AQA Physics A-level

Topic 2: Particles and radiation

Key Points

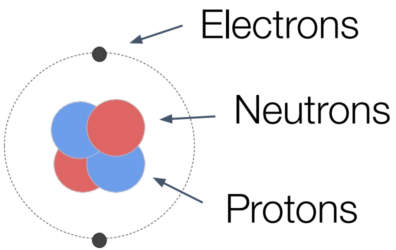
Constituents of the Atom

Atoms consist of protons and neutrons (called nucleons) and electrons. The nucleons are in the nucleus and electrons are in orbitals. The proton and electron have equal and opposite charges.

Specific charge is the **ratio of charge to mass**. This can be of a nucleus or of an ion.

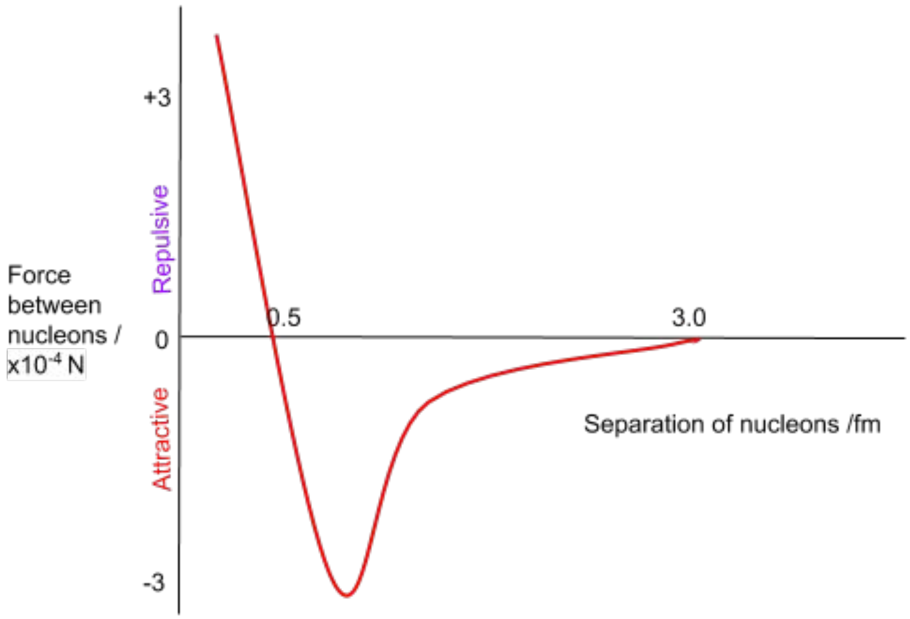
An isotope is a form of an element's atom with the same proton number but a different number of neutrons.

Particle	Relative Mass	Relative Charge	Mass	Charge
Proton	1	+1	1.6×10^{-27}	$+ 1.6 \times 10^{-19}$
Neutrons	1	0	1.6×10^{-27}	0
Electrons	0.0005	-1	9.11×10^{-31}	$- 1.6 \times 10^{-19}$



Forces in the Nucleus

The strong nuclear force acts between nucleons at a very short range. Between **3fm and 0.5fm** it is an **attractive force.** At **separations smaller** than this it is **repulsive.** It holds together nucleons by overcoming **electrostatic repulsion** between positively charged protons.



Types of Decay

Beta minus decay is when a **neutron** turns into a **proton.** It then emits an **electron** and an **electron antineutrino**.

$$^{A}_{Z}x \rightarrow ^{A}_{Z+1}y + ^{0}_{-1}e + ^{0}_{0}\overline{v_e}$$

Beta plus decay is when a **proton** turns into a **neutron.** It also emits a **positron** (the antiparticle of an electron) and an **electron neutrino**.

$$^{A}_{Z}X \rightarrow ^{A}_{Z-1}Y + ^{0}_{+1}e^{+} + \nu_{e}$$

Alpha Decay is when a **helium nucleus** is emitted, often referred to as an **alpha particle.**

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha$$

The existence of the neutrino was hypothesised in the **conservation of energy** in beta decay.

