Unit 2 - Particles and Waves – Part 1

THE STANDARD MODEL

1. Orders of Magnitude
    - The range of orders of magnitude of length from the very small (sub-nuclear) to the very large (distance to furthest known celestial objects).

2. The Standard Model of Fundamental Particles and Interactions
    - The evidence for the sub-nuclear particles and the existence of antimatter
    - Fermions, the matter particles, consist of:
        i. **Quarks** (6 types)
        ii. **Leptons** (**electron**, **muon** and **tau**, together with their neutrinos)
    - **Hadrons** are composite particles composed of **Quarks**
    - **Baryons** are made of three **Quarks**
    - **Mesons** are made of two **Quarks**
    - The force mediating particles are bosons (**Photons**, **W** and **Z Bosons** and **Gluons**)
    - Description of beta decay as the first evidence for the neutrino

FORCES ON CHARGED PARTICLES

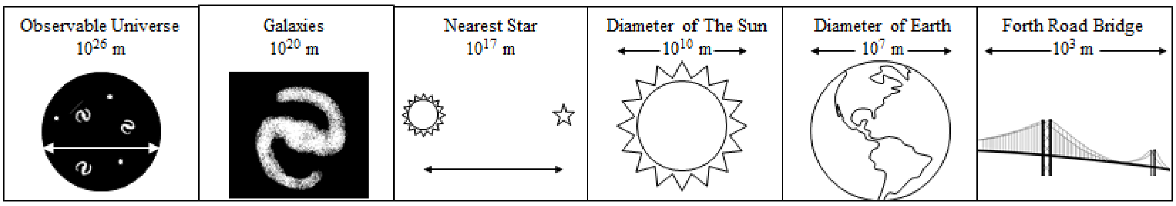
3. Electric fields around charged particles and between parallel plates
    - Examples of electric field patterns including single point charges, systems of two point charges and the field between parallel plates
4. Movement of charge in an electric field, p.d. and work, electrical charge
    - The relationship between potential difference, work done and charge gives the definition of the volt
    - Calculating the speed of a charged particle which has been accelerated in an electric field
5. Charged particles in a magnetic field
    - A moving charge produces a magnetic field
    - The direction of the force on a charged particle moving in a magnetic field should be described for negative and positive charges
6. Particle accelerators
    - Basic operations of particle accelerators in terms of acceleration, deflection and collision of charged particles

NUCLEAR REACTIONS

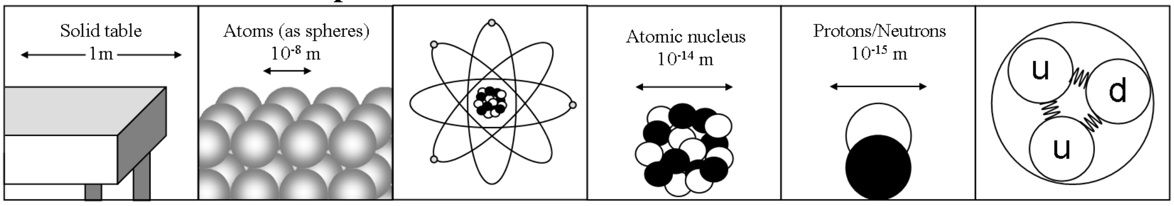
7. Fission and fusion
    - Nuclear equations to describe radioactive decay, fission and fusion reactions
    - Mass and energy equivalence, including calculations
    - Coolant and containment issues in nuclear fission reactors

ORDERS OF MAGNITUDE

In Physics it is necessary to measure extremely large and extremely small objects.
From the size of the **Universe:**



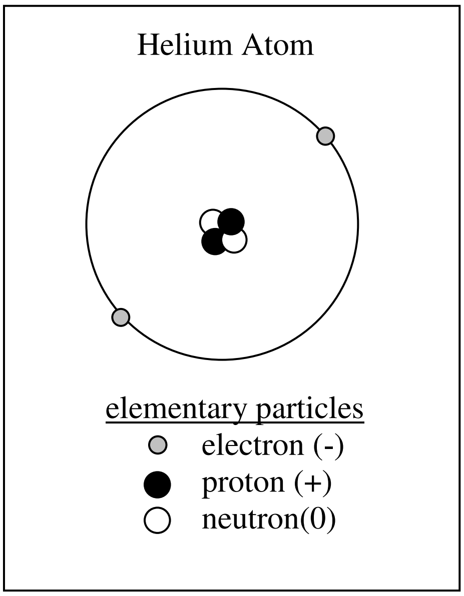
To the size of **subatomic particles**.



The average distance from the Earth to the Sun is 150 000 000 km. There are two problems with quoting a measurement in this way: the **inconvenience** of writing so many zeros, the **uncertainty** in the value (How many significant figures are important?) These are over come if **scientific notation** is used. 150 000 000 km = 1.5 x 10^8 km.

THE STANDARD MODEL

In a **particle accelerator** a very small particle, eg an electron, can be accelerated by electric and magnetic fields to a **very high speed**. Being very small, speeds near to the speed of light may be achieved. When these particles collide with a stationary target, or other fast-moving particles, a substantial amount of **energy** is **released** in a small space. Some of this energy may be converted into mass ($E=mc^2$), producing showers of **nuclear particles**. By passing these particles through a magnetic field and observing the deflection their **mass** and **charge** can be measured. For example, an electron with low mass will be more easily deflected than its heavier cousin, the muon. A positive particle will be deflected in the opposite direction to a negative particle. Cosmic rays from outer space also contain particles, which can be studied in a similar manner.



Most matter **particles**, such as protons, electrons and neutrons have corresponding **antiparticles**.

These have the same rest mass as the particles but the **opposite charge**. With the exception of the antiparticle of the electron e^-, which is the positron e^+, antiparticles are given the same symbol as the particle but with a bar over the top.

