

Edexcel Physics A-level

Topic 8: Nuclear and Particle Physics

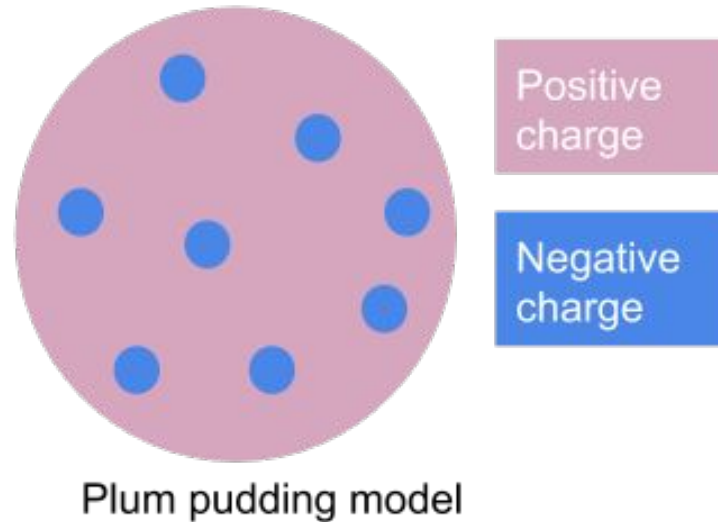
Key Points

Changes in Atomic Models

- In the early days (1803) Dalton thought that everything was made up of **indivisible particles**.
- It was then thought later in 1897 that atoms were positive bodies of