Photons

The energy of a photon, which has wave-like properties, can be shown by combining a few equations and constants.

$$\text{Energy of a Photon} = \frac{\text{Planck's Constant x Speed}}{\text{Wavelength}} \qquad E = \frac{hc}{\lambda}$$

We know that electromagnetic waves (and therefore photons) travel at the speed of light, and we also know Planck's constant. We can put these two constants into the equation and use that to find the energy.

$$\text{Energy of a Photon} = \frac{(6.63 \times 10^{-34}) \times (3 \times 10^{8})}{\text{Wavelength}}$$

Antimatter

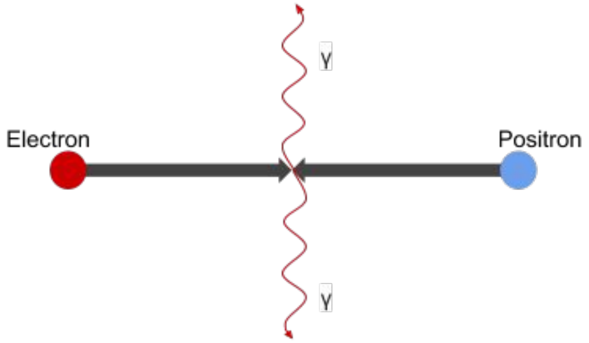
Antiparticles have the **same mass/rest energy** but **opposite charges and other quantum numbers** compared to their normal matter counterparts.

A particle and corresponding antiparticle annihilate each other in an annihilation reaction, releasing two photons. The photons must go in different directions to conserve momentum.

$$2E_{min} = 2E_{rest}$$

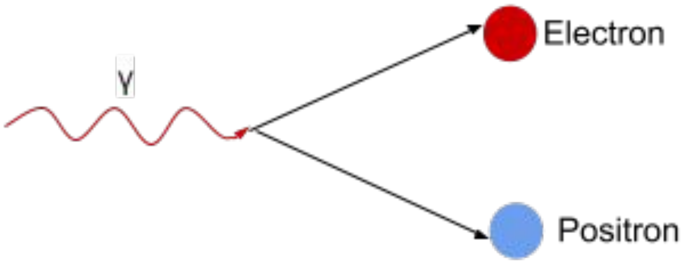
$$E_{min} = E_{rest}$$

$$hf = E_{rest} + E_k$$



Pair Production

A photon interacts with a nucleus and its energy is converted into the mass of a **particle** and its corresponding **antiparticle**.



$$E_{min} = 2E_{rest}$$

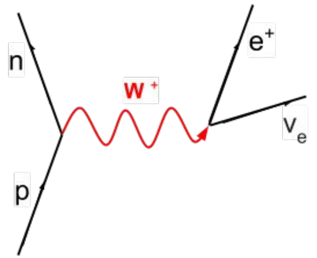
$$hf = 2E_{rest} + K_e$$

Particle Interactions

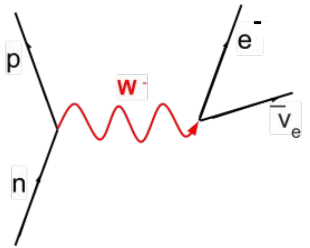
Exchange particles are the **force carriers** for the fundamental forces. They transfer energy, momentum, force and sometimes charge. The **size** of the exchange particle determines the **range** of the force; the bigger the particle, the shorter the range.

Type	Gauge Boson	Particles Affected
Strong	Pions	Hadrons
Electromagnetic	Virtual Photon	Charged Particles
Weak	W^-/W^+ Bosons	All Types

Feynman diagrams show particle interactions. **Time** moves from the bottom to the top and their position is shown by their position horizontally.