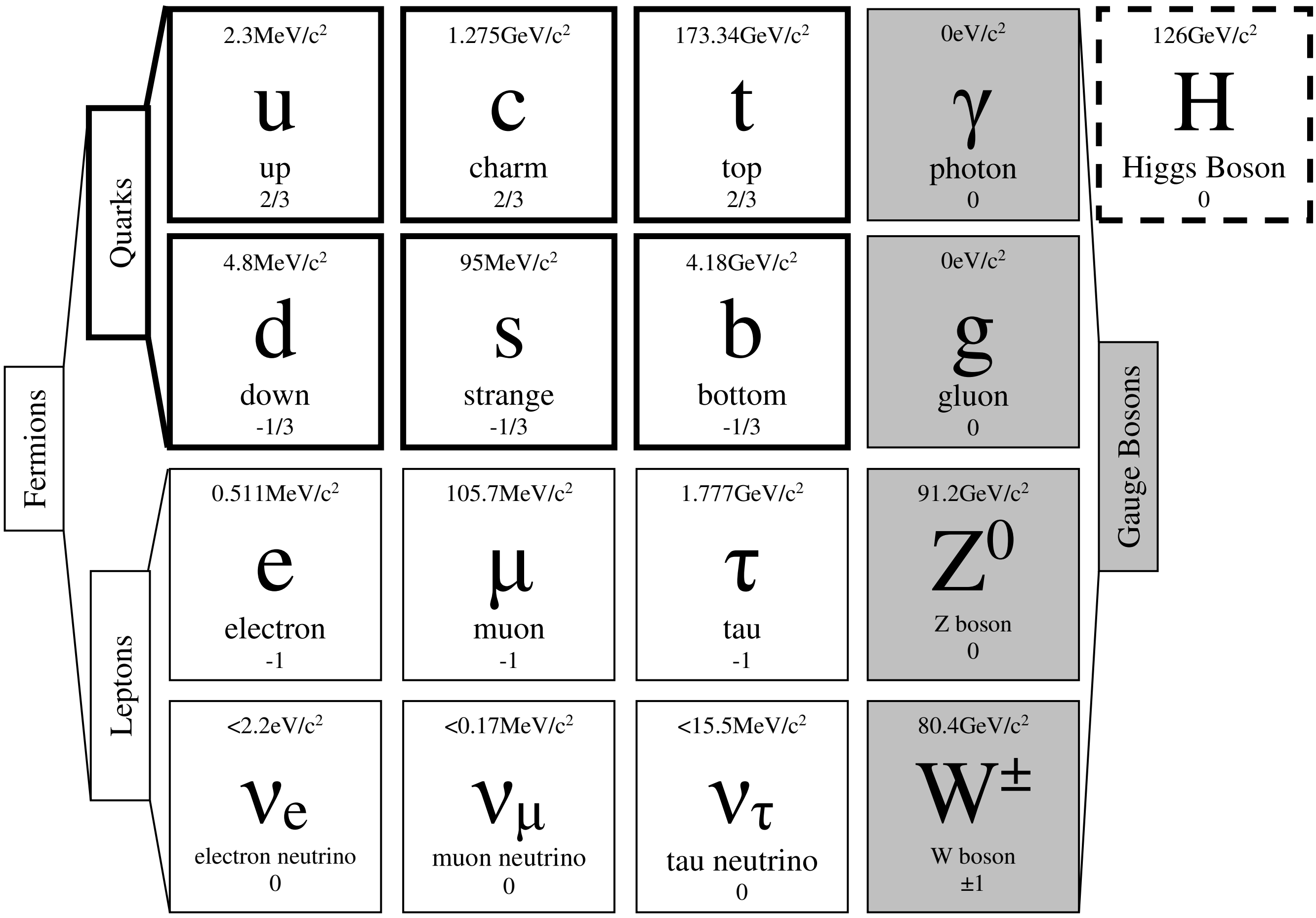
When a particle and its antiparticle meet, in most cases, they will **annihilate** each other and their combined mass is converted into energy. There are far more particles than antiparticles in the Universe, so annihilation is **extremely rare**.

THE FUNDAMENTAL PARTICLES

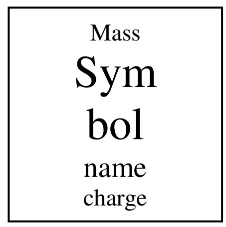
Fundamental particles are particles that cannot be divided into smaller particles. In the standard model of particle physics, there are 12 fundamental particles (called Fermions). There are 6 types of **quarks** and 6 types of **leptons**. These all have corresponding **antiparticles**. There are also 4 **force carriers**, also known as force mediators.

Quarks have **fractional charges**. The top quark is the most massive fundamental particle, almost 200 times the mass of a proton. There are also three generations. Individual quarks have never been detected.

Leptons have **no size** and in most cases low or no mass. There are **three generations** of leptons, only electrons occur in ordinary mass. Muons occur in the upper atmosphere and the tau has only been seen in laboratory experiments.



Each of these particles has an antimatter counterpart with equal mass and lifespan but opposite charge!

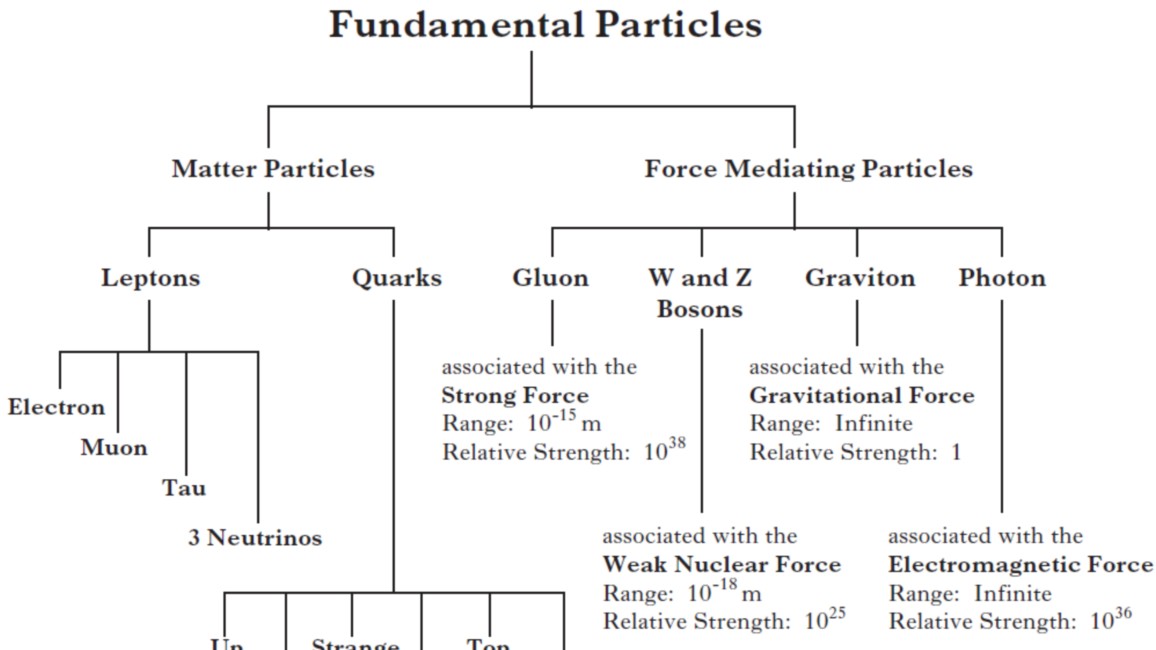


In Particle Physics mass is denoted in units of eV/c^2. This notation is derived from the equations $E = mc^2$ and $W = QV$. During interactions certain quantities must be conserved, these values include charge and mass.

