\sqrt{19.6 \times y}}$$

Where,
u = initial velocity
x = horizontal distance
y = vertical height

The graph of this relationship is shown below, (where z axis is u)



Statistical Analysis of Data
Average horizontal distance: 2.263 m
Range horizontal distance: 1.36 m

Average initial velocity: 7.4263ms^{-1}
Initial Velocity Standard Deviation: 1.294

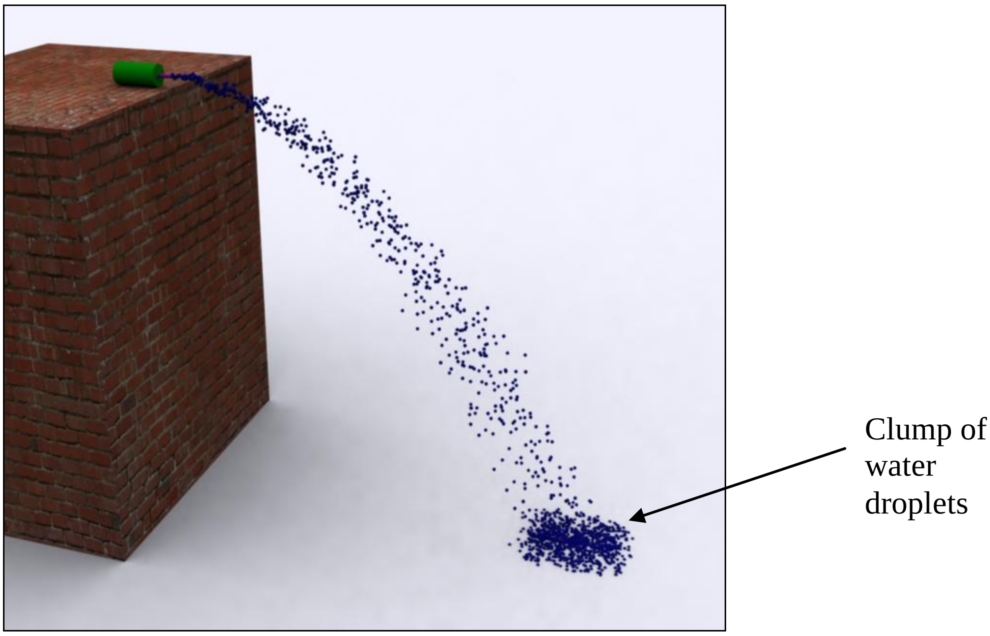
Discussion of Reliability and Conclusion:

Using this method and these calculations eliminates the need for measuring time, which would be impractical and unreliable, especially as it is a stream of water not a single object, and given that the time of flight is relatively short.

Also the lower the height then the less horizontal distance traveled, and thus less affected by air resistance (as my formula used do not account for air resistance), and thus a more accurate velocity, however the greater the horizontal distance, the more accurate your measurements are. But also if the height is too high then the water will reach its terminal velocity and thus the results would be less reliable. Also different values of height result in different values of *g*. So this should be taken into account and *g* should be calculated. However even if you change your height 100m the value of *g* will only change by 0.0003.

The reliability of this experiment was also decreased because the trigger of the water pistol was controlled by a human, this leads to the problem that a human cannot apply the same amount of force on the trigger every time.

