Fighting Cancer with Particle Beams

Key Stage 4 Programme

Pupil Name	
Handbook Designed by	Dr Stephen Flood

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
Tutorial 1	Wednesday 12th December	14:00-15:00	Manchester University
Tutorial 2	Tuesday 8th January	08:45-09:45	
Tutorial 3	Monday 14th January	09:45-10:45	
Tutorial 4	Tuesday 22nd January	08:45-09:45	
Tutorial 5	Monday 28th January	09:45-10:45	
Tutorial 6	Tuesday 5th February	08:45-09:45	
Tutorial 7 (Feedback)	Monday 11th February	09:45-10:45	
Tutorial 8 (Feedback)	Monday 18th March	09:45-10:45	

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Homework 1	Particles, Forces and Atomic Structure	Tuesday 8th January
Homework 2	Electromagnetic Forces in Accelerators	Monday 14th January
Homework 3	An In-Depth Look at an Accelerator	Tuesday 22nd January
Homework 4	Presentation for PARASOL @ Oasis	Monday 28th January
Homework 5	"Particle Accelerators in the World Around Us" Draft	Monday 11th February
Final Assignment	"Particle Accelerators in the World Around Us"	Thursday 28th February

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 9th August	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Uni Pathways – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of RIS teacher	Dr Stephen Flood		
Title of Assignment	Fighting Cancer with Particle Beams		
Name of Pupil			
Name of School	Oasis Academy Oldham		
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:

Knowledge and Understanding
Critical Evaluation/Problem Solving
Structure and Presentation
Resilience Comment

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Course Rationale

> *"A beam of particles is a very useful tool. A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey or discover the secrets of the universe."*
>
> *Accelerators for America's Future, US Dept. of Energy 2010*

Particle accelerators are some of the most impressive machines in modern science. The Large Hadron Collider (LHC) is the most famous example with a number of notable medals attached: the world's largest machine; the hottest temperature ever recorded; the world's most powerful supercomputer and so on. Physics aside, the LHC as a machine boasts an impressive achievement for mankind in general – the collaboration has contributions from over 60 countries around the world!

But the LHC is but one of many accelerators in use in the world around us. And not all are kilometres-wide in size! Accelerators are used in medicine (both to diagnose and treat illnesses), in industry (e.g. making computer chips, sealing crisp packets) and to allow us to protect ourselves from attack – particle accelerators can allow us to scan through walls!

This course will shine a light on just what particle accelerators are, how they work and just why so many people care about them so much! You will have the chance to see the types of accelerators in use in the world right now, and learn how we can harness them to fight cancer far more effectively. By the end of this course you will get some real insight into the world of modern particle physics and learn some key skills that will be invaluable in any scientific discipline.

Mark Scheme

Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Knowledge and Understanding	• All content included is relevant to the general topic and to the specific question/title • Good understanding of all the relevant topics • Scientific terms are defined and used accurately throughout • Clear justification on how the content included is related to the specific issues that are the focus of the assignment	• Most of the content included is relevant to the general topic and to the specific question/title • Good understanding of most of the relevant topics • Scientific terms are used accurately but not always clearly defined • Adequate justification on how the content included is related to the specific issues that are the focus of the assignment	• Some of the content included is relevant to the general topic and to the specific question/title • Good understanding of some of the relevant topics but occasional confusion on others • Scientific terms are used mostly accurately with occasional confusion and often not defined • Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical Evaluation/ Problem Solving	• Move beyond description to an assessment of the value or significance of what is described • Evaluative points are consistently explicit/systematic/ reasoned/justified • Effective critiques on the reliability of sources provided • Consistently demonstrate clear, analytical and logical steps to solving problems	• Mostly description but some assessment of the value or significance of what is described • Evaluative points are mostly explicit/systematic/ reasoned/justified • Some evidence of critiques on the reliability of sources provided • Some examples of solving problems but not consistently clear, analytical and logical	• Only description with minimal assessment of the value or significance of what is described • Evaluative points are at times explicit/systematic/ reasoned/justified • Limited evidence of critiques on the reliability of sources provided • Demonstrate clear steps to solving problems but not consistently analytical or logical

Structure and Presentation	• Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment • The introduction clearly outlines how the essay/report will deal with the issues • The conclusion summarises all the main points clearly and concisely • All calculations, formulas and methods are clearly structured, clear to follow and correct • Tables and graphs are effectively constructed including appropriate headings, units and scales • All sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment • The introduction adequately describes how the essay/report will deal with the issues • The conclusion summarises most of the main points clearly • Calculations, formulas and methods are mostly structured, clear to follow and correct • Most tables and graphs are well constructed • Most sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure • The introduction mentions how the essay/report will deal with the issues • The conclusion summarises some of the main points clearly • Calculations, formulas and methods are not always structured, clear to follow and correct • Some tables and graphs are well constructed but contains some errors • Some sources are referenced correctly in the agreed format with occasional errors

Subject Vocabulary

Word	Definition	Examples/notes
Particle	A particle is a small object that can be assumed to have its location pinned down to a single point. Particles can vary in size greatly – the word particle is not a very precise one.	
Elementary Particle	An elementary particle is a physical object with no underlying structure – an elementary particle is not composed of any other particles!	
Charged Particle	A charged particle is a particle with a non-zero electrical charge. Charged particles interact with electric and magnetic fields, while non-charged particles do not.	
Particle Accelerator	Particle accelerators accelerate charged particles to high speeds (high energies) for various reasons.	
Electrostatic Force	The force that occurs between two electric charges: like charges repel; opposite charges attract.	
Nuclear Strong Force	The (incredibly short-range) force that overcomes the repulsion felt by protons in the nucleus of an atom.	
Electron volt (eV)	A measure of energy: the amount of energy gained by an electron moving through a voltage of 1 volt.	
Cathode Ray Tube (CRT)	A very early particle accelerator, which accelerated electrons into a screen in early televisions.	
Cathode/Anode	Cathode and Anode are terms used in circuits where there is a gap. Negative charge builds up on one edge of the gap (the cathode), and the other edge (the anode) becomes positively charged. This results in an electric field between the two.	
Relativity	Relativity is Einstein's theory involving the concept of the speed of light being a universal speed limit. When speeds or energies get too high, we have to modify everyday equations to take relativistic corrections into account.	

Electric/Magnetic Field	Electric/magnetic fields are simply areas in which a charged particle will experience an electric/ magnetic force.	
Cyclotron	A type of particle accelerator consisting of two half-discs (Dees). Particles are accelerated in an outward spiral.	
Linear Accelerator (linac)	A type of particle accelerator in which particles are accelerated in one long line.	
Synchrotron	A type of particle accelerator in which particles are accelerated in rings (in opposite directions) and then collided into each other.	
CERN	"Conseil Européen pour la Recherche Nucléaire" – The European Council for Nuclear Research – the entity behind the Large Hadron Collider (LHC).	
Cancer/tumour	Cancerous cells are cells of the body that divide too much and for no good reason. They divide into lumps of tissue called tumours.	
X-ray	High-energy radiation (high-energy photons) often used in medical imaging or in radiotherapy.	
Radiotherapy	Radiotherapy is used to treat cancers by bombarding tumours with radiation, damaging the cells and leaving them unable to multiply further.	
Bragg Peak	When charged particles decay, they lose the vast majority of their energy in a short distance just before coming to rest – this peak in energy loss is called a Bragg Peak.	
Proton Therapy	Proton therapy is similar to radiotherapy except that it uses protons instead of photons (X-rays) in order to exploit the Bragg peak for higher, more precise energy doses.	

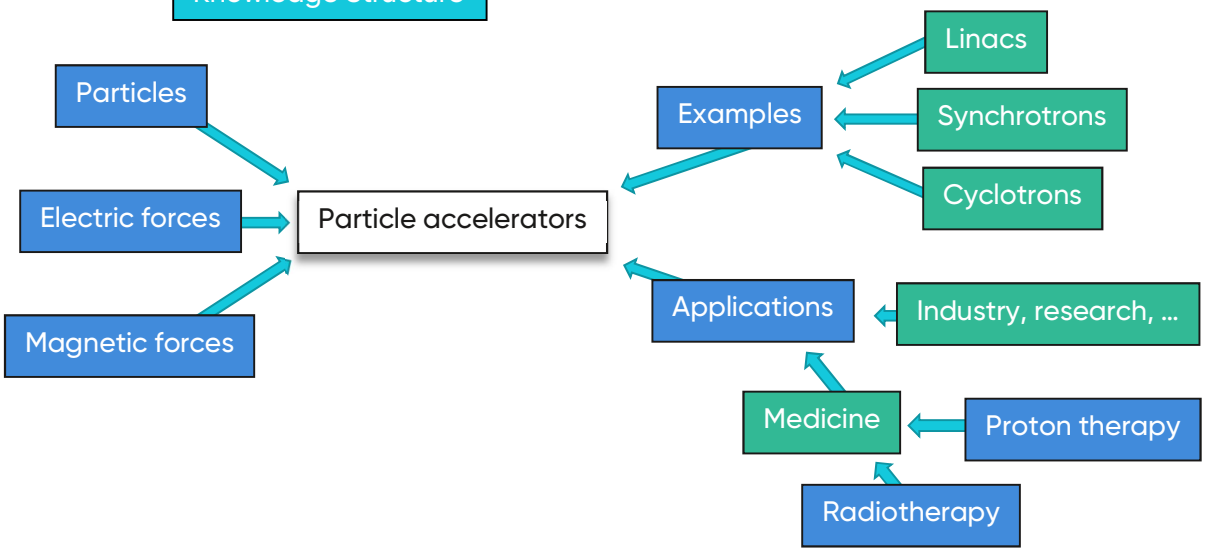
Knowledge Organisers

Important Particles	
Atom	The smallest unit that can be obtained via chemical processes – formed of electrons surrounding a central nucleus.
Nucleus	The positive centre of the atom, consisting of protons and neutrons.
Electron	A small negatively charged particle orbiting the nucleus of an atom.
Proton	Larger than the electron, but with equal yet opposite (i.e. positive) charge.
Neutron	Approximately the same size as the proton, but with no electric charge.