Energies are also denoted in terms of the electron volt, eV. Which again comes from the equation $W = QV$.

Hadrons are particles made from quarks that are held together by the strong force, Hadrons are **composite** particles. The strong force is so strong that quarks have never been found individually.

There are two types of hadron:
Baryons - made of **three** quarks or **three** antiquarks (known as antibaryons)
Mesons - made of a **quark** and an **antiquark**.



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The baryons and mesons can only have whole **integer** charges, 2e, e, 0, -e and -2e. There are other rules governing the joining of interactions, strangeness, spin, topness.
We will not cover these in this course.

Quarks	Quark charges	Total charge	Baryon or meson
udd (neutron)	2/3 -1/3 -1/3	0	baryon
udu (proton)	2/3 2/3 -1/3	+1	baryon
$u\bar{d}$ (pion)	2/3 1/3	+1	meson
$\bar{u}d$ (negative pion)	-2/3 -1/3	-1	meson

There are approximately 140 possible meson combinations, there are a predicted 40 possible baryons.

Ordinary matter contains only the first generation of quarks as the lifetime of higher generation quarks are very low, they quickly decay into up quarks or down quarks. Very high energies are needed to make hadrons composed of other quarks.

Fundamental Forces and Force Mediating Particles

Particles may experience four forces: **strong (nuclear)** force, **weak (nuclear)** force, **gravitational** force and **electromagnetic** force.

Strong (Nuclear) Force • Electrostatic theory predicts that the protons in the nucleus should fly apart. This does not happen so there must be another force present. This is known as the **strong force** and holds the nucleons together • The strong force acts over a short range and over this short range it is stronger than the electrostatic force. • Only **experienced by quarks**	Gravitational Force • See Unit 1 notes • Has infinite range • **Weakest** of the fundamental forces
Weak (Nuclear) Force • Involved in radioactive beta decay • Acts over a **short range** • Is **weaker** than the strong nuclear force (hence its name) • Experienced in quark and lepton interactions	Electromagnetic Force • Combination of the **electrostatic** and **magnetic** forces • Has infinite range

Grand Unification Theory

Scientists are working towards a **Grand Unification Theory** which will link all the forces into one theory. The Gravitational Force is proving more difficult to link to the other forces. For this reason the gravitational force is not included in the Standard Model. The gravitational force is relatively **very** weak and therefore can be ignored in terms of subatomic particles.

The sub-atomic non contact forces are explained using **force carriers**. The force carriers are:

Force Carrier	Photon	Gluon	W boson	Z boson	Graviton*
Force	Electromagnetic	Strong Nuclear	Weak Nuclear	Weak Nuclear	Gravitational

*Gravitons are purely theoretical and have not been discovered. It should be noted that he graviton is <u>not</u> the Higgs Boson. The Higgs Boson is responsible for the mass of particles, with mass the particle produces a gravitational field (like a charged particle produces an electric field). The graviton is the mediator for the gravitational field (like the photon is the mediator for the electromagnetic).

Beta Decay and the Evidence for the Neutrino

More often than not it is when a theory is proven incorrect that we learn the most about it. One example of this is beta decay.

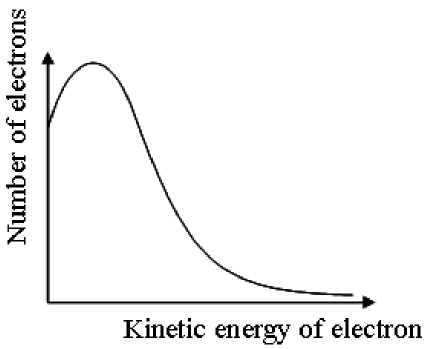
Beta decay can occur in unstable nuclei where the nucleus emits an electron, leaving a nucleus with the same mass number but an increase in atomic number of 1. For example:

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

In more general terms we can consider just the neutron becoming a proton:

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

Notice that mass number and charge number are conserved. These are not the only quantities that need to be conserved in a situation like this. Energy must also have been conserved. While mass number is conserved the actual mass of the proton is less than the mass of the neutron, this decrease in mass results in a release of energy ($E=mc^2$), available as kinetic energy to the electron. Particle Physicists discovered that the kinetic energy of the electron was not always equal to this value, in fact the electron could have any of a number of values for its kinetic energy:



The evidence points to the presence of a second particle, which shares the kinetic energy. This particle would have to have no charge (since charge is already conserved) and a very low mass since it is almost undetectable. This neutral, tiny one was named the neutrino (which in Italian means just about the same thing).

And so the equation can be completed:

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}_e$$

Ultimately the particle was determined to be an electron anti neutrino, the antimatter equivalent to the electron neutrino, which we have seen earlier.

Advanced Beta Decay

For further interest we can analyse the interaction in terms of the fundamental particles involved. We would see that a neutron (udd) becoming a proton (udu) would require a down quark to become an up quark:

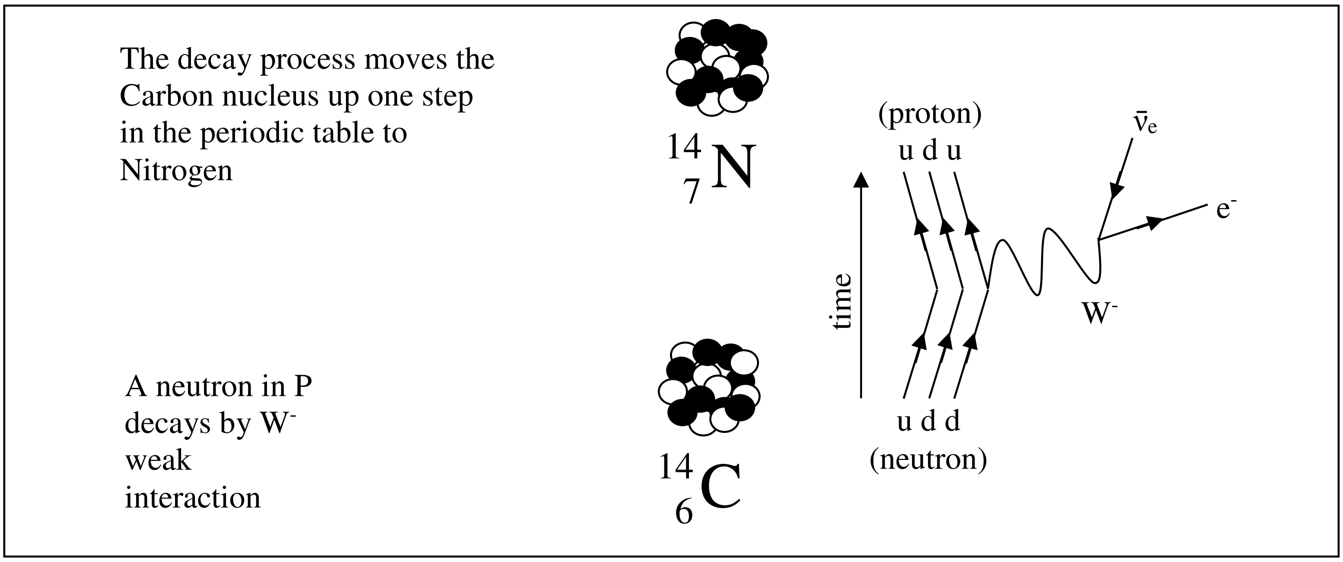
$$_{-1/3}d \rightarrow {}_{2/3}u + {}_{-1}e + \bar{\nu}_e$$