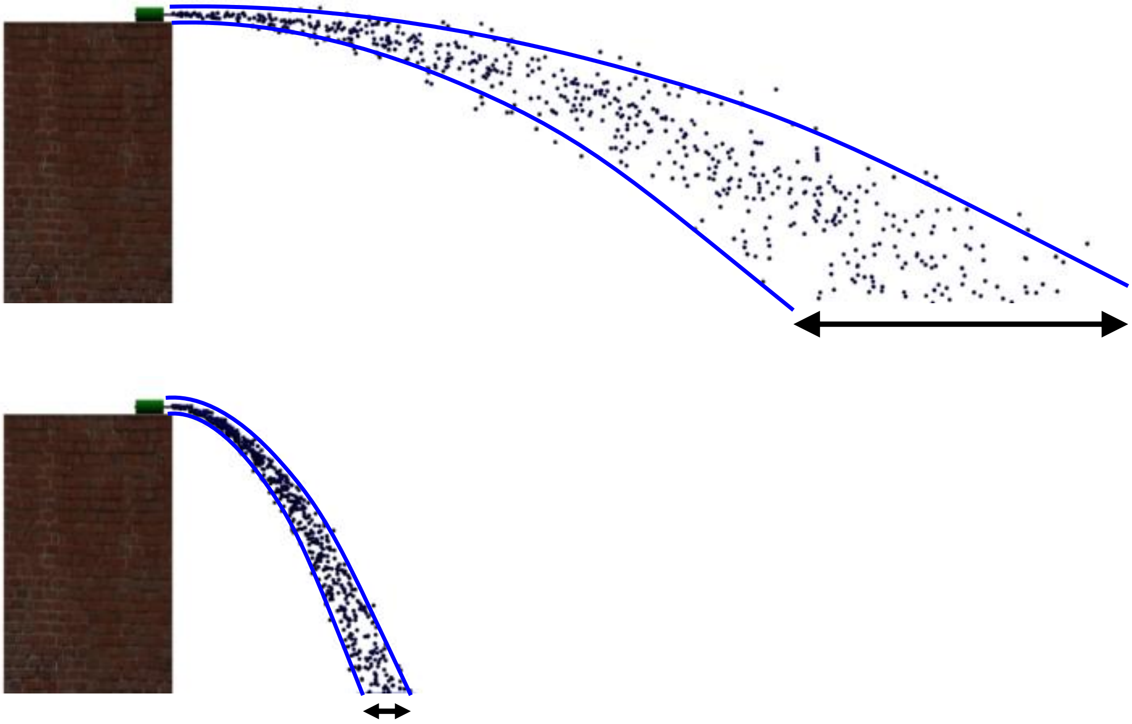
There are flaws in my method and thus this experiment is less reliable. This can be explained with the diagram below.



As you can see above, when the water pistol is fired, the water initially follows one line and stays stuck together, however after just falling slightly in height, the water disperses, and once it lands on the ground there are many different droplets in different places. In order to correctly fulfill the aim of the experiment, I would need to measure the distance from the position of every one of those droplets landed at, to the wall directly underneath the water pistol muzzle. Then take the *average* of all those distances. However there are far too many droplets for this to be done. Not to mention the problem of when 2 or more drops land on the same spot, as you wouldn't know if only one drop or if there were multiple drops that landed in that position, as this would affect the average.

The standard deviation of the data was quite high, so this means that the experiment is not very reliable.

The ratio of elevation to average distance was 455:2263. So the distance was quite long compared to the height. This is bad in terms of experiment reliability because the long distance means that there is more dispersion of the water droplets, and the water is more affected by air resistance. The reason for the dispersion error is shown in the figure below. As you can see the further the water went, the more it spread out.



The only way to compensate of this is to increase the height. However as mention previously, this also has adverse effects, unless in a vacuum.

As with any experiment, it could have repeated it more times to get a more accurate result.

Another factor that could have affected the reliability of my experiment was air currents (wind). This is a problem because non zero air currents are not taken into account in the formula that were used. This can be controlled to a certain extent by conducting the experiment indoors, without the fans on.

A problem also arose by trying to apply a constant force to the trigger, for the duration of the firing, and also each time the water pistol is fired. This could be controlled using a spring balance attached to the trigger. But this method has a factor of human error, so it could be automated with a robot.