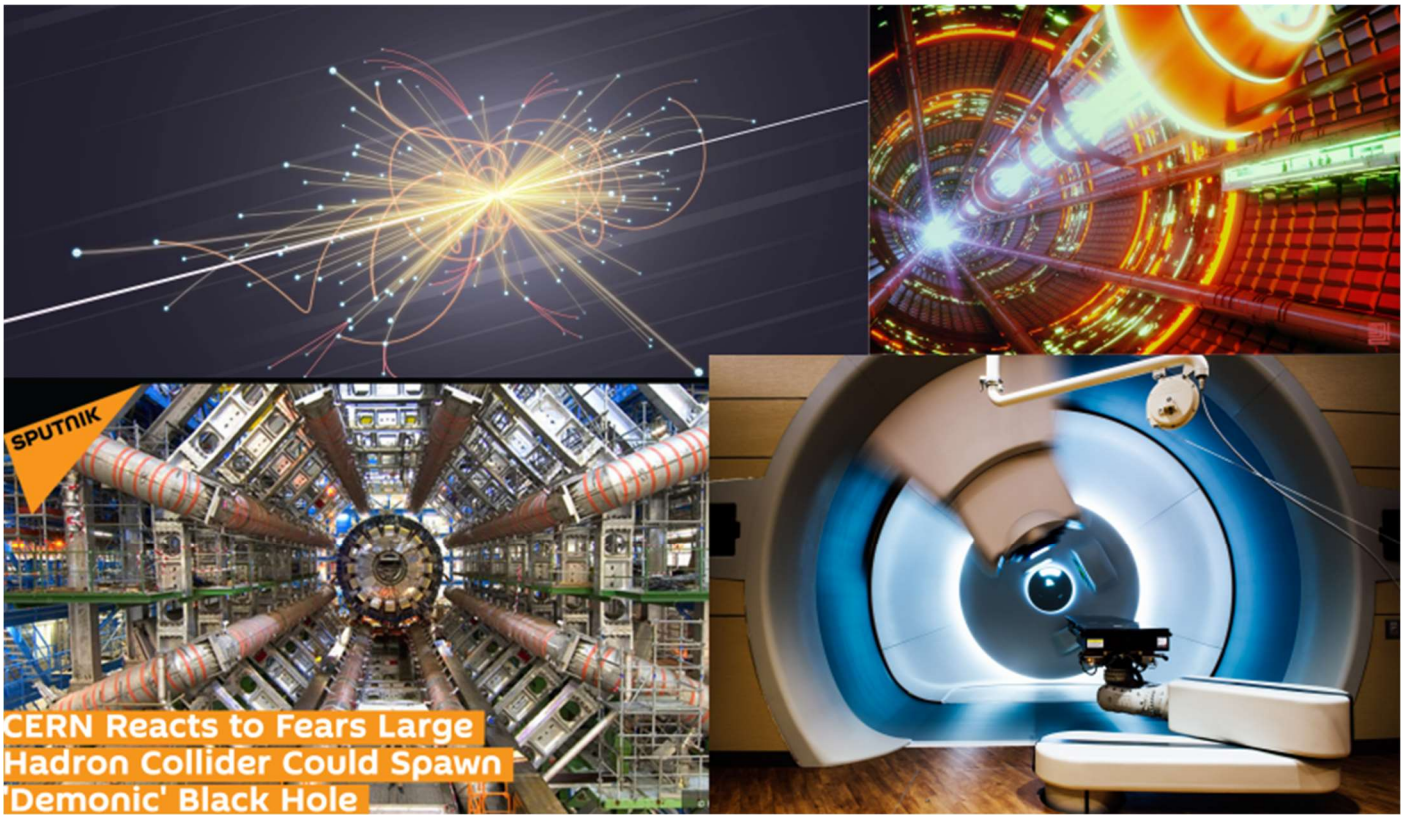
Important Ideas
Electric fields *accelerate* charged particles.
Magnetic fields allow us to *steer* charged particles.
Moving particles gain *kinetic energy* – this energy is often used in preference to the speed, particularly in powerful accelerators.
The speed of light is the *universal speed limit*: after a certain point, further acceleration increases *energy* but not *speed!*
There are several ways to make particle accelerators, even in modern-day settings – each have their own pros and cons.
Particle accelerators can be used to deliver carefully targeted high energy doses thanks to how charged particles deposit their energy.

Accelerator Types and Examples		
Cyclotron	Acceleration of particles via two 'Dees' – particles are accelerated in a spiral-shape.	TRIUMF in Canada.
Synchrotron	Acceleration of particles in rings – particles are accelerated and collided head-on with other particles.	LHC in Geneva.
Linac	Acceleration of particles in one long straight line.	SLAC in the USA.

Knowledge Structure



Tutorial 1 – Particle Physics 101



What is the Purpose of Tutorial 1?

- Students will understand the layout of the Uni Pathways course and what is expected of them
- Students will understand what a *particle* is (and - in particular - a *charged particle*)
- Students will be able to draw the structure of an atom and label correctly *protons*, *neutrons* and *electrons*
- Students will understand the *forces* responsible for the structure of the atom

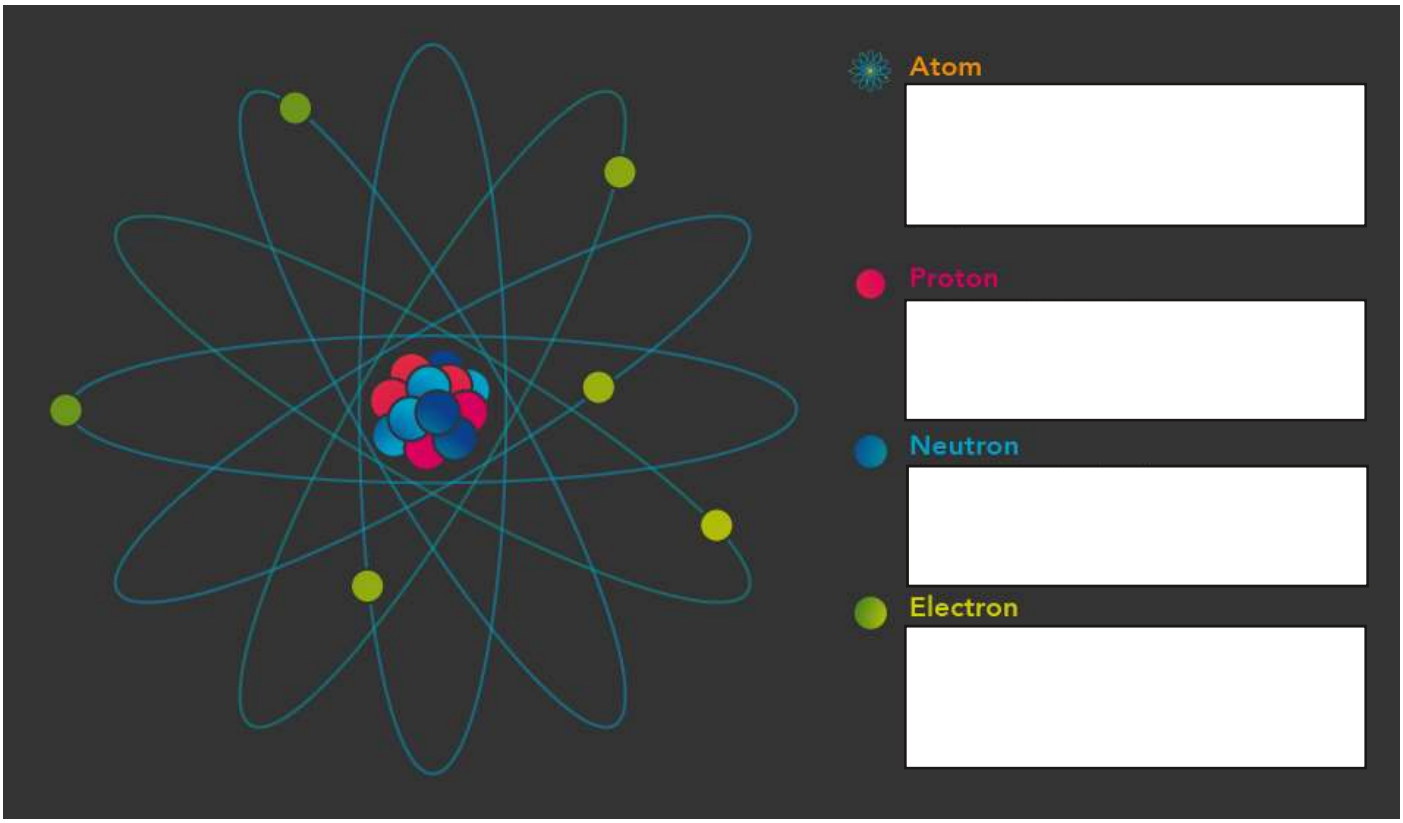
Already Known

Write down any thoughts or things you know about particle accelerators – either from the above pictures, your own experience, popular culture, other lessons etc.

Write down any questions you have already about particle accelerators – be it what they do, how they do it or why they're used at all.

Particle Physics and the Atom

Fill in the gaps in the atomic diagram below:



What is meant by the word *particle*?

What is the definition of a *charged* particle?

What is the definition of an *elementary* particle?

Which forces are responsible for the structure of the atom?

Forces in the Atom

There are several forces in play that are responsible for the structure of the atom. The two most obvious everyday forces we encounter are gravity and electromagnetism – let's compare their impact in the atom:

$$Gravitational\ Force = Gravitational\ Constant \times \frac{(mass\ of\ particle\ 1) \times (mass\ of\ particle\ 2)}{(distance\ between\ particles)^2}$$

$$F_{grav} = \frac{GM_1M_2}{r^2}$$

$$Electrostatic\ Force = Electrical\ Constant \times \frac{(charge\ of\ particle\ 1) \times (charge\ of\ particle\ 2)}{(distance\ between\ particles)^2}$$

$$F_{elec} = \frac{K_EQ_1Q_2}{r^2}$$

Using the information provided in Appendix 3, calculate and compare the electrical and gravitational forces between two electrons.

Comment on the relative strengths of the gravitational and electromagnetic forces. Can you think of any examples in everyday life where this difference is visible?

There are four fundamental forces: the gravitational force, the electromagnetic force and the nuclear weak and strong forces.

Force	Responsible for	Relative Strength	Range
Gravity			
Electromagnetism			
Nuclear Weak			
Nuclear Strong			

The electromagnetic force is the one we use to accelerate charged particles – can you explain why?

Homework Assignment 1: Baseline - Forces and Atomic Structure

(1) Helium consists of two electrons orbiting a nucleus containing *two neutrons and two protons*.

(a) The distance between the protons in the nucleus is approximately 1.6 femtometres (1.6×10^{-15} m). Calculate the strengths of the electrostatic repulsion and the gravitational attraction of the protons in the nucleus.

(b) What does the above information tell us about the stability of the Helium nucleus? Does this make sense?

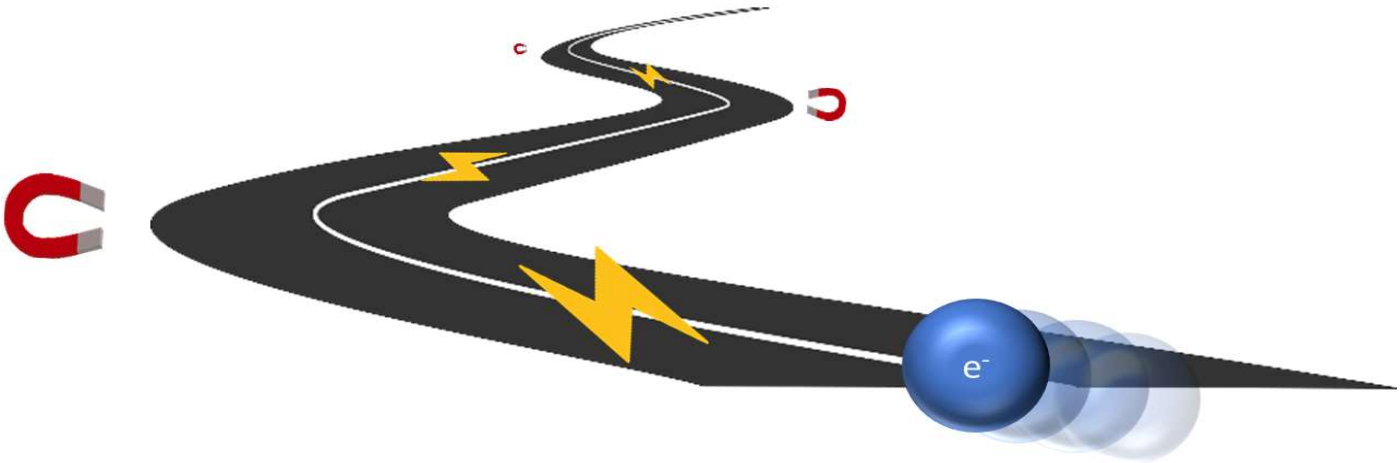
(2) Make an academic poster explaining the different particles and forces important in atomic structure – make sure to discuss which particles are *charged* and which are *elementary*.