Beta-Plus Decay

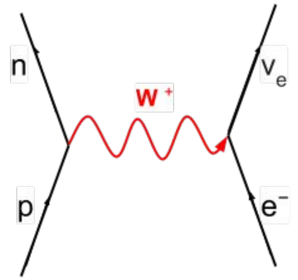


Beta-Minus Decay

Other Weak Interactions

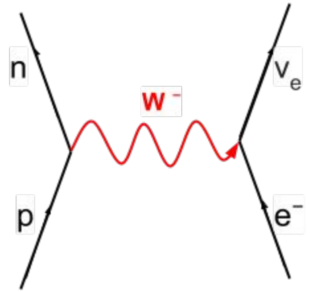
Electron Capture

A **proton** captures an inner shell **electron** and turns into a **neutron** and **electron neutrino**. A **W^+ Boson** is exchanged in the process.



Electron-Proton Collision

A **proton** and **electron** collide and a **W^- Boson** particle is exchanged. The electron turns into an **electron neutrino** and the proton turns into a **neutron**.



Classification of Particles

Hadrons interact by the strong nuclear force and are made of quarks.

Baryons are made from 3 quarks (antibaryons from 3 antiquarks) and all decay into a proton, the only stable baryon. The two baryons which you need to know are protons and neutrons.

Mesons are made from a quark and antiquark pair.
They include pions (the exchange particle in the strong nuclear force) and heavier kaons which decay into pions.

Leptons are fundamental particles that don't interact by the strong interaction, only the weak interaction.

Electrons are stable leptons; **muons** are heavier leptons which decay into electrons. There are also **neutrinos**: the electron neutrino and the muon neutrino, which have almost no mass and no charge.

Quarks

Name	Symbol	Charge	Baryon Number	Strangeness
Up	u	+2/3	+1/3	0
Down	d	-1/3	+1/3	0
Strange	s	-1/3	+1/3	-1

Quarks **only** come as a group of **three** (baryon) or as a quark antiquark **pair** (meson).

Conservation

Charge: Always indicated by the particle.
Baryon number: 0 except for baryons which are +1
L_μ: 0 except for a muon and muon neutrino which are +1
L_e: 0 except for an electron and electron neutrino which are +1
Strangeness: K^+ and K^o are +1, K^- and anti-K^o are -1.

Of course, if it is an antiparticle all of these are opposite, +1 becomes -1 and 0 remains 0.

Using this knowledge you can work out the structure and numbers for all the particles.

Conservation

Only **strange quarks** have a strangeness number (-1). Therefore only a particle containing a strange quark has strangeness and can be referred to as a **strange particle**. Strange particles are **created through the strong interaction** and **in pairs**. They **decay through the weak interaction**. Strangeness is conserved in strong interactions but changes by 0, +1, or -1 in weak interactions.

All other quantum numbers and energy and momentum are conserved in particle interactions, and this can be used to prove/disprove whether interactions occur or not.

The Photoelectric Effect

The photoelectric effect is the process by which a metal with photons incident on it emits electrons (in the form of **photoelectrons**).

No photoelectrons are released if the radiation's frequency isn't greater than the **threshold frequency,** which is the frequency at which the photon has energy equal to the **work function,** the minimum amount of energy needed for an electron to be emitted.

Photoelectrons are released with different kinetic energies up to a maximum. The value of the maximum kinetic energy increases with the frequency of the incident photons.

Intensity of radiation is the total power delivered per unit area. The **number of photoelectrons emitted per second increases as intensity increases**.

$hf = \varphi + E_{kmax}$

Threshold Frequency $= \varphi/h$

This goes against the original wave model of light, which predicts there would be no such thing as a 'threshold frequency' because the metal would gradually accumulate enough energy to release electrons. However this doesn't happen, meaning it must be described in terms of particles where **one electron absorbs one photon.**

Demonstrations

The photoelectric effect can be demonstrated with a **UV lamp** and a negatively charged zinc plate with a gold leaf. UV light is shone on it and the gold leaf returns to the vertical position.