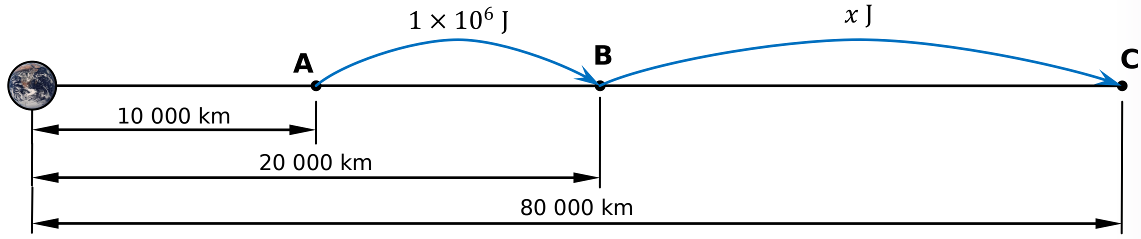
Conclusion:

The average muzzle velocity of my water pistol was 7.4263ms^{-1}, in the direction that the water pistol was oriented.

TOPIC REVIEW SOLUTIONS

9.2 Space – Review Questions Solutions

Q1. Firstly you need to know "that a change in gravitational potential energy is related to work done", which is the second syllabus dot point. Now it may be a bit clearer if we draw a diagram.



We know that the work done needed to move the object within the planets gravitational field will be equal to the change in gravitational potential energy of the object. So,

$$GPE_B - GPE_A = 1 \times 10^6$$

$$\frac{-Gm_1m_2}{20 \times 10^6} - \frac{-Gm_1m_2}{10 \times 10^6} = 1 \times 10^6$$

$$(-Gm_1m_2) - (-2Gm_1m_2) = (1 \times 10^6) \times (20 \times 10^6) = 2 \times 10^{13}$$

$$-Gm_1m_2 + 2Gm_1m_2 = 2 \times 10^{13}$$

$$Gm_1m_2 = 2 \times 10^{13}$$

Using the same method,

$$GPE_C - GPE_B = x$$

$$\frac{-Gm_1m_2}{80 \times 10^6} - \frac{-Gm_1m_2}{20 \times 10^6} = x$$

$$\frac{-2 \times 10^{13}}{80 \times 10^6} - \frac{-2 \times 10^{13}}{20 \times 10^6} = -250 \times 10^3 + 1 \times 10^6 = 750\ 000\ \text{J} = 750\ \text{kJ}$$

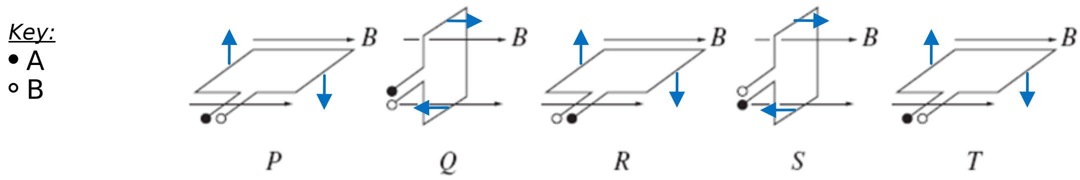
9.3 Motors and Generators – Review Questions Solutions

Q1. (D) $F = BIl \sin\theta = 0.5 \times 3 \times \sqrt{0.4^2 + 0.4^2} \times \sin 90° = 0.849$ N

The key thing here, I guess, is not to use 45° in the formula. If you use the right hand push rule, placing fingers down into the page, and thumb in the direction of the current, you can see that the angle between fingers and thumb (which is the θ in the formula) is 90°.

The other thing is make sure you don't use 0.4 as the length, you must use Pythagoras theorem to find the length.

Q2. (B) There are several ways to solve this question. The first way is using the right hand push rule to determine the direction of the induced current. Using this will tell you where the direction of the current changes direction, which is where the induced emf is zero.

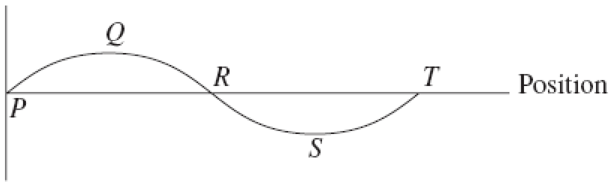


Now, placing the fingers pointing to the right, as the magnetic field is to the right, and at point P the thumb is down for the LHS (ie. A), so the electron flow will be from B to A. Next at Q, this is where the direction of the current is changing, so induced emf will be zero. This means that the correct answer is either B or C. Now the current will not be zero at R so B must be the correct answer.