Academic posters are different to the posters you're likely to have come across so far – Appendix 2 has some examples and guidance on the style, structure and content of an academic poster.

Homework 1 Success Criteria: What Good Looks Like

Knowledge and Understanding	• Calculations correct and with units • Scientific terms used accurately throughout and relevant to the problem • Work demonstrates a good and clear understanding of content
Critical Evaluation/ Problem Solving	• Work describes and determines the significance of relevant content • Problem solving demonstrates clear, analytical and logical steps • Reasoning is clear and justified
Structure and Presentation	• Calculations are clearly and logically structured and easily followed • Other work is presented in paragraphs or otherwise appropriate structure

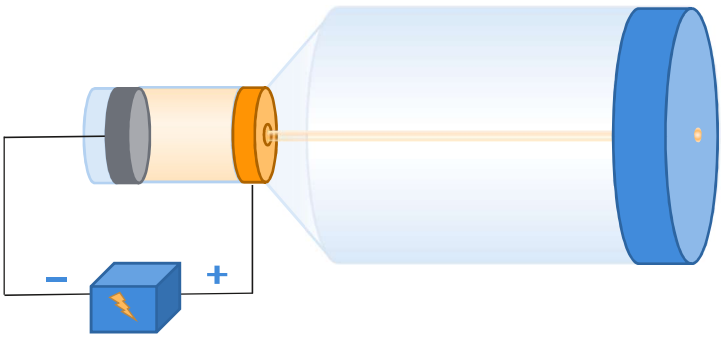
Tutorial 2 – How to Accelerate Particles: Electromagnetic Forces



What is the Purpose of Tutorial 2?

- Students will understand the effects of electric and magnetic forces on a particle
- Students will understand that accelerated particles are often discussed using energy rather than speed
- Students will be able to use the right-hand rule to find the direction a charged particle will move under the influence of a magnetic field
- Students will understand why accelerators are said to accelerate particles up to e.g. 20 MeV – (a unit of energy, not speed)

Cathode Ray Tubes and Electron Beams



Describe the significance of the Cathode Ray Tube.

CRTs can reach voltages of as high as 3,000 volts! We can work out the speed of the electrons as follows:

The *energy* the electrons gain over the voltage of 3,000 volts is given by:

$$Energy = (charge\ of\ the\ electron) \times (voltage\ travelled\ through)$$
$$K = qV$$

The electric charge of an electron can be found in Appendix 3. Calculate the energy gained by an electron in the CRT.

This energy is all *kinetic* energy: this is related to the *velocity* of a particle, *v*, by:

$$Kinetic\ Energy = \frac{1}{2} \times mass\ \times velocity^2$$

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

Rearrange this formula and use the energy you just calculated to work out the velocity of the electrons as they leave the CRT:

The speed of light is c = 299792458 m/s. What speed are the electrons as a fraction of the speed of light?

Acceleration and Relativity

While it might *seem* like we can accelerate our electrons to a faster speed than the speed of light by simply increasing the voltage (i.e. the strength of the electric field), this isn't quite the case: relativity steps in and we have to be a bit more careful with our formulae! [See Appendix 4 for some details].

Using the *relativistic formula* for kinetic energy:

$$K = mc^2\left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right)$$ (which can be rearranged to give) $$v = c\sqrt{1 - \frac{1}{\left(\frac{K}{mc^2} + 1\right)^2}}$$

Calculate what speed the electrons will reach if the CRT could reach a voltage of 10,000 volts.

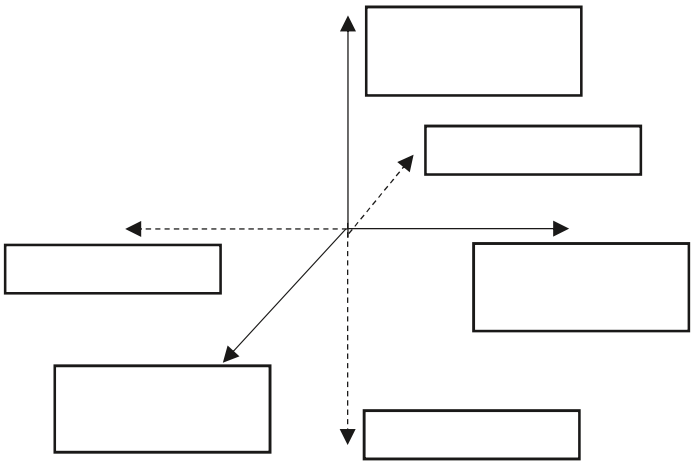
What is this speed as a fraction of the speed of light?

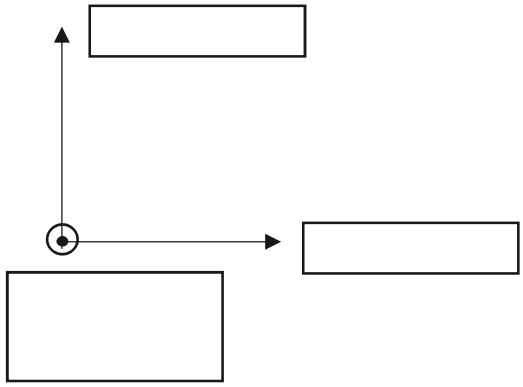
However, we *can* keep increasing the voltage – and while we get diminishing returns on the *speed* of the electrons, we still increase their *energy!* This is in fact the reason why particle accelerators like the LHC at CERN exist – to create very *high energy collisions*! The higher the energy of the collisions, the higher the potential *mass* of the resulting products, via Einstein's $E = mc^2$.

Part 2: How to *Steer* Particle Beams

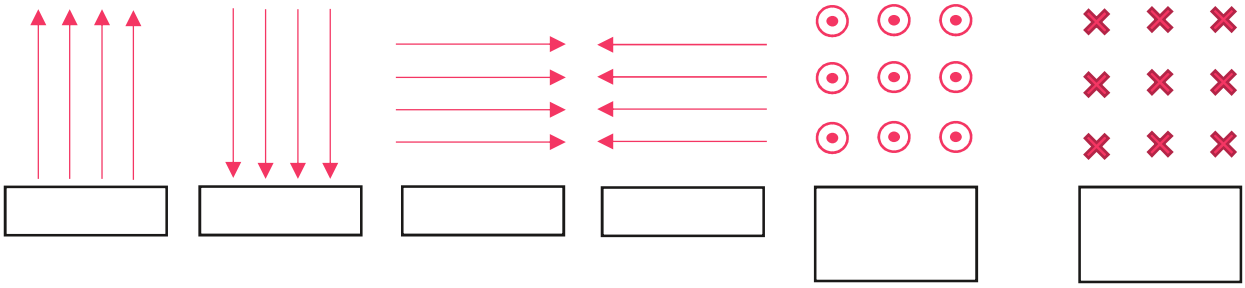
We use magnetic fields to steer particle beams – i.e. to make the beam *change direction*. How do we know how to put our magnets down and how they'll affect the beam direction?

We use a three-dimensional coordinate system (x, y, z) with axes:

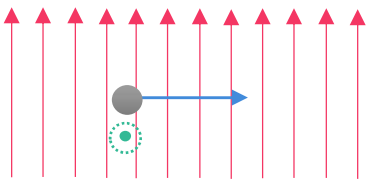


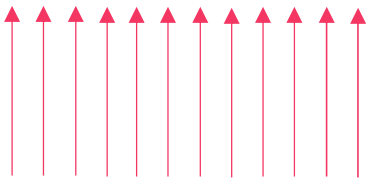


Example: label the direction of the following magnetic fields:

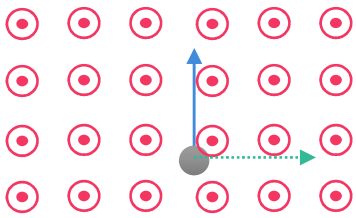


A charged particle moving in the x direction enters a magnetic field pointing in the y direction. The particle experiences a force in the z direction.



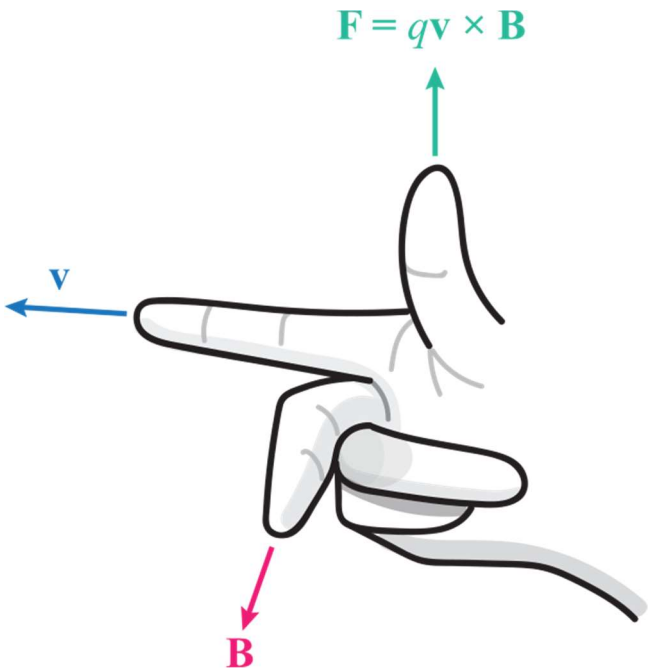


A charged particle moving in the y direction enters a magnetic field pointing in the z direction. The particle experiences a force in the x direction.



How do we know it's the +x direction and not the -x direction?
We use the Right-Hand Rule

(1) Make a fist with your thumb up and pointing finger pointing outward (right-angled to the thumb)
(2) Point your middle finger so that it's right-angled to both (perpendicular to both)
(3) Align your pointing finger with the *direction* the particles are heading in
(4) Align your middle finger with the magnetic field
(5) Now your thumb is pointing in the direction of the force the particle will experience!



For each of the following examples draw a diagram and use the Right-hand rule to see which direction the following particles will move in:

Example 1: A charged particle moving in the -x direction enters a magnetic field pointing in the *z* direction. What direction is the force on the particle due to the magnetic field?

Example 2: A charged particle moving in the *z* direction enters a magnetic field pointing in the *x* direction. What direction is the force on the particle due to the magnetic field?

Example 3: A charged particle moving equally in the x and y directions enters a magnetic field pointing in the $-z$ direction. What direction is the force on the particle due to the magnetic field?

What happens if a particle moves into a large area where the magnetic field is constant? What will the path of the particle look like? (hint: draw a series of pictures a short time apart!)

Homework Assignment 2: Electromagnetic Forces in Accelerators

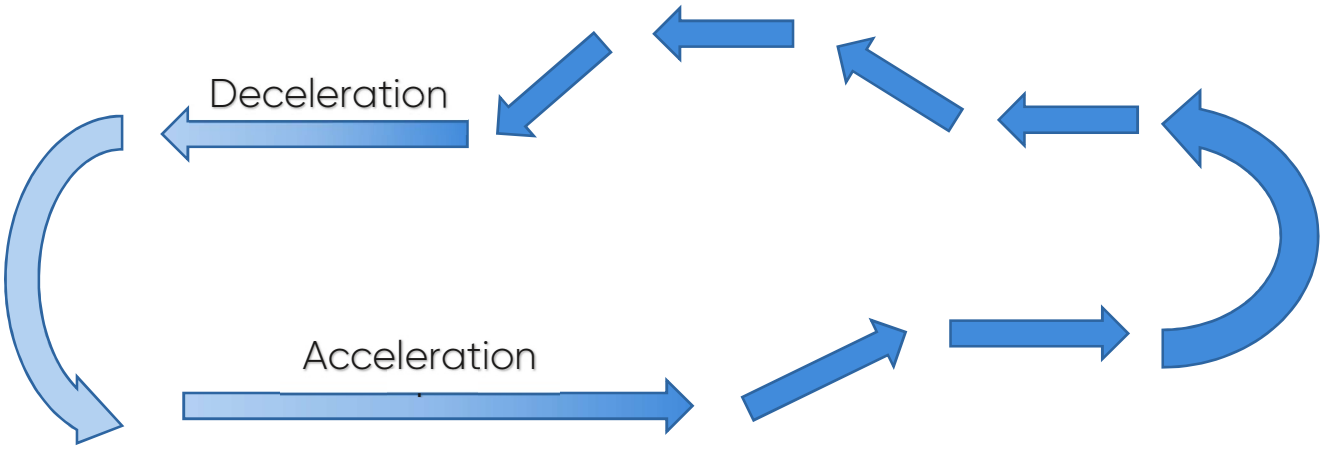
(1) The first accelerators used electrostatic forces, which have a practical maximum voltage of 1MV. What is the maximum speed of an electron accelerated in such a machine?