Notice that charge, even with fractional charges is still conserved.

Richard Feynman developed a way to represent such an interaction in terms of the particles involved and the mediating particles, these are now known as Feynman diagrams. In a Feynman diagram a particle may be changed in form, or direction, by a mediating particle.

All interactions can only involve these three parts: "particle in", "particle out" and the mediator (represented by the wavy line). Any of these lines can then go on to be part of another interaction, where the rules are the same.

The full Feynman Diagram for beta decay is shown below. Notice that two quarks are unaffected by the interaction (we could technically ignore them here).

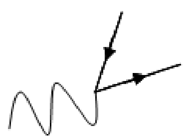


The important down quark decays into an up quark, emitting a W$^-$ boson (charge, -1, still conserving charge):

$${}_{-1/3}d \rightarrow {}_{2/3}u + {}_{-1}W^-$$

The W$^-$ boson has an extremely short lifespan and is never truly observed. It decays into an electron and an electron antineutrino

$${}_{-1}W^- \rightarrow {}_{-1}e + \bar{\nu}_e$$



Again charge is conserved (and with the electron antineutrino, so is electron-ness, this is apparently a thing!)

You may notice that the electron antineutrino travels backwards in time on this diagram. Not only does this fit with the rules for the Feynman diagram, this notation actually interprets the behavior of antimatter correctly and all antimatter particles are drawn to move backwards in time.

There is also another type of beta decay, known as beta +. In this process a proton decays into a neutron, a positron (anti electron) and an electron neutrino are emitted.

Detecting and Identifying Particles

While these notes are presented to follow the order of the course as set out by the SQA, it is recommended that students familiarise themselves with the section on electric and magnetic fields and the forces which charged particles experience within these fields. This section is included here to help understand how fundamental particles and anti-matter can be identified.

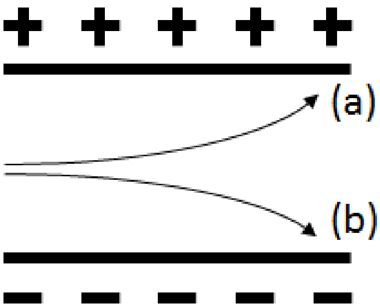
Cloud Chambers

A cloud chamber is a container which contains a supersaturated vapour. The molecules in this vapour are polar, meaning that they have a positive end and a negative end. When a charged particles, say an electron, passes though the chamber the vapour is ionised along the path of the particle. The ionised particles then act as condensation nuclei, the polar molecules align themselves and are drawn towards the electrons path. As they become closer the vapour condenses enough to become visible and we trails of "cloud", similar in appearance to the vapour trails left in the sky by aeroplanes.

Fields

If we apply an electric field across the cloud chamber then charged particles will be deflected from their paths. Negatively charged particles will be attracted to positively charged plates and repelled by negatively charged plates, and vice versa. By observing the given paths we can make comparisons and determine the nature of the particles travelling through the chamber.

Example 1



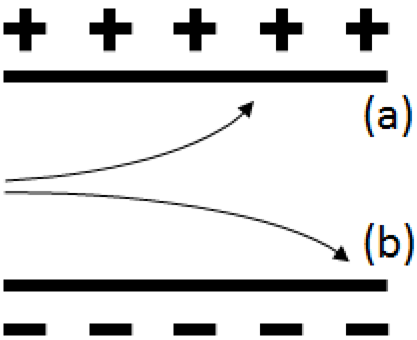
Here two particles are observed to deflect in opposite directions.

Since their paths are seen to be symmetrical in can be determined that:

- they have opposite but equal charge
- the have equal mass

Conclusion: we are observing a **particle** and its equivalent **antiparticle**.

Example 2



Two particles are observed to deflect in opposite directions.

Since their paths are not symmetrical we determine that:

- they have opposite charge (can we say equal?)
- (b) is most likely more massive than (a)

Conclusion: we may be observing an **electron** (a) and a **proton** (b)

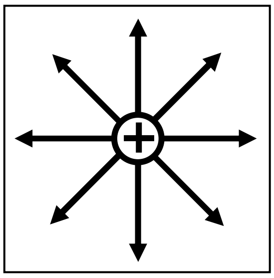
There are more complex and precise detectors in use at CERN and other facilities but this gives you an introduction to the basics.

FORCES ON CHARGED PARTICLES

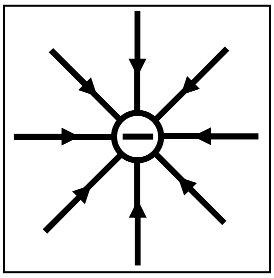
Electric Fields

An **electric field** is a region where a **charged particle** (such as an **electron** or **proton**) experiences a **force** (an **electrical force**) without being touched.
If the charged particle is free to move, it will accelerate in the direction of the unbalanced force.