The second way to solve this question is to use the fact that,

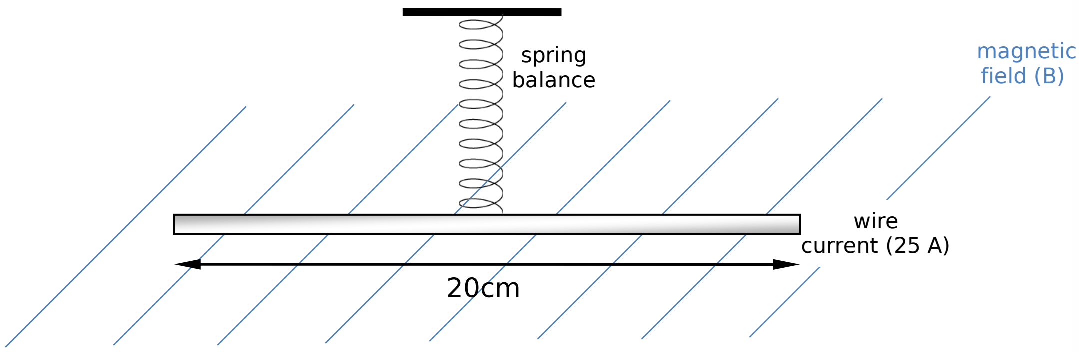
$$\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}n$$

, where Φ_B is magnetic flux (inside the coil). Now we know that Area = xy. In this case the depth will always be the same, but the vertical component will change. The vertical component will be given by sin theta. And will be zero at P, R and T, and max at Q and S.

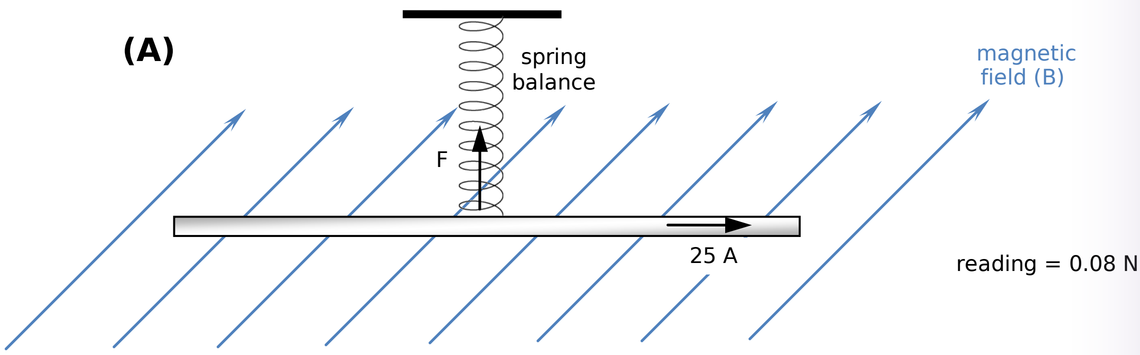


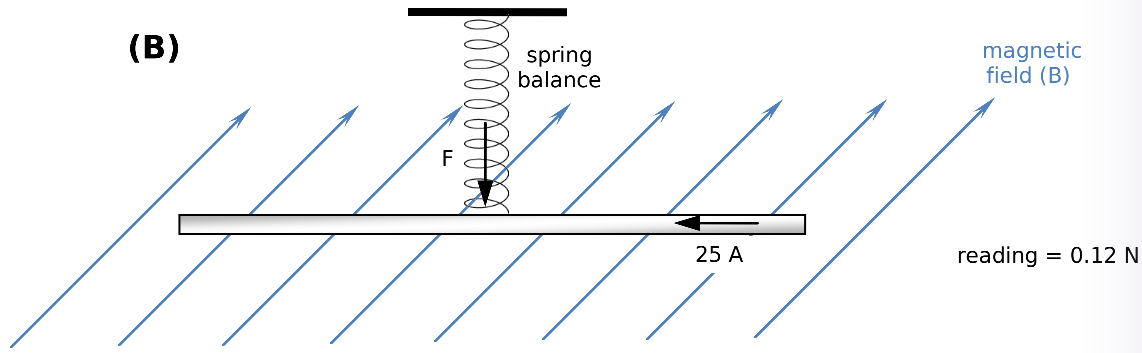
Now the derivative of this will yield induced emf, which is the option B.