(2) Industrial accelerators are often used to clean or sterilise products by using a low-energy electron beam to kill harmful bacteria etc. Beams of less than 3 MeV are used (higher than this might cause unstable radioactive isotopes to form on the material!) – what voltage would a linear accelerator have to produce in order to accelerate electrons to 3 MeV?

(3) Medical accelerators often use particle beams to generate x-rays. Doing so requires careful steering of an electron beam into a fixed target. If the electron beam was headed in the y direction but needed to be turned into the z direction, what direction would the magnetic field need to point in?

(4) Consider the difference between a magnetic force acting on a particle moving with very low speed and a particle moving with very high speed. Do you think it is easier to control the direction of a particle moving at high speed or low speed? Explain how you came to your conclusion.

(5) For a science fair you are asked to build a particle racecourse with the following setup:



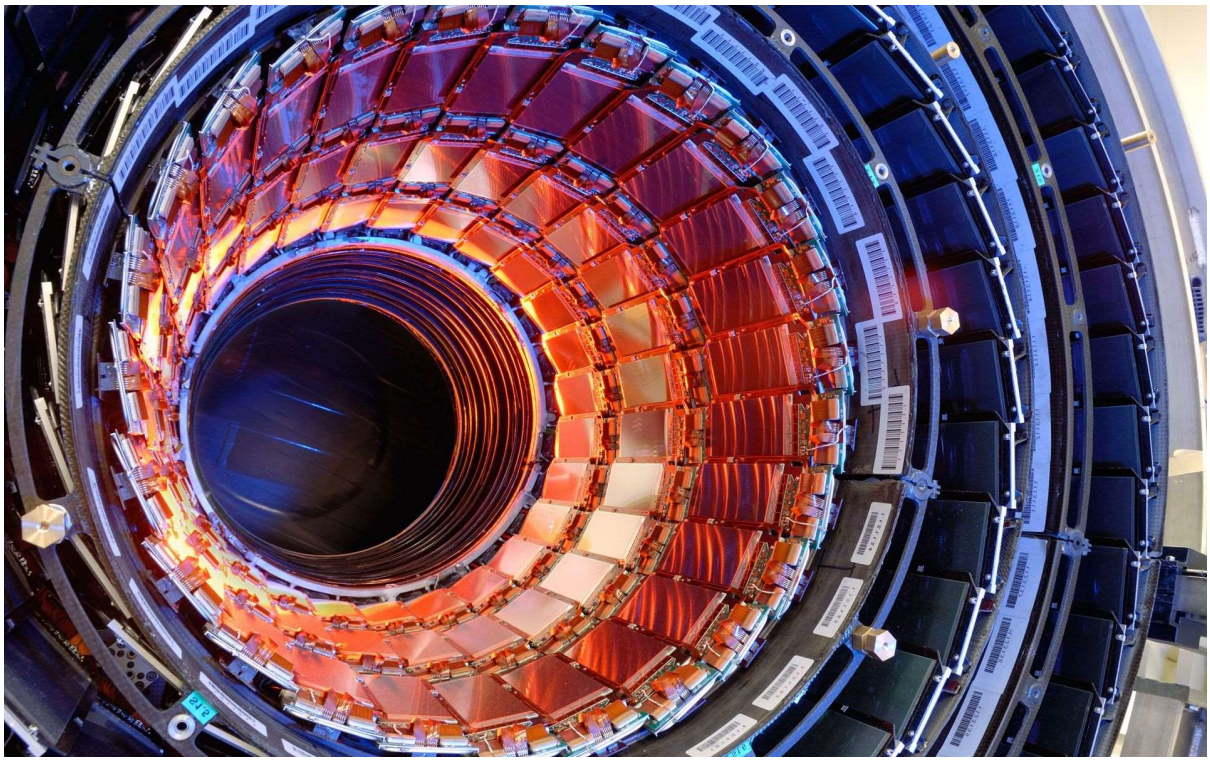
(6) You have **eight magnets** capable of producing magnetic fields in various orientations and **two electric fields** capable of producing high voltages. Annotate the diagram to show where you would need to put electric or magnetic fields and what directions they would need to be oriented in to make the course work.

(7) Summarise in your own words why electric and magnetic fields are used in particle acceleration (100 words).

Homework 2 Success Criteria: What Good Looks Like

Knowledge and Understanding	• Calculations correct and with units • Scientific terms used accurately throughout and relevant to the problem • Work demonstrates a good and clear understanding of content
Critical Evaluation/ Problem Solving	• Work describes and determines the significance of relevant content • Problem solving demonstrates clear, analytical and logical steps • Reasoning is clear and justified
Structure and Presentation	• Calculations are clearly and logically structured and easily followed • Other work is presented in paragraphs or otherwise appropriate structure

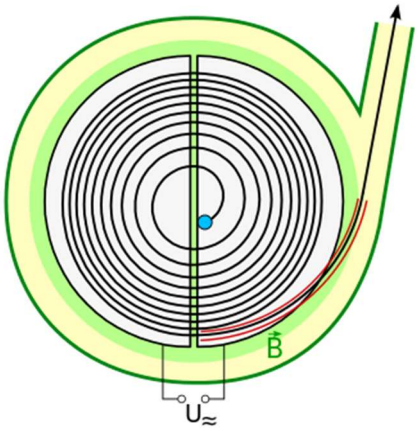
Tutorial 3 – Particle Accelerators: Lines, Circles and Spirals



What is the Purpose of Tutorial 3?

- Students will understand that there are several types of particle accelerators
- Students will understand the advantages and disadvantages of both linear and circular accelerators
- Students will know the history of particle acceleration – including 'whens', 'whys' and 'hows'
- Students will be able to provide some examples of particle accelerators

Cyclotrons



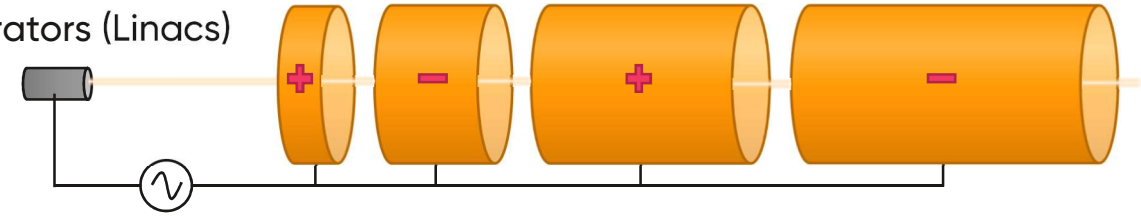
Describe in your own words how cyclotrons operate.

What are cyclotrons used for?

What are the advantages of cyclotrons?

What are their disadvantages?

Linear accelerators (Linacs)



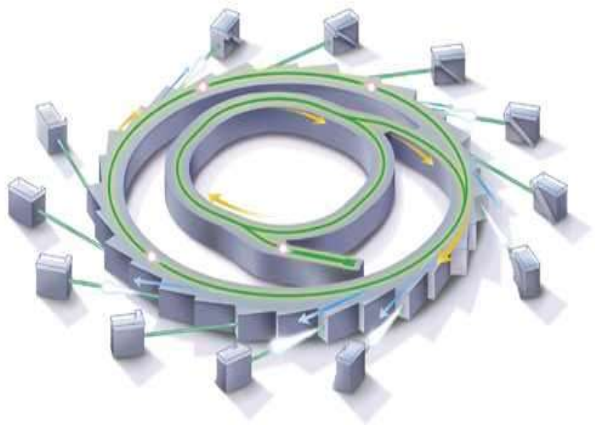
Describe in your own words how linacs operate.

What are linacs generally used for?

What are the advantages of linacs?

What are their disadvantages?

Synchrotrons



Describe in your own words how Synchrotrons operate.

What are Synchrotrons generally used for?

What are the advantages of Synchrotrons?

What are their disadvantages?

Homework Assignment 3: An In-Depth Look at an Accelerator

Choose an example of one of the above accelerator types - for instance the LHC is an example of a synchrotron, TRIUMF is an example of a cyclotron, SLAC is an example of a linac (but feel free to research and choose your own examples!) - and write 200 words summarising:

- The history of the accelerator
- The aims of the project
- Any discoveries made so far

along with any other interesting facts you can find!

Homework 3 Success Criteria: What Good Looks Like

Knowledge and Understanding	• Scientific terms used accurately throughout and relevant to the problem • Work demonstrates a good and clear understanding of content
Critical Evaluation/ Problem Solving	• Work describes and determines the significance of relevant content • Problem solving demonstrates clear, analytical and logical steps • Reasoning is clear and justified
Structure and Presentation	• Work is well-structured in sentences and paragraphs • Sources used are referenced correctly (see Appendix 1 for more details)

Tutorial 4 – Cancer versus Physics

What is the Purpose of Tutorial 4?

- Students will understand the basics of what cancer is and why it is difficult to treat
- Students will know how radiation therapy (radiotherapy) is used to attack cancer cells and some of its limitations
- Students will understand the concept of energy loss for high-energy particles and distinguish the decay patterns of photons vs protons
- Students will understand the distinct advantages of proton therapy over radiotherapy

Cancer: A Wolf in Sheep's Clothing

Outline how cancer cells differ from ordinary healthy cells.

What medical treatments are used? Why are these medical treatments of cancer so challenging?

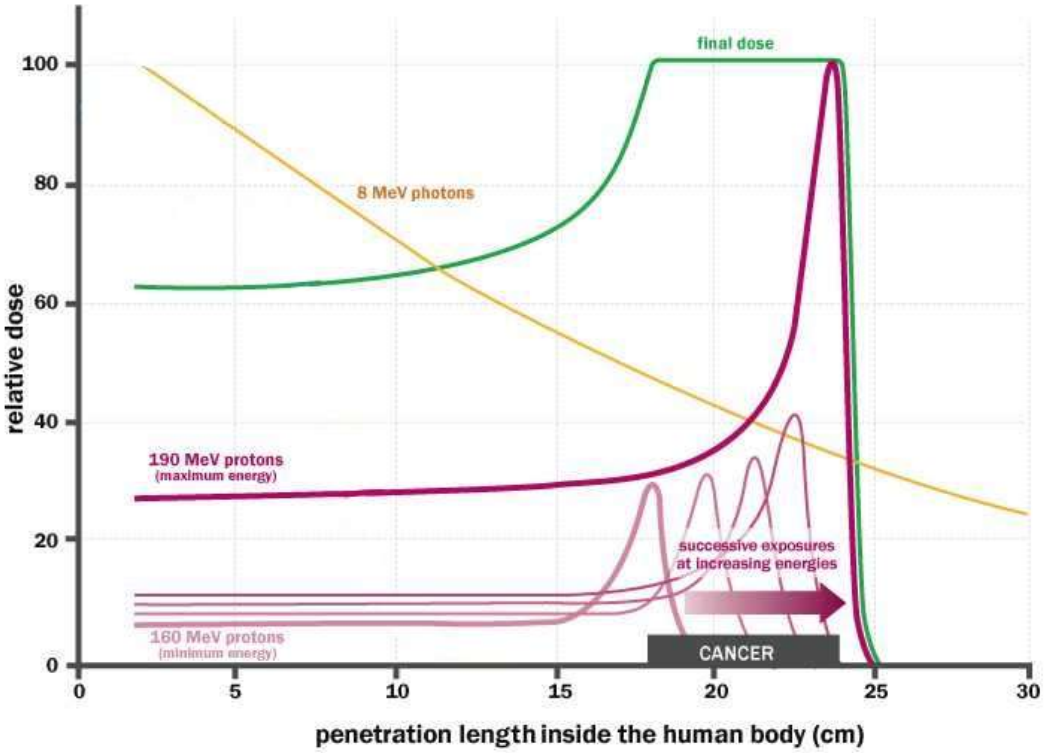
Describe how x-rays (radiotherapy, high-energy photons) are used to attempt to fight cancer cells.