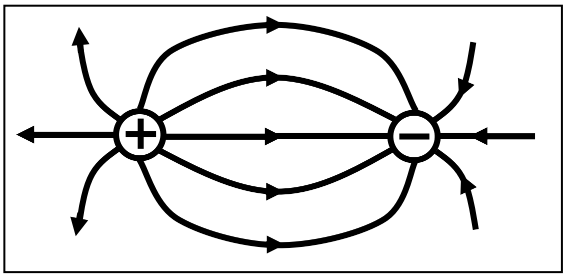
To represent an **electric field**, we draw **electric field lines**. The **field line** represents the motion of a **test positive charge.**

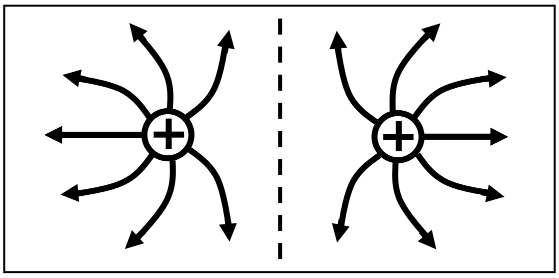


The electric field from an isolated positive charge. A positive test charge would experience a repulsive force



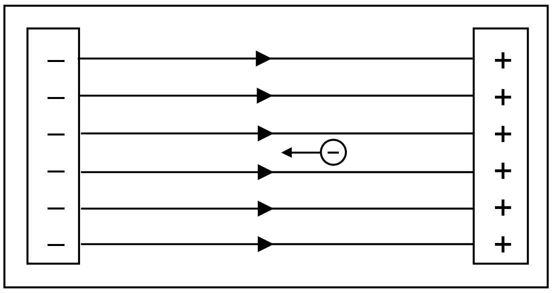
The electric field from an isolated negative charge. A positive test charge would experience an attractive force



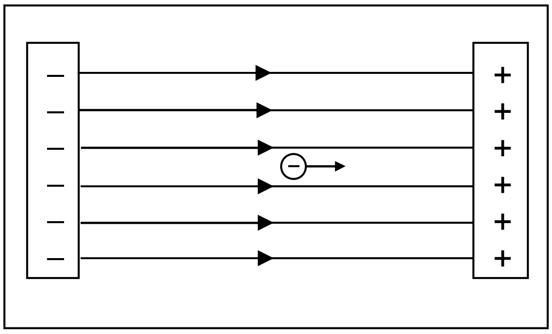


Work is done when a **charge** is moved in an **electric field.**

To move an **electron** (negative charge) towards the negatively charged plate, **energy** must be needed in order to overcome the repulsion force between the electron and the negatively charged plate. The **work done** is gained by the electron as **electrical potential energy**.



If the **electron** is free to move back towards the positively charged plate, the **electric field** does **work on** the electron. The electron's **electrical potential energy** is changed to **kinetic energy** as the **electric field** accelerates the electron towards the positively charged plate.



Work Done Moving a Charge and Potential Difference

The **potential difference** (**V**) between 2 points in an electric field is a measure of the **work done** (**W**) in moving **1 coulomb of charge** between the 2 points.

$$W = QV$$

- W: work done in moving quantity of charge between 2 points in an electric field/ joules (J)
- V: potential difference between 2 points in an electric field/ joules per coulomb (JC^{-1}) OR volts (V)
- Q: quantity of charge/ coulombs (C)

Calculate the potential difference between 2 points in an electric field, if the field does:

25 J of work moving 5 C of charge W = 25 J W = QV Q = 5 C 25 = 5 x V V = 5V	100 J of work moving 2.5 C of charge between the 2 points. W = 100 J W = QV Q = 2.5 C 100 = 2.5 x V V = 40V

Electrical Potential Energy to Kinetic Energy

When an **electron** is free to move in the **electric field** between two oppositely charged metal plates, the **work done** by the **electric field** on the **electron** is converted to **kinetic energy** of the **electron**.

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

[This equation also applies to any other charged particle in an electric field].

Example

An electron is free to move in an electric field. The electron is accelerated by the field from rest through a potential difference of 500 V. Calculate the speed of the electron at the end of the acceleration.

work done on electron by electric field = gain in kinetic energy of electron

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

$$(1.60\times10^{-19})\times500 = \frac{1}{2}\times(9.11\times10^{-31})\times v^2$$

$$v^2 = \frac{(1.60\times10^{-19})\times500}{\frac{1}{2}\times(9.11\times10^{-31})}$$

$$v = \sqrt{\frac{(1.60\times10^{-19})\times500}{\frac{1}{2}\times(9.11\times10^{-31})}}$$

$$v = 1.33\times10^{7}\,ms^{-1}$$

Charged particles in a magnetic field

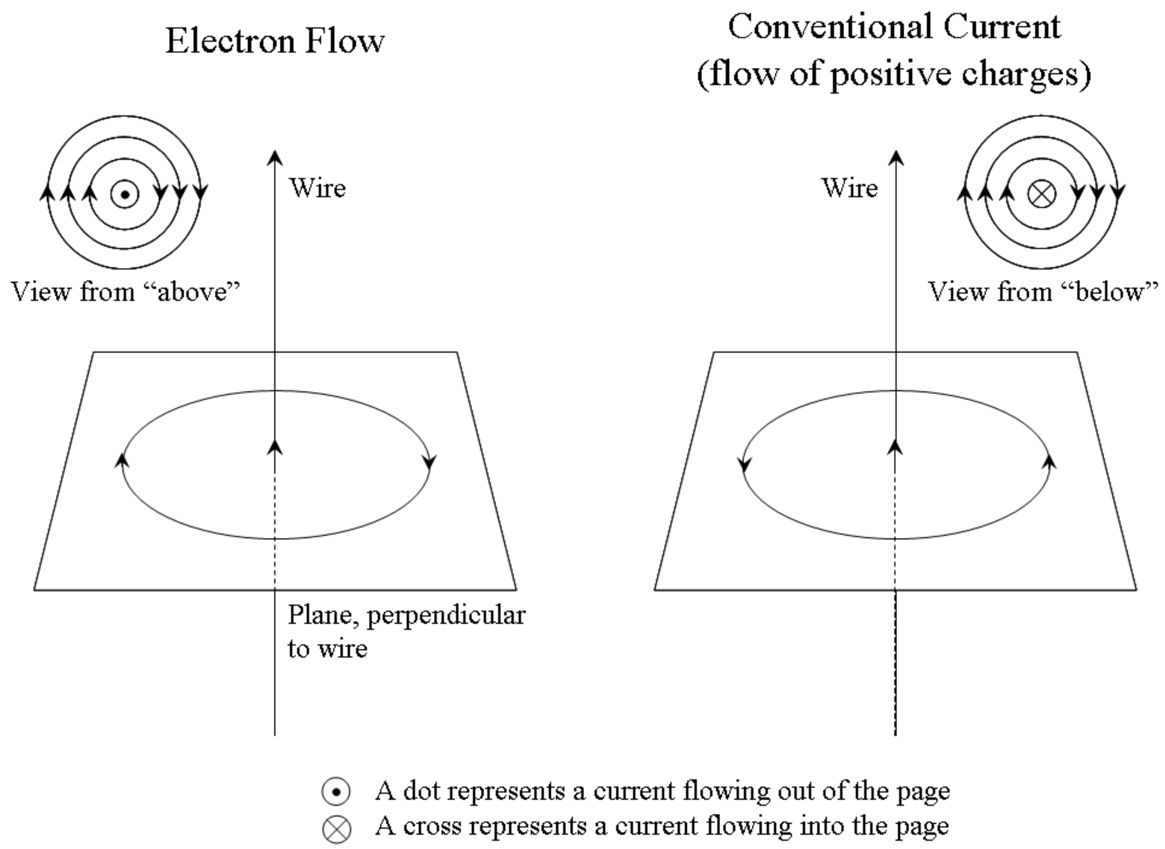
Magnetic fields are produced by **moving charges** or currents in wires. In a simple bar magnet there do not appear to be any currents but the magnetic field is generated by **electrons** orbiting atoms that make up the structure of the magnet.