Q3. (A) The first thing you should do is draw a diagram showing the information given in the question. This is shown below.



The question describes two situations, I shall refer to these as (A) and (B), as shown below.





I have drawn the two situations with the current in the different directions, I does not matter which way you choose to direct the magnetic field. This will not affect the answer. Note also that I have shown the force on the wire, I have worked this out from the right hand push rule. Also from the direction of the force we can determine which apparatus will yield which reading. As when the force is acting down the reading will be more than when the force is acting up.

The spring balance measures force, and there are two forces acting on the wire. They are the weight force and the force due to the current flowing through the wire in the presence of a magnetic field. Hence in situation (A) the net force on the wire which will be equal to the reading is given by,

$$F = mg - BIl$$

$$mg = 0.08 + BIl$$

And for situation (B),

$$F = mg + BIl$$

$$mg = 0.12 - BIl$$

As the mass of the wire and g are the same we can equate the two equations.

$$0.12 - BIl = 0.08 + BIl$$

$$0.02 = BIl$$

As we know the current and the length of the wire,

$$B = \frac{0.02}{25 \times 200 \times 10^{-3}} = 4 \times 10^{-3}\ \mathrm{T}$$

9.2 Space – Tough Problems Solutions

Q1. Scales measure the weight force; however the scales will convert the weight force to your mass using the pre-determined $9.8\ \mathrm{ms}^{-2}$ for acceleration due to gravity. As, $w = mg$, the scales will divide your weight force by 9.8 to give you your mass. Thus, $m = \frac{w}{9.8}$. This works for earth as you weight will be $mass \times 9.8$ and the 9.8 cancel out and so the scales tell you your mass. However if you were to use this scales on Mars where $g = 3.7\ \mathrm{ms}^{-2}$, then you would have the scales say that your mass is given by $m_{reading} = \frac{m_{actual} \times 3.7}{9.8}$, as you can see they will not give you your actual mass. We can calculate part a. as follows,

$$m_{reading} = \frac{m_{actual} \times 3.7}{9.8}$$

$$26.4 = \frac{m_{actual} \times 3.7}{9.8}$$

$$m_{actual} = \frac{26.4 \times 9.8}{3.7} \approx 70 \text{ kg}$$

For part b. we know that we need to have $m_{reading} = m_{actual}$, hence we need to multiply it by $\frac{9.8}{3.7}$, thus

$$m_{reading} = \frac{m_{actual} \times 3.7}{9.8} \times \frac{9.8}{3.7} = m_{actual}$$

Q2. Let R_E be the radius of the Earth and let r be the distance you are from the centre of Earth. Now we know that when $r \geq R_E$ then $g = \frac{GM}{r^2}$. We also know that when $r = 0$ the particle is at the centre of Earth and so all the forces of gravity will cancel each other out so $g = 0$. But what happens in between for $0 < r < R_E$? I'll let you to figure this out!

Q3. Sorry, I am still working on the solution for this one!