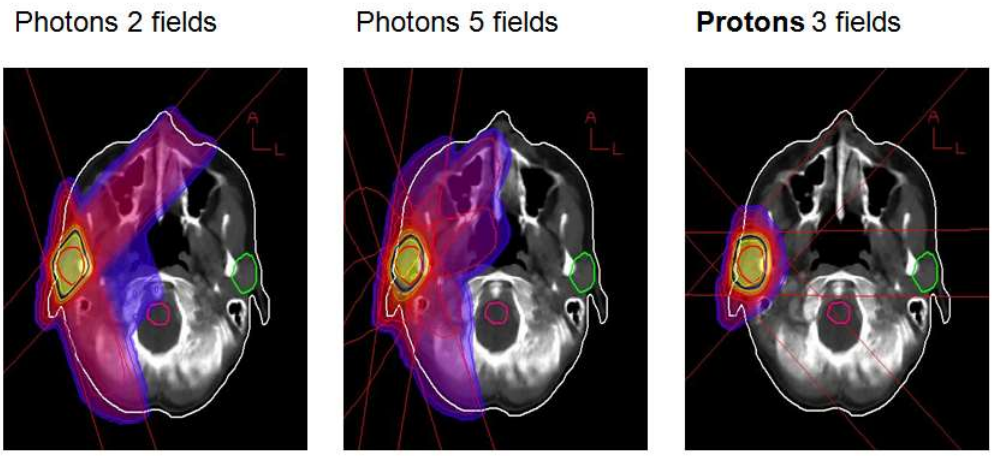
What is the major limitation to using photons (x-rays, etc) to fight cancer?

Describe one way that this limitation can be lessened.

Treating Cancer with Particle Beams

Explain what a *Bragg peak* is and its relation to charged particles.





Courtesy: University clinic for radiotherapy and radio-biology, AKH Vienna, Austria

With reference to the above graph and image, summarise proton therapy and its advantages over radiotherapy.

Homework Assignment 4: Presentation for PARASOL @ Oasis!

With a partner, research an application of particle accelerators and prepare a presentation for PARASOL @ Oasis! PARASOL will be a university-style mini-conference at which all students will present their work and receive peer-feedback on their work.

Some points to consider in your research:

- What is the application of the particle accelerator?
- What sort of particle accelerator is used in the application?
- Why is a particle accelerator used for the purpose? What, if anything was used before particle accelerators were adopted for the task?

Some general points for the presentations themselves:

- Ten minutes will be allocated for each pair of speakers – five minutes each. Try to ensure a smooth transition between the two speakers – working together on the overall content and then working out who says what will work better than doing two totally separate five-minute presentations!
- You should aim your talks at your fellow students – they'll be taking notes on your presentations and you from them!
- After each ten-minute presentation each other pair will offer feedback: something they thought went well and something for you to consider improving, as well as any questions on the talk itself
- In order to fit everything in, timing will be enforced, so try not to run over!

I'm working with:

On the topic:

Tutorial 5 – PARASOL @ Oasis Oldham

What is the Purpose of Tutorial 5?

- Students will share the results of their research into particle accelerator applications with their peers
- Students will take notes on the research and presentations of others ready for the final assignment
- Students will give constructive criticism outlining strengths and weaknesses to their peers
- Students will understand the format of academic conferences and how to get the best from them

Format of the mini-conference

Each pair of speakers (or presenters) will be given 10 minutes to give their presentation using slides, boards, etc. while the others (the conference participants) will take notes on what is said.

The notes taken should fall into one of two categories:

1) Notes on the *content* of the presentation: these notes will help you to remember key information for later, to help complete your workbook and give you a firm grasp of the work done by all groups
2) Notes on the *presentation itself*: these notes are a form of peer-assessment and feedback – getting friends and colleagues to tell you what you did well and what you can improve upon is a vital skill!

Presentation Success Criteria: What Good Looks Like

Knowledge and Understanding	• Scientific terms used accurately throughout and relevant to the topic • Presentation and question-answering demonstrates a good and clear understanding of content • Questions asked are logical and thought provoking
Critical Evaluation/ Problem Solving	• Work describes and determines the significance of relevant content • Reasoning is clear and justified • Feedback given to other student groups is clear and constructive
Structure and Presentation	• Work is well-structured and flows logically • Presentation slides or other material are of high quality and relevant to spoken material • Speakers communicate the subject clearly and effectively • The presentation is of appropriate length (no longer than 10 minutes, no shorter than 8 minutes)

Presentation Example

What application of magnets is being presented?

Using magnets in speakers, headphones etc

Why is a magnet used for this application?

- Magnetic repulsion can cause vibration leading to production of sound waves
- Magnets are smaller and simpler than any other mechanisms that could make the same vibration

Questions for the speakers:

1) You mentioned microphones in your talk – how are they related to speakers and headphones?

2) What's the difference between a magnet and an electromagnet?

What did the speakers do/include in their presentation that made it better, or helped your understanding?

1) Spoke clearly and energetically without needing to look at notes!

2) Great use of diagram to explain the production of sound waves from the magnet vibration!

What could the speakers do to make their presentation even better? Try to be *constructive* and *specific*!

1) Try to talk to the whole audience, not just one person

2) Try to manage the speaker transitions better – they felt a bit disjointed!

General notes.

Speakers have two kinds of magnet in talk – regular fixed magnets and ?electromagnets?

Using different currents makes the magnets have a stronger/weaker repulsion/attraction

The magnet getting pushed back and forth moves the air back and forth

Air moving back and forth = sound

Presentation 1

What application of particle physics is being presented?

Why is a particle accelerator used for this application?

Questions for the speakers:

1)

2)

What did the speakers do/include in their presentation that made it better, or helped your understanding?

1)

2)

What could the speakers do to make their presentation even better? Try to be *constructive* and *specific*!

1)

2)

General notes.

Presentation 2

What application of particle physics is being presented?

Why is a particle accelerator used for this application?

Questions for the speakers:

1)

2)

What did the speakers do/include in their presentation that made it better, or helped your understanding?

1)

2)

What could the speakers do to make their presentation even better? Try to be *constructive* and *specific*!

1)

2)

General notes.

Presentation 3

What application of particle physics is being presented?

Why is a particle accelerator used for this application?

Questions for the speakers:

1)

2)

What did the speakers do/include in their presentation that made it better, or helped your understanding?

1)

2)

What could the speakers do to make their presentation even better? Try to be *constructive* and *specific*!

1)

2)

General notes.

Homework Assignment 5: First Draft of 'Particle Accelerators in the World Around Us'

The final assignment for this course is to create an academic poster outlining the knowledge you've gained from this course. These posters will be individual work and should contain at least the following information:

- What are particle accelerators?
- What do they do?
- How do they work?
- An example calculation with electric and/or magnetic fields
- What are some examples of particle accelerators?
- What are they used for? (at least two examples)

This is an *open-ended* assignment – so long as all of these points are addressed, you may add as much detail as you want about as any particular part. You may use the previous homework assignments to help you, though each person must make their own poster – no pair-work is allowed. As a guide, an academic poster will contain around 700 words of text.

What is an academic poster? (See Appendix 2 for more details)

Academic posters are presented at conferences to outline the work that a researcher has done. They often contain months of work, but are presented in a way that can be understood by other researchers simply by reading the poster. At a conference, the researcher who makes a poster will stand nearby the poster to answer any questions that other reading researchers might have. The best academic posters are able to explain their topics and concepts clearly, are easy to read and are visually appealing. The more your poster stands out, the more memorable your work is! Just make sure that your poster's content can match your visual flair!

Academic posters are usually printed on paper as large as A0 or A1 (or card, or even fabric!) – you should design your poster accordingly. Posters can be submitted as files and will be printed when finalised to be displayed.

Academic posters contain:

- Full prose (full sentences, not just brief remarks!)
- Pictures, diagrams, etc. to capture interest
- Balance – huge equations, overly complicated graphs or lengthy paragraphs of pure text will lose the interest of your reader! Think how best to balance what you want to describe!
- Colour! The best posters are visually appealing, and colour is one of the best ways of achieving this
- The author's name and institution (along with any organisational logos, etc.)

See Appendix 2 for more help with (and examples of) academic posters.

For a detailed breakdown of the success criteria and markscheme for this final assignment, see pages 6 & 7.

Tutorial 6 – Working on Final Assignments

What is the Purpose of Tutorial 6?

- To receive dedicated time to work on the first draft of your final assignments
- To ask for help on any problems you're facing so far
- To ask for guidance on any areas that could be enhanced
- To ask for any technical help in poster creation

My notes:

Tutorial 7 – Draft Feedback Tutorial

What is the Purpose of Tutorial 7?

- To receive feedback on final assignments
- To share examples of best practice with the other students in your group
- To receive feedback from other students in your group
- To write targets for improvement

Final assignment draft feedback: One-to-one feedback from Dr. Flood

What am I doing well?

What should I improve?

What have I not included that I should?

Other notes:

Final assignment draft feedback: Peer feedback from other students

What do other students think I'm doing well?

What do other students think I can improve?

Ideas that I've seen in other students' work that I like and might want to incorporate into my own work:

Final assignment draft feedback summary

What I did well...	What I can improve on...
•	•
•	•
•	•

My target for the final draft is:

Tutorial 8 – Final Assignment Feedback Tutorial

What is the Purpose of Tutorial 8?

- To receive feedback on final assignments
- To share examples of best practice with the other students in your group
- To write targets for improvement in school lessons
- To reflect on the programme including what was enjoyed and what was challenging

Final assignment feedback

What I did well…	What I could have improved on…
•	•
•	•
•	•

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
• • •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing Correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment that says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. A marker in your assignment : After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. Bibliography: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

    a. Websites – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. Books – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. Articles – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2 – Academic Posters: Examples, Templates and Guidance

Academic posters are presented at conferences to outline the work that a researcher has done. They often contain months of work, but are presented in a way that can be understood by other researchers simply by reading the poster. At a conference, the researcher who makes a poster will stand nearby the poster to answer any questions that other reading researchers might have. The best academic posters are able to explain their topics and concepts clearly, are easy to read and are visually appealing. The more your poster stands out, the more memorable your work is! Just make sure that your poster's content can match your visual flair!

Academic posters are usually printed on paper as large as A0 or A1 (or card, or even fabric!) – you should design your poster accordingly. Posters can be submitted as files and will be printed when finalised to be displayed.