A **photocell** also shows the photoelectric effect. UV radiation is incident on the negatively charged plate which allows electrons to flow to the positive cathode.

The **stopping potential** lets us measure the maximum kinetic energy. The circuit is set up but the power supply is reversed. The p.d causes a **force** on the electrons back towards the plate. Eventually, when **no current flows** then the product of the stopping potential and electron charge equals the **max Ek** of the electrons.

Electron Energy Levels

Electrons only exist in discrete energy levels.

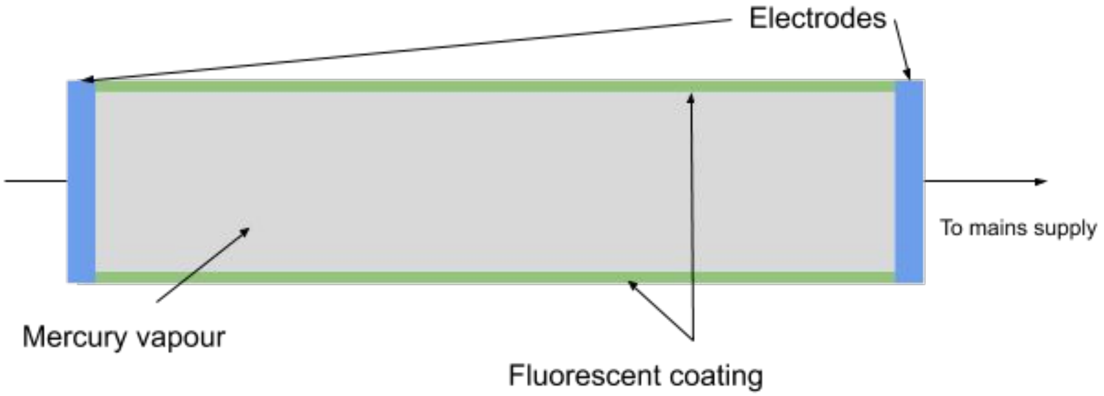
Ionisation is when an electron is removed from an atom. **Excitation** is the movement of electrons up to a higher energy level; either an electron collides with the orbital electron or a photon is absorbed by it, transferring energy to it. When the electron de-excites, it moves down in energy levels and emits a photon.

This can be demonstrated by **emission and absorption spectra.** In an emission spectrum you can see the frequency of photons that certain elements emit. In an absorption spectrum you can see what frequency photons certain elements absorb. These both correlate to the energy levels within its atoms.

Line spectrum

Fluorescent Tubes

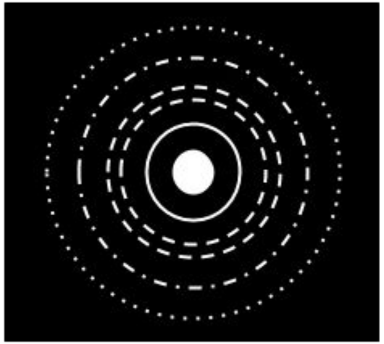
A beam of free electrons flows through the tube from one end to the other. These free electrons **collide** with orbital electrons in **mercury** atoms. The orbital electrons gain energy and are **excited** to a higher energy level. The electrons quickly return to their **ground state** and **UV photons** are released. The electrons within the **phosphorous coating** on the inside layer of the tube absorb these photons and are excited to higher energy levels. The excited electrons then return to a **lower** energy level, emitting visible light photons.



Wave Particle Duality

The wave-like nature of light is observed when diffraction takes place when light passes through a narrow slit. The particle-like nature of light is observed in the photoelectric effect as energy is received in discrete packets which are called photons.

Evidence for this in electrons is that they can be diffracted when they are directed at a crystal with atomic spacing similar to the wavelength. Evidence for the particle properties of electrons is that they are deflected by an electric field.



The electron diffraction interference pattern forms concentric rings