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INDEX

HIGHER SCHOOL CERTIFICATE EXAMINATION

Physics

DATA SHEET

Charge on electron, q_e	-1.602×10^{-19} C
Mass of electron, m_e	9.109×10^{-31} kg
Mass of neutron, m_n	1.675×10^{-27} kg
Mass of proton, m_p	1.673×10^{-27} kg
Speed of sound in air	340 m s^{-1}
Earth's gravitational acceleration, g	9.8 m s^{-2}
Speed of light, c	3.00×10^{8} m s^{-1}
Magnetic force constant, $\left(k \equiv \frac{\mu_0}{2\pi}\right)$	2.0×10^{-7} N A^{-2}
Universal gravitational constant, G	6.67×10^{-11} N m^2 kg^{-2}
Mass of Earth	6.0×10^{24} kg
Planck constant, h	6.626×10^{-34} J s
Rydberg constant, R (hydrogen)	1.097×10^{7} m^{-1}
Atomic mass unit, u	1.661×10^{-27} kg 931.5 MeV/c^2
1 eV	1.602×10^{-19} J
Density of water, ρ	1.00×10^{3} kg m^{-3}
Specific heat capacity of water	4.18×10^{3} J kg^{-1} K^{-1}

FORMULAE SHEET

$$v = f\lambda$$

$$I \propto \frac{1}{d^2}$$

$$\frac{v_1}{v_2} = \frac{\sin\ i}{\sin\ r}$$

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

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

$$P = VI$$

$$\text{Energy} = VIt$$

$$v_{\text{av}} = \frac{\Delta r}{\Delta t}$$

$$a_{\text{av}} = \frac{\Delta v}{\Delta t} \text{ therefore } a_{\text{av}} = \frac{v-u}{t}$$

$$\Sigma F = ma$$

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

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

$$W = Fs$$

$$p = mv$$

$$\text{Impulse} = Ft$$

$$E_p = -G\frac{m_1 m_2}{r}$$

$$F = mg$$

$$v_x{}^2 = u_x{}^2$$

$$v = u + at$$

$$v_y{}^2 = u_y{}^2 + 2a_y\Delta y$$

$$\Delta x = u_x t$$

$$\Delta y = u_y t + \tfrac{1}{2}a_y t^2$$

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

$$F = \frac{Gm_1 m_2}{d^2}$$

$$E = mc^2$$

$$l_v = l_0\sqrt{1-\frac{v^2}{c^2}}$$

$$t_v = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$m_v = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

FORMULAE SHEET

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

$$F = BIl\sin\theta$$

$$\tau = Fd$$

$$\tau = nBIA\cos\theta$$

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

$$d = \frac{1}{p}$$

$$M = m - 5\log\left(\frac{d}{10}\right)$$

$$\frac{I_A}{I_B} = 100^{(m_B - m_A)/5}$$

$$m_1 + m_2 = \frac{4\pi^2 r^3}{GT^2}$$

$$F = qvB\sin\theta$$

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

$$E = hf$$

$$c = f\lambda$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\lambda = \frac{h}{mv}$$

$$Z = \rho v$$

$$\frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

$$A_0 = \frac{V_{\text{out}}}{V_{\text{in}}}$$

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_{\text{f}}}{R_{\text{i}}}$$

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number Atomic Weight	79 Au 197.0 Gold	Symbol of element Name of element

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.41 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc [97.91] Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanides	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.8 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po [209.0] Polonium	85 At [210.0] Astatine	86 Rn [222.0] Radon
87 Fr [223.0] Francium	88 Ra [226.0] Radium	89–103 Actinides	104 Rf [261.1] Rutherfordium	105 Db [262.1] Dubnium	106 Sg [266.1] Seaborgium	107 Bh [264.1] Bohrium	108 Hs [277] Hassium	109 Mt [268] Meitnerium	110 Ds [271] Darmstadtium	111 Rg [272] Roentgenium							

Lanthanides

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm [144.9] Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.0 Ytterbium	71 Lu 175.0 Lutetium

Actinides

89 Ac [227.0] Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np [237.0] Neptunium	94 Pu [244.1] Plutonium	95 Am [243.1] Americium	96 Cm [247.1] Curium	97 Bk [247.1] Berkelium	98 Cf [251.1] Californium	99 Es [252.1] Einsteinium	100 Fm [257.1] Fermium	101 Md [258.1] Mendelevium	102 No [259.1] Nobelium	103 Lr [262.1] Lawrencium

Where the atomic weight is not known, the relative atomic mass of the most common radioactive isotope is shown in brackets.
The atomic weights of Np and Tc are given for the isotopes ^{237}Np and ^{99}Tc.