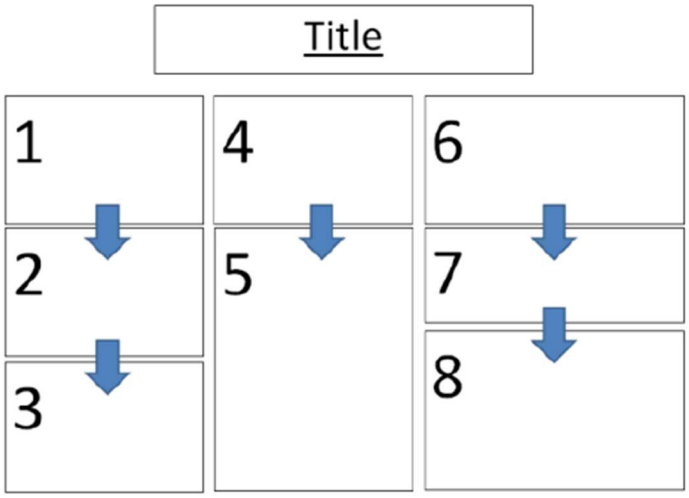
Academic posters contain:

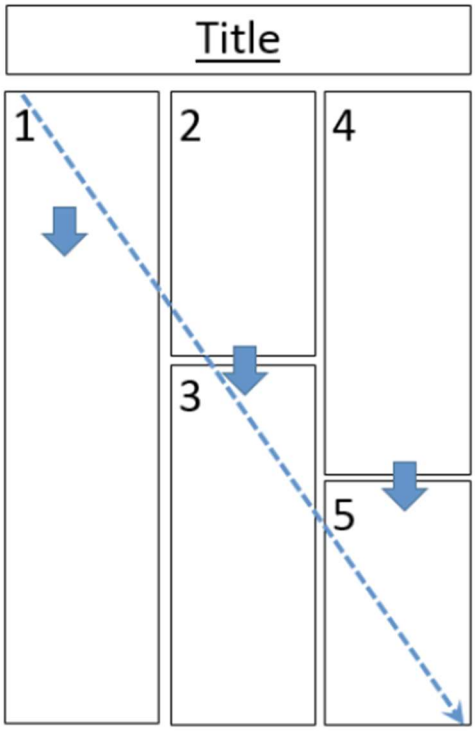
- Full prose (full sentences, not just brief remarks!)
- Pictures, diagrams, etc. to capture interest
- Colour! The best posters are visually appealing, and colour is one of the best ways of achieving this
- The author's name and institution (along with any organisational logos, etc.)

Some things to be careful of:

- Think about the *structure* of your poster: in what order should the reader move from box to box, or section to section? Is it obvious that the order you want them to read your poster is the way they'll read it?
- Balance – huge equations, overly complicated graphs or lengthy paragraphs of pure text will lose the interest of your reader! On the other hand, giant pictures with no text will lead to a poster with little real information on. Think about how best to balance what you want to describe!
- Portrait or landscape? Either is fine, but think about how best to present what your content

Example academic poster templates :

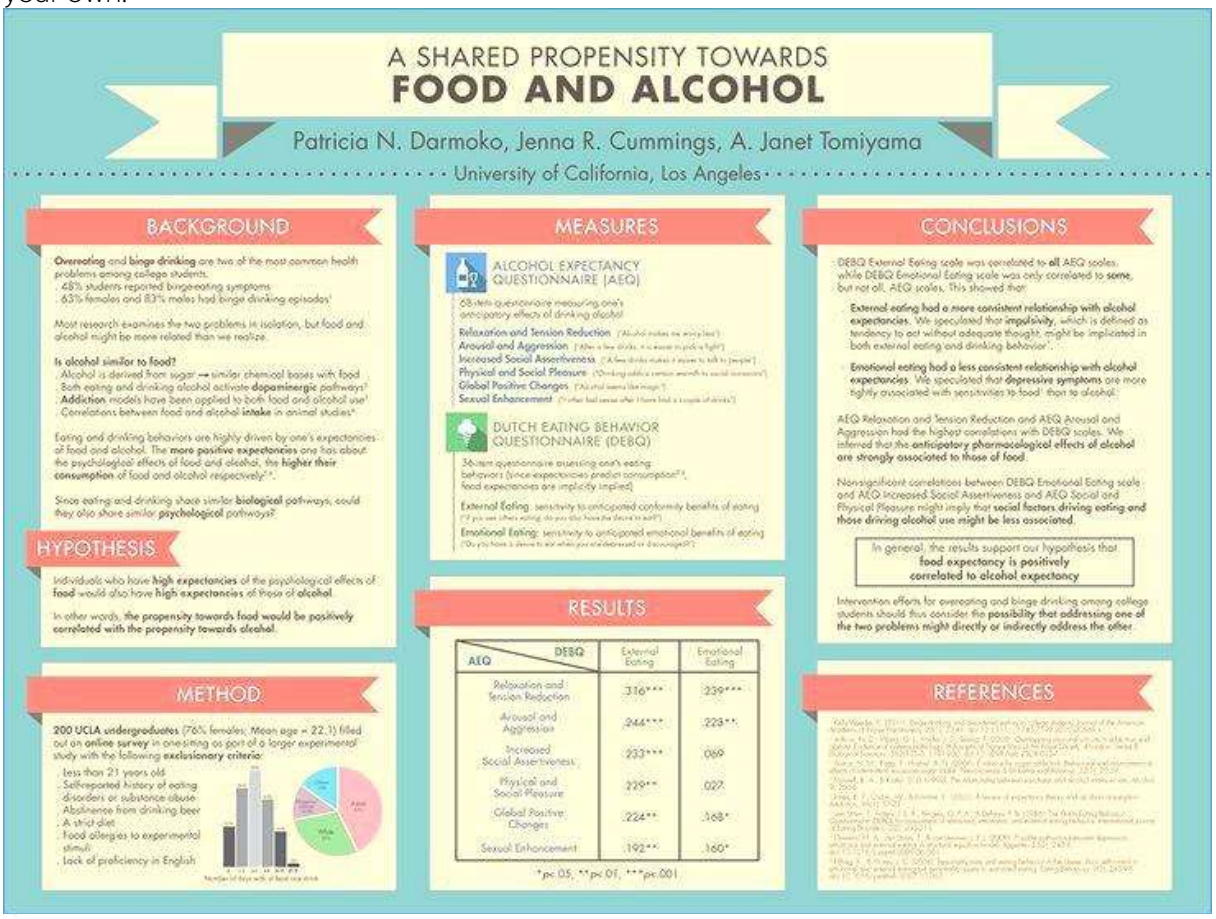


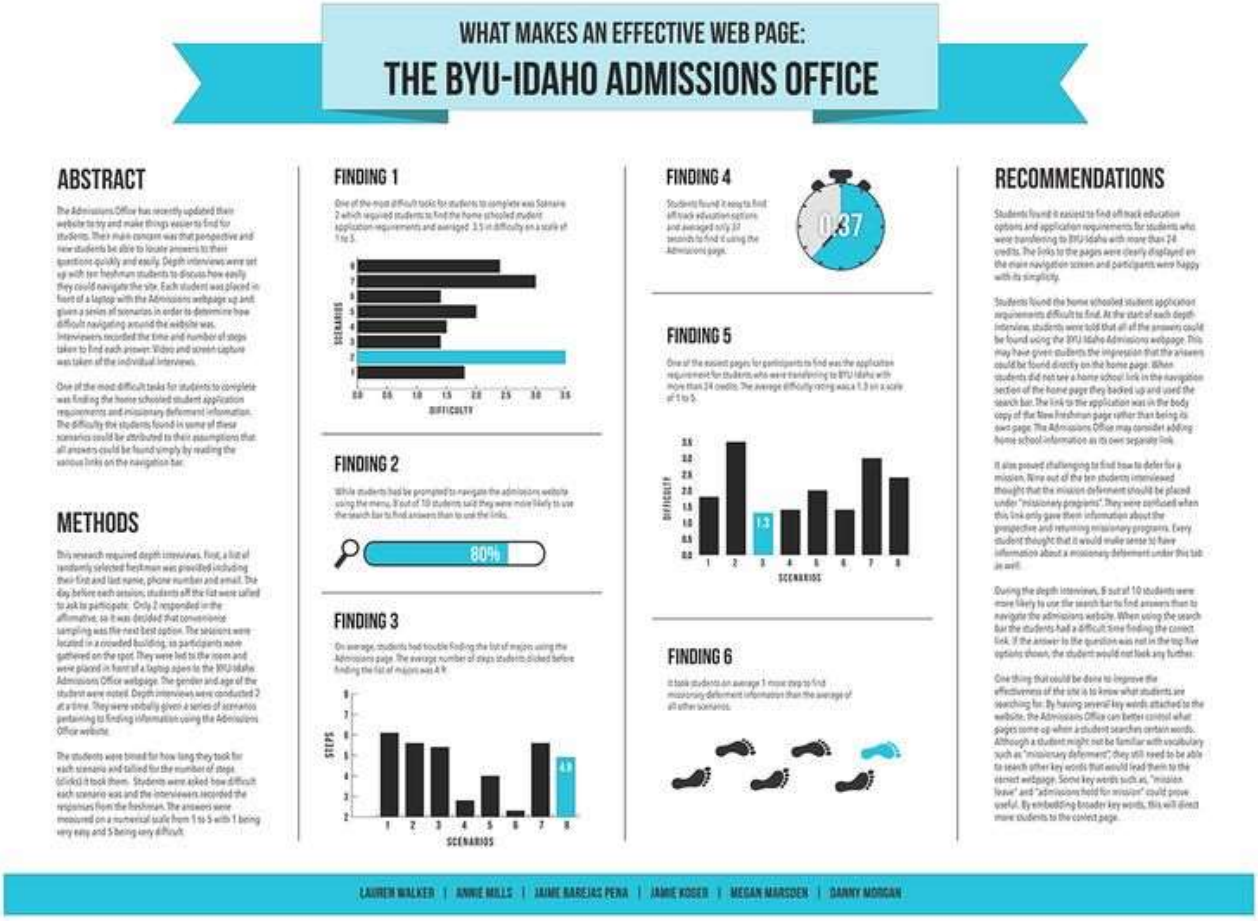


There is no catch-all template that works in every case – think about the overall question you'd like to answer and think of the smaller questions that make up the main one. Usually the first section is an introduction or background section and the final section is a conclusion & references section – otherwise the middle can vary, as can be seen in the following example posters:

Some example academic posters

Think about how these posters use structure, colour, graphics and style. Not every academic poster shown here is ideal! Some will be too text-heavy, some may have a confusing layout or a picture that takes up too much space – think about what these posters do well or badly and use them for inspiration in your own!





Developing and characterising a novel combined nanoelectrode system

L. P. Robinson, A. Mount

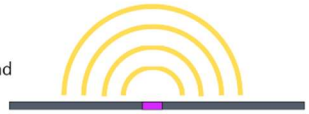
Electrochemistry at nanoelectrodes

Nanoelectrodes have several advantages for electrochemical sensing.

Linear diffusion profile

Transport to macroelectrodes proceeds through a relatively inefficient linear diffusion profile. They are also are highly affected by convection and iR drop.

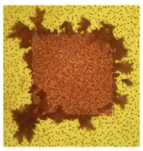
In contrast, the diffusion pattern for nanoelectrodes quickly becomes hemispherical. This profile is much more efficient, and they are not so affected by convection or iR drop. They can reliably detect very low (attomole) concentrations of analyte.



Hemispherical diffusion profile

A Pt microsquare nanoband edge electrode (MNEE) array system in which the Pt nanoband acts as the working electrode has been developed. The project now aims to create a nanoelectrode device based on this system which has all three electrodes necessary for analysis on one chip.