> ***WARNING***
>
> **Current can be considered as the flow of electrons or as conventional current (the flow of positive charges). For Higher Physics you need to know how to interpret the effects of <u>BOTH</u> on a current carrying wire.**

If a **current** flows through a piece of **wire** then a **magnetic field** will be produced around the wire.

The direction of the magnetic field depends on the **direction** of current flow.

The direction can be determined using the **screw rule**.

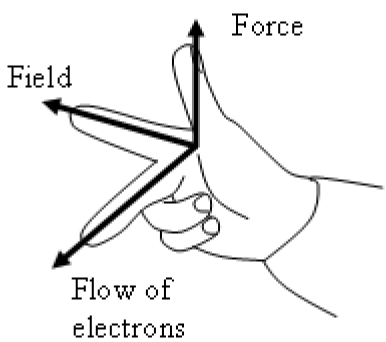


Forces acting on a current carrying wire

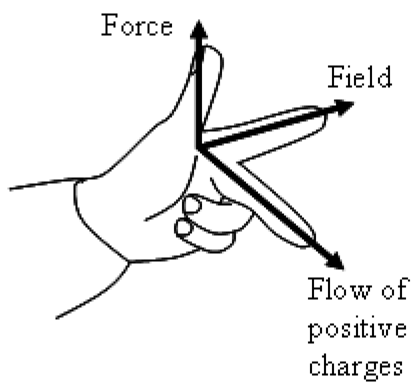
A wire carrying an **electric current** will experience a mechanical **force** when placed in a magnetic field. When this happens, the magnetic field pushes on the wire. The force of this "push" relates directly to the **intensity of the current**, the **strength of the magnetic field** and the **length of the wire in the field**.

You can visualize this relationship by using the **"right hand rule"** (electron current) or **"left hand rule"** (conventional current). If the first finger points in the direction of the magnetic field, the second finger in the direction of the current, then the thumb represents the direction of the force thrust (or motion).

Electron Current



Conventional Current

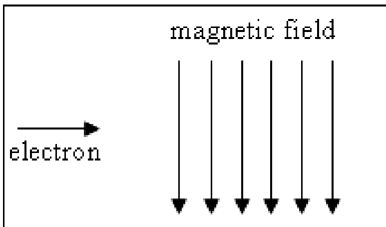
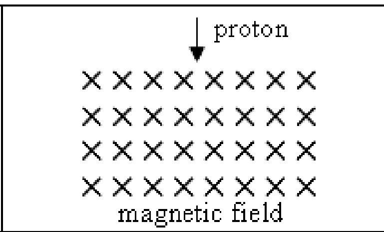
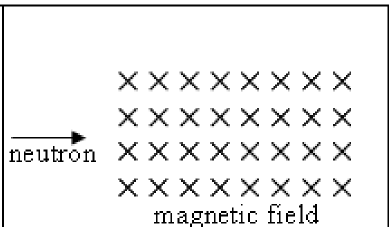


Forces acting on a charged particles

Conversely if we have a magnetic field acting on a moving charge it will experience a force. However, if the charge travels parallel to the magnetic field, it will not experience a force.

The direction of the force is determined using the same "hand rules".

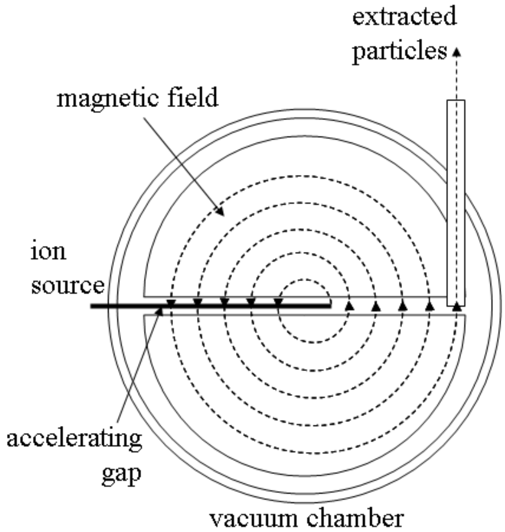
The speed of the charge will not change, only the direction of motion changes.

		
The electrons will curve out of the page	The proton will curve to the right	There is no change in direction as the particle is neutral

Particle Accelerators

Beams of charged particles experience a deflection by both **electric** and **magnetic** fields. This can be used to **accelerate** particles, cause **collisions** and investigate the particles and energies produced.

Cyclotron

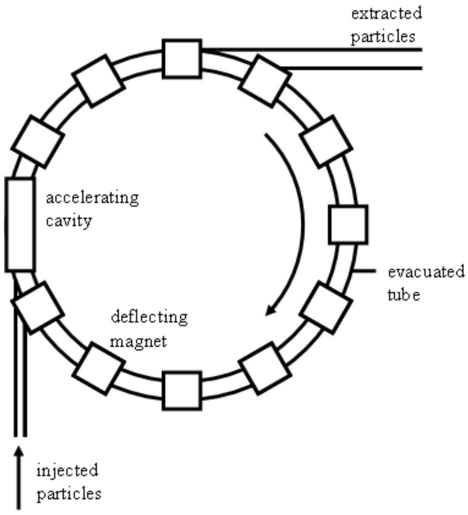


In a cyclotron, ions are injected at a point near the centre. An alternating potential difference between the 'dee' shaped electrodes accelerates the particles. A magnetic field causes the particles to move in a circular path. When the particle crosses from one dee to another it accelerates. After each acceleration the particle moves to a slightly larger orbit. When it reaches the outer edge of the cyclotron the particle beam is extracted and used in other experiments.

Linear accelerator (LINAC)

Charged particles are accelerated in a vacuum pipe through a series of electrodes by an alternating voltage. The beam of particles is then directed at a target or into a synchrotron.