Ag/AgCl as a combined electrode



Dendritic growth

The combined reference/counter electrode is created by electroplating a thin film of Ag onto the Pt microsquare.

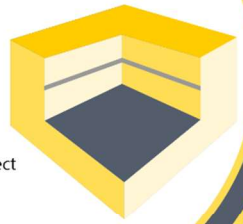
Potentiostatic plating causes Ag to grow preferentially at the corners, creating dendrites. A galvanostatic plating protocol is being developed to provide the required smooth, shiny Ag deposit.

To convert the newly plated Ag surface to AgCl, it must be functionalised. Chemical functionalisation by immersion in $FeCl_3$ has been shown to produce uniform deposits of AgCl.

Combined nanoelectrode system

This design consists of a microsquare at the bottom of each cavity in the array, with the nanoband around the cavity edge.

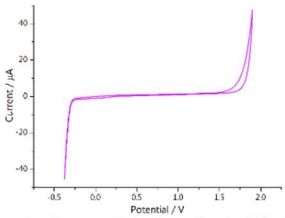
The Ag/AgCl microsquare is a combined reference and counter electrode. As its area is so much larger than the Pt nanoband, the current passing through the square is not large enough to affect its use as the reference electrode.



This could create an on-chip device for sensitive analytical detection.

Characterisation

Cyclic voltammetry and electrochemical impedance spectroscopy will be used to verify that the system is behaving as predicted. The nanoband should have a similar reponse to the current nanoelectrode array.



Example of a nanoelectrode cycling in 100mM KCl solution. This cycle is used to determine the cleanliness of the electrode surface.

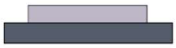
Fabrication

This design has been fabricated at the Scottish Microelectronics Centre using photolithography. In this technique layers of metal and insulator are deposited and patterned to produce the desired arrangement.

1. Si wafer with oxide surface

2. Metal is then deposited and coated in a nitride passivation layer

3. Photoresist layer is deposited and exposed to UV light through a patterned mask

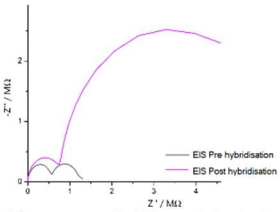


4. Nitride is removed and process repeated to pattern metal layer

Each layer is deposited and patterned sequentially. This approach reliably produces uniform electrodes cheaply and easily.

An application

By coating the surface of the working electrode in a probe nucleic acid, the corresponding DNA sequence can be detected using electrochemical impedance spectroscopy (EIS). Before the target molecule is hybridised, the resistance measured for the redox couple is small. When the correct target is hybridised the resistance, and therefore the EIS reponse, is much larger.



EIS measurement of 50 nm electrode shows the increase in resistance upon addition of the target nucleic acid.

Pre hybridisation - the redox species has access to the electrode.

Post hybridisation - the access of the redox species is restricted, and so the resistance rises at the electrode.

Objectives

Having made the initial measurements, the next steps will include;

- complete fabrication of the combined system, including optimisation of nanoband and cavity dimensions
- further investigation of the sensitivity of nanoelectrodes for use in DNA sensing and the relationship between the response and concentration of the target
- optimisation of a galvanostatic silver plating protocol

Many thanks to Dr Damion Corrigan, Ilka Schmueser, Professor Andy Mount, the Mount group and the SMC for their continuing support and expertise.

SMC

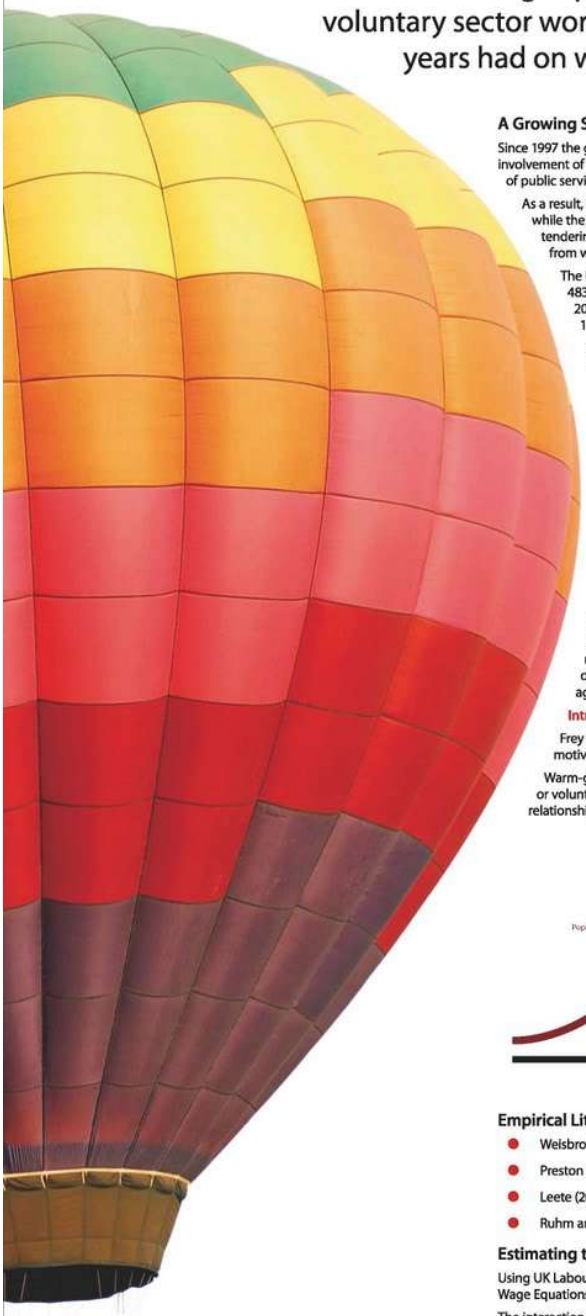
EPSRC
Pioneering research and skills

UNIVERSITY OF STIRLING

On The Up: Voluntary Sector Wages in the UK 1998-2007

Alasdair Rutherford

What effect has the big expansion of the UK voluntary sector workforce in the past ten years had on wages in the sector?



A Growing Sector

Since 1997 the government in the UK has promoted the involvement of the independent non-profit sector in the provision of public services.

As a result, the voluntary sector has grown dramatically while the increasing use of commissioning and competitive tendering has exerted many market forces on the sector from which it had previously enjoyed some shelter.

The UK voluntary sector workforce has grown from 483,000 employees in 1996 to 611,000 employees in 2005. This is an increase of 26% in ten years (Private 11%, Public 14%).

The value of government contracts with the UK voluntary sector increased from around £2 billion in 1996/97 to £6.88 billion in 2005/06.

What is the Voluntary Sector?

- Non-distribution of profits constraint;
- Public-benefit Purpose;
- Independent.

The Voluntary Sector Labour Market

Warm-Glow Theory

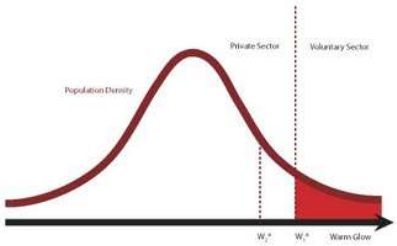
The most comprehensive model is Besley & Ghatak's (2005) Motivated Agent model.

Motivated Principals and Agents match, and the model predicts lower wages in mission-motivated organisations as warm-glow utility forms part of the agents' compensation.

Intrinsic Motivation Theory

Frey (1997) argues that compensation crowds out intrinsic motivation.

Warm-glow is therefore applicable to donating money or volunteering time, but not to the contracted worker relationship.



Empirical Literature

- Weisbrod (1983) found a nonprofit wage discount of 20%;
- Preston (1989) found a nonprofit sector wage discount of 18%;
- Leete (2001) found some differences at the industry level;
- Ruhm and Borkoski (2003) found no sig. dif. in panel data.

Estimating the Model

Using UK Labour Force Survey data 1998 to 2007 we estimate Mincer Wage Equations.

The interaction of sector and year variables estimates the sector wage differences in each year.

Tackling Unobserved Heterogeneity

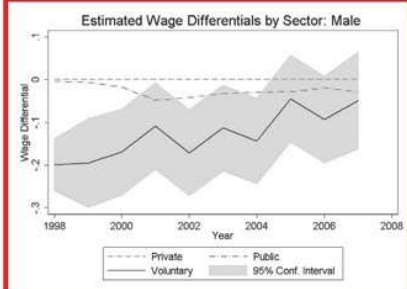
Government policy since 1997 has provided an exogenous shock that has increased the size of the sector.

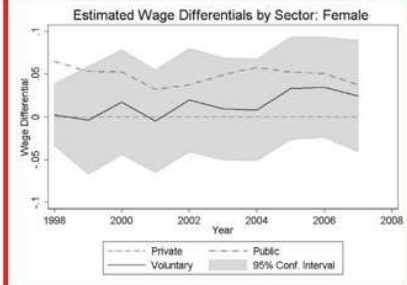
The panel element of the LFS is used to estimate a Fixed Effects model.

Andreoni (1990) used the phrase "warm glow" to describe the impure altruism of utility from the act of giving to charity

Alasdair Rutherford
ar34@stir.ac.uk
acrutherford.blogspot.com

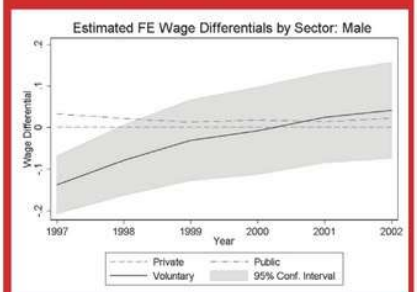
Model 1: Pooled Cross-Section

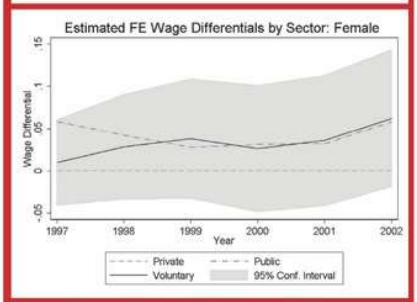




$$\ln(w) = \beta_0 + \beta_{VOL}VOL + \beta_{VOLYEAR}VOL \times YEAR + \beta_{PUB}PUB + \beta_{PUBYR}PUB \times YEAR + \beta_{EDUC}EDUC + \beta_{EXP}EXP + \beta_{EXP2}EXP^2 + \beta_X X + \varepsilon$$

Model 2 : Panel Fixed Effects





$$\ln(w_{it}) = CONS + \beta_{VOL}VOL_{it} + \beta_{VOLYEAR}VOLXYEAR_{it} + \beta_{PUBLIC}PUBLIC_{it} + \beta_{PUBYEAR}PUBXYEAR_{it} + \beta_{EDUC}EDUC_{it} + \beta_{EXP}EXP_{it}^{2} + \beta_X X_{it} + u_i + \varepsilon_{it}$$

Discussion

Voluntary Sector wages are significantly lower for male workers, less clear for female workers.

Lower Voluntary Sector wages for both male and females in 1998 – but wages in the sector have grown faster over the past ten years than the other two sectors.

This reduces the average level of warm-glow in the sector. If this intrinsic motivation is crowded out by increasing extrinsic incentives, then this is an issue. An unintended consequence of the policy to contract out services could be an undermining of the sector's main advantage.

Vortex Motion around Impenetrable Objects

Student: Stephen Flood

Supervisor: David Burton

LANCASTER UNIVERSITY

1: Introduction

Vortices are regions of highly rotational fluid. Common examples of vortices include tornadoes and whirlpools.

Vortices are very important in any fluid flow and can have devastating effects on structures like chimneys and off-shore facilities. Vortex induced vibration can have a massive effect on these strcutures.