Synchrotron



This is similar to a linear accelerator, bent into a ring so the charged particles can be given more energy each time they go round. Electromagnets keep the particles in a curved path. As the speed increases, the magnetic field strength is increased. As the speed increases and relativistic effect cause the mass of the particles to increase, a larger force is needed to accelerate them and keep them in a circular path.

CERN

CERN is the European particle physics laboratory, it is near Geneva in Switzerland and was established in 1954. 20 European countries collaborated in funding and running CERN. About 3000 people work there, with are many visiting scientists that represent over 80 nations. They have a number of accelerators and a number of detectors, ATLAS, ALICE, CMS and TOTEM.

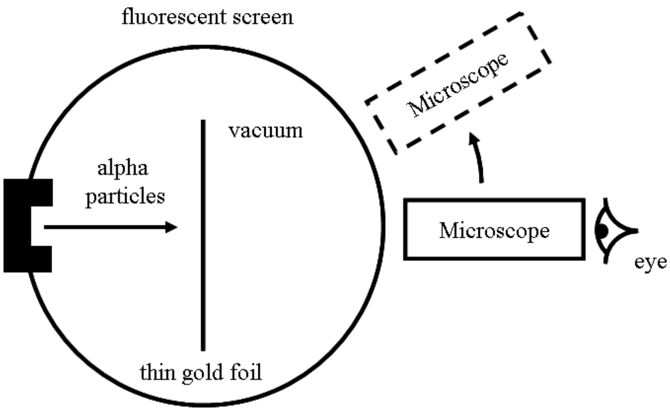
Scientists working at CERN have a large amount of information to send to each other. In 1989 Tim Berners Lee wrote a proposal for an information system, and by the end of 1990 the World-Wide Web was up and running.

Nuclear Physics

Rutherfords Scattering Experiment - model of the atom

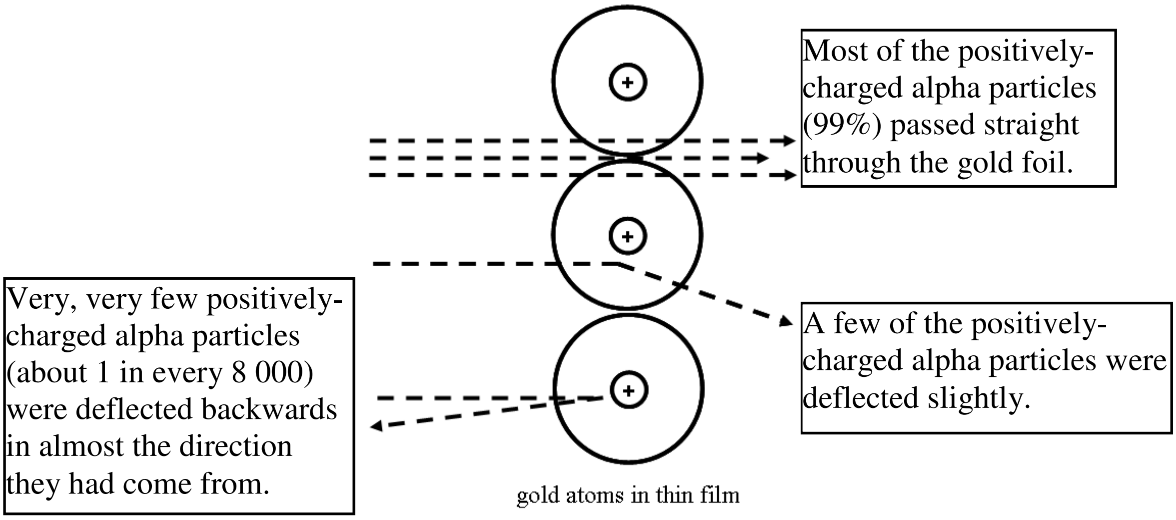
At the start of the 20th century, Ernest Rutherford devised an experiment to investigate the structure of atoms.

Positively-charged alpha particles were fired at a very thin piece of gold foil in the apparatus shown below. Because of the vacuum, the alpha particles were able to travel freely.



Every time an alpha particle hit the fluorescent screen, the screen glowed for a short time. The microscope was moved all around the outside of the circular fluorescent screen, so that the number of alpha particles hitting the screen at every position could be observed.

Observations



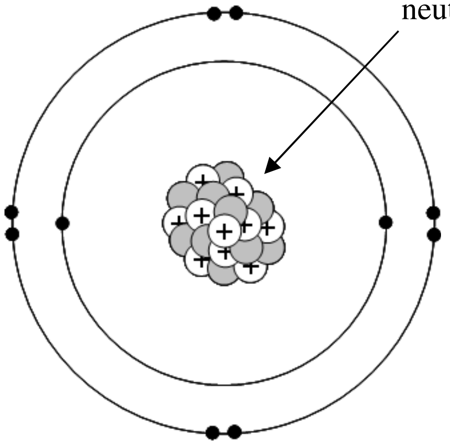
FROM THE RESULTS OF THIS EXPERIMENT, RUTHERFORD MADE THESE DEDUCTIONS ABOUT THE STRUCTURE OF ATOMS:

1) Because most of the positively-charged alpha particles passed straight through the gold atoms in the foil, **most of the atom must be empty space**.

2) Because only very, very few positively-charged alpha particles were deflected backwards in almost the direction they had come from, **most of the mass of the atom must be concentrated in a very small central area** (**which we call the nucleus**).

3) Because some of the positively-charged alpha particles were deflected backwards by the **nucleus**, the **nucleus** must be **positively-charged**. (Like charges repel).

Model of the Atom



Nuclide Notation

The symbol for an atom is often written in this form:

$$^{235}_{92}\mathrm{U}$$

mass number (represents the total number of protons plus neutrons in the nucleus)

atomic number (represents the number of protons in the nucleus)

chemical symbol

Nuclear Decay

From National 5 Physics, you know that three types of radioactivity may be emitted from atomic nuclei during radioactive decay - **alpha particles**, **beta particles** and **gamma rays**.

Alpha Decay

Alpha decay takes place when an **alpha** particle (consisting of **2 protons plus 2 neutrons**) is ejected from an atom's nucleus.

An alpha particle is represented by the symbol: $^{4}_{2}\mathrm{He}$

A different atom is created as a result:

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

The mass number of the new (daughter) atom is four less than the original (parent). The atomic number is two less than the original. **Mass number and atomic number have been conserved.**

Beta Decay

Beta decay takes place when a **neutron** in the nucleus decays into a **proton** and an **electron** The **proton** stays in the **nucleus** (so the atomic number increases by 1) while the **electron** is ejected from the atom's **nucleus** as a **beta particle**.