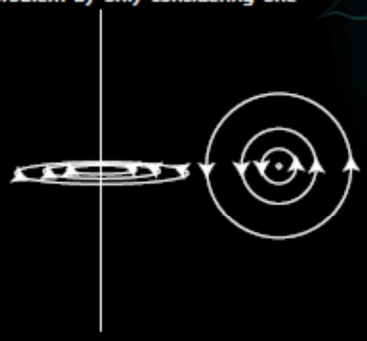
Understanding vortex dominated flows helps us to reduce damage. Vortices are also invaluable when considering airflight applications.

2: Point Vortices in the Complex Plane

Line vortices are very useful to consider in calculations as they have uniform strength along their lengths, so:

- Strength (circulation) can be used as a defining parameter, so that any vortex can be defined by strength and position alone

- We can effectively take a 3D line vortex a 2D problem by only considering one slice.



3: Tools of the Trade

We use the complex plane to solve these situations of point vortices due to the simple nature of calculations. The fact that incompressibility and irrotationality are guaranteed makes the complex plane ideal.

The velocity field induced by a single vortex of strength Γ_0 at position z_0 in the complex plane is

$$v^*(z) = \frac{\Gamma_0}{2\pi i}\frac{1}{z - z_0}$$

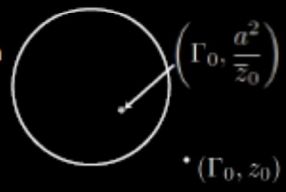
The method of images is then used to find the velocity in flows containing impenetrable boundaries. This involves
- Finding the complex potential in the unbounded fluid and adapting in image vortices.
- Adding image vortices for each vortex in the outside area, as if the interior region were also full of fluid.

4: Motion of a vortex near a disc

Using the method of images, we can consider the velocity of a line vortex near an impenetrable cylinder by simply taking a 2D slice as shown in this picture. The method of images then gives the complex velocity as

$$v^*(z) = \frac{\Gamma_0}{2\pi i}\left[\frac{1}{z - z_0} - \frac{1}{z - \frac{a^2}{\overline{z_0}}}\right]$$

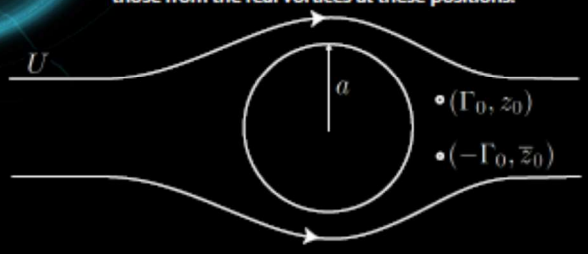
This has a rotating solution, so we can see that the vortex orbits the circle.



5: Föppl Vortices

An interesting case to study is that of Föppl Vortices. Here two vortices of opposite strengths are shielded from an constant inflow U by an impenetrable cylinder.

We can see, via the method of images, that there exists a set of positions such that the vortices do not move. This is because the velocity contributions from the image vortices exactly cancels those from the real vortices at these positions.



6: Contact Forces on Impenetrable Objects

The contact force of one vortex on a cylinder as above is found using the unsteady generalisation of the Blasius theorem

$$\overline{f} = \rho_0\left(2\pi a^2\frac{d\overline{U}}{dt} - \sum_k i\Gamma_k\left(\frac{d\overline{z}_k}{dt} - \frac{d\overline{z}_{ik}}{dt}\right)\right)$$

The contact force imparted on a disc by a single vortex as above is hence inversely proportional to the distance of the vortex to the disc, and time dependent. It is here that the vortex induced vibration phenomenon can be observed.

It is interesting to note that as the force is dependent on the velocity of the vortices, and the inflow is constant, the force on the cylinder induced by

7: Conclusion

- Vortices move along impenetrable boundaries due to image vortices.
- There exist configurations of vortices which do not move due to cancellation of velocity components
- The contact force caused by a vortex on a disc is inversely proportional to the vortex's distance from the disc
- As the contact force is dependent on velocities, any situation in which the vortices are stationary impart no force on any objects in the flow

Appendix 3 – The Standard Model of Particle Physics

Here are (a selection of) the particles and forces in the *standard model of particle physics.*

HADRON	Quark constitution
Proton	u u d
Anti-proton	$\bar{u}\ \bar{u}\ \bar{d}$
Neutron	u d d
Anti-neutron	$\bar{u}\ \bar{d}\ \bar{d}$
Kaon (K^+, K^-, K^0)	$u\bar{s}$, $s\bar{u}$, $d\bar{s}$
Pion (π^+, π^-, π^0)	$u\bar{d}$, $d\bar{u}$, $d\bar{d}$ / $u\bar{u}$

LEPTON	Symbol	Lepton Number	Rest energy/MeV
Electron	β^-	+1	0.51
Positron	β^+	-1	0.51
Electron-neutrino	ν_e	+1	0
Electron-antineutrino	$\bar{\nu}_e$	-1	0
Negative muon	μ^-	+1	105
Positive muon	μ^+	-1	105
Muon-neutrino	ν_μ	+1	0
Muon-antineutrino	$\bar{\nu}_\mu$	-1	0
Negative tau	τ^-	+1	1780
Positive tau	τ^+	-1	1780
Tau-neutrino	ν_τ	+1	0
Tau-antineutrino	$\bar{\nu}_\tau$	-1	0

Quarks	symbol	Charge/e	Baryon number	strangeness
Up	u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
Anti-up	$\bar{u}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
Down	d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
Anti-down	$\bar{d}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0
Strange	s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
Anti-strange	$\bar{s}$	$+\frac{1}{3}$	$-\frac{1}{3}$	+1

Fundamental force	Exchange boson	Mass (in MeV/c^2)	Expected range
Electromagnetic	Photon, γ	0 (< 3 x 10^{-33})	infinite
Weak	W^+, W^-, Z^0 [$W^\pm = \{W^+, W^-\}$]	$W^\pm$ = 80.6 x 10^3 Z^0 = 91.16 x 10^3	~ 0.001 fm
Strong	Gluon, g	Not observable as an individual particle, expected = 0	~ 1 fm
Gravity	graviton?	Not known to exist, expected = 0	infinite?

Quantity	Symbol, equation	Value
speed of light in vacuum	c	299 792 458 m s^{-1}
Planck constant	h	$6.626\ 069\ 57(29)\times10^{-34}$ J s
Planck constant, reduced	$\hbar \equiv h/2\pi$	$1.054\ 571\ 726(47)\times10^{-34}$ J s
electron charge magnitude	e	$1.602\ 176\ 565(35)\times10^{-19}$ C
conversion constant	$\hbar c$	197.326 9718(44) MeV fm
conversion constant	$(\hbar c)^2$	0.389 379 338(17) GeV^2 mbarn
electron mass	m_e	$9.109\ 382\ 91(40)\times10^{-31}$ kg
proton mass	m_p	$1.672\ 621\ 777(74)\times10^{-27}$ kg $= 1836.152\ 672\ 45(75)\ m_e$
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854\ 187\ 817\ \ldots \times10^{-12}$ F m^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N A^{-2}
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	$1/137.035\ 999\ 074(44)^\dagger$
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$2.817\ 940\ 3267(27)\times10^{-15}$ m
(e^- Compton wavelength)/2π	$\lambdabar_e = \hbar/m_e c = r_e\alpha^{-1}$	$3.861\ 592\ 6800(25)\times10^{-13}$ m
Bohr radius ($m_{\mathrm{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	$0.529\ 177\ 210\ 92(17)\times10^{-10}$ m
Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\ 381\ 8066(38)\times10^{-11}$ MeV T^{-1}
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\ 451\ 2605(22)\times10^{-14}$ MeV T^{-1}
electron cyclotron freq./field	$\omega^e_{\mathrm{cycl}}/B = e/m_e$	$1.758\ 820\ 088(39)\times10^{11}$ rad s^{-1} T^{-1}
proton cyclotron freq./field	$\omega^p_{\mathrm{cycl}}/B = e/m_p$	$9.578\ 833\ 58(21)\times10^{7}$ rad s^{-1} T^{-1}
gravitational constant‡	G_N	$6.673\ 84(80)\times10^{-11}$ m^3 kg^{-1} s^{-2}
standard gravitational accel.	g_N	9.806 65 m s^{-2}
electric constant	K_E	$8.987,551,788... \times 10^9$m F^{-1}
electron volt	eV	$1.6021766208(98) \times 10^{19}$ J

Appendix 4 – All is Not as it Seems: Relativity and Quantum Physics – a Quick-Start Guide

In extreme situations the things we think of as common sense start to break down. In high-energy situations we have to implement Einstein's theory of relativity to take account of this; for very low-energy situations we have to implement quantum physics.

Relativity

Relativity deals with the concept of *frames of reference* e.g. the frame of reference of a person on a platform vs. the frame of reference of a person on a train passing the platform. In each reference frame, the observer is stationary.
Einstein's (weak) equivalence principle tells us that the laws of physics are the same in *every reference frame* (so there is no experiment you can perform to tell whether you're stationary or moving with constant velocity).
This combined with the fact that the speed of light (in vacuum) is the speed limit of the universe leads to some very unusual phenomena.

- For an observer on a rocket travelling very* fast, *time slows down*
- For an observer on a rocket travelling very* fast, *distances contract*
- Observers can accelerate and accelerate and accelerate but they can't exceed the speed of light. An increasing proportion of the energy used to accelerate the rocket actually goes to increase the *mass* instead of increasing the *speed* of the rocket

For an introductory video:
https://www.youtube.com/watch?v=30KfPtHec4s
For a series of three videos outlining relativity, length contraction and time dilation:
https://www.youtube.com/watch?v=rBmYUEnafok
https://www.youtube.com/watch?v=ilEeSiT3SI4
https://www.youtube.com/watch?v=FPzGAksFCbs
For a summary document with formulae:
http://theory.uchicago.edu/~nelia/SRsummary.pdf

*For this to be noticeable, faster than half the speed of light.

Quantum Physics

Quantum physics deals with very small length scales, or very low energies, such as predicting the behaviour of single atoms or subatomic particles. Our common sense and intuition fails on several fronts:

- Some things we think of as particles (e.g. electrons) also behave like waves (wave-particle duality)
- Some things we think of as smooth (how much energy can a particle have?) are in fact *discrete* – a particle might be able to have energy x or $2x$ but *NOT* $1.5x$
- Particles like electrons can be thought of as having *either* a defined position *or* a defined speed – not both! (Heisenberg uncertainty principle)
- Particles have a chance of passing through solid objects - the thicker the object the harder it is, but always *possible* (if unlikely!)

For an introductory video on wave-particle duality:
https://www.youtube.com/watch?v=Y6TlKUn1zlw
Another video about quantum physics (ignore the video title!):
https://www.youtube.com/watch?v=ARWBdfWpDyc
For an introductory article on quantum physics, see:
https://www.thoughtco.com/wave-particle-duality-2699037

Appendix 5 – Internet Resources on Particle Acceleration: Where to Start Researching?

Here are some helpful places to begin any research you might want to do into particle physics, particle accelerators and so on.

Particle accelerators:

http://www.particleadventure.org/accel.html

https://www.energy.gov/articles/how-particle-accelerators-work

Particle accelerator applications

http://www.accelerators-for-society.org/

https://www.quora.com/What-are-some-practical-applications-of-particle-accelerators

http://nautil.us/issue/14/mutation/10-reasons-why-you-cant-live-without-a-particle-accelerator

http://hte.ankara.edu.tr/files/2014/10/applications.pdf

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Fighting Cancer with Particle Beams

researchersinschools.org