An beta particle is represented by the symbol: ${}^{0}_{-1}e$

A different atom is created as a result:

$${}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$$

The mass number of the new (daughter) atom is the same as the original (parent). The atomic number is increased by 1. **Mass number and atomic number have been conserved.**

Gamma Decay

Gamma rays are photons of **electromagnetic energy** - They are not **particles**. When **gamma rays** are ejected from an atom's nucleus, this does not change the mass number or atomic number of the atom. It does however change the energy state of the nucleus.

Nuclear Reactions

Nuclear Fission

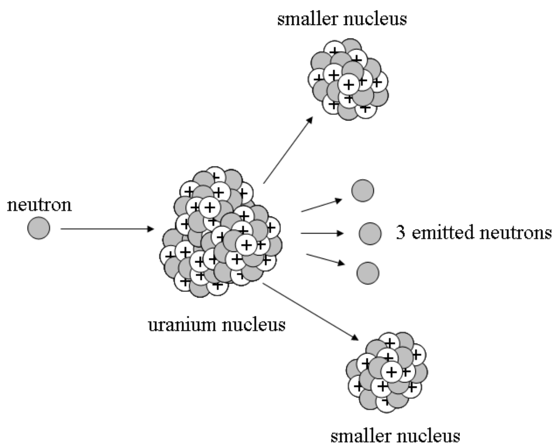
In **nuclear fission**, a large **atomic nucleus** splits into **2 smaller nuclei** and sometimes **several neutrons**. The **smaller nuclei** and **neutrons** that are produced gain **large amounts of kinetic energy**, we interpret this energy as heat.

Fission may be either:

(a) Spontaneous

The large **atomic nucleus** splits up by itself at random - There is no **"outside influence"**.

(b) Stimulated by Neutron Bombardment



A neutron is "fired" at a uranium nucleus, causing the uranium nucleus to split.

Smaller Daughter particles are produces as well as 3 further neutrons, all of which have a great deal of kinetic energy.

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n$$

Note that the mass numbers (top) and atomic number (bottom) must be conserved.

Nuclear Fusion

In **nuclear fusion**, **2 small atomic nuclei** combine to form a **larger nucleus**. Other small particles (such as **neutrons**) may also be left over.

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

The **larger nucleus** and **other particles** produced gain **large amounts of kinetic energy**, which we interpret as heat energy. **Nuclear fusion** takes place in **stars**, like the **sun**.

Lost Mass and E = mc^2

In both **nuclear fission** and **nuclear fusion** reactions, the **mass** of the **products** formed is **always less than** the **mass** of the **starting species** - **Mass is lost during the reaction.**

The **"lost mass"** is converted into **kinetic energy** of the **products**, in accordance with Albert Einstein's famous equation:

kinetic energy of the products (J) → $$E = mc^2$$ ← speed of light ($3x10^{8}ms^{-1}$)

↑ mass lost in reaction (kg)

Example 1 (fission)

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{134}_{52}Te + ^{98}_{40}Zr + 4\,^{1}_{0}n$$

$3.901x10^{-25}$kg $0.017x10^{-25}$kg $2.221x10^{-25}$kg $1.626x10^{-25}$kg $0.017x10^{-25}$kg

(a) Describe what happens in a nuclear fission reaction:

A larger atomic nucleus splints into 2 smaller nuclei, several neutrons and large amounts of energy.

(b) Explain whether the above nuclear fission reaction is "spontaneous" or "induced":

Induced. A neutron is fired at the nucleus to start the process.

(c) Calculate the total mass of the species on the left of the arrow (the reactants):

$3.901x10^{-25}$ + $0.017x10^{-25}$ = $3.918x10^{-25}$ kg

(d) Calculate the total mass of the species on the right of the arrow (the products):

$2.221x10^{-25}$ + $1.626x10^{-25}$ + (4 x $0.017x10^{-25}$) = $3.915x10^{-25}$ kg

(e) Calculate the lost mass when this nuclear fission reaction happens once:

$3.918 \times 10^{-25} - 3.915 \times 10^{-25} = 0.003^{-25}$ kg

(f) Calculate the kinetic energy gained by the products when this nuclear fission reaction happens once:

$E = mc^2$
$E = 0.003 \times 10^{-25} \times (3 \times 10^8)^2$
$E = 2.7 \times 10^{-11}$ J

Example 2 (fusion)

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

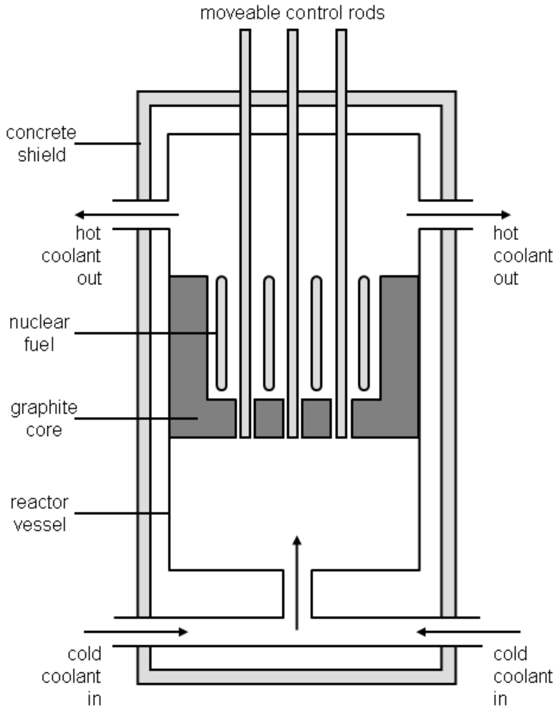
3.342×10^{-27}kg 3.342×10^{-27}kg 5.004×10^{-27}kg 1.674×10^{-27}kg

Calculate the kinetic energy gained by the products when this nuclear fusion reaction happens once.

lost mass = $(3.342 \times 10^{-27} + 3.342 \times 10^{-27}) - (5.004 \times 10^{-27} + 1.674 \times 10^{-27})$
lost mass = 0.006×10^{-27} kg

$E = mc^2$
$E = 0.006 \times 10^{-27} \times (3 \times 10^8)^2$
$E = 5.4 \times 10^{-13}$ J

Shielding and Cooling of Reactors



nuclear fuel - where the reaction takes place

graphite core - main reaction rate control

control rods - control the rate of the nuclear reaction by absorbing neutrons when inserted

concrete shield - outermost containment preventing the release of radioactive material into the environment

reactor vessel - innermost containment preventing the release of radioactive material into the environment

liquid coolant - maintains a safe operating temperature for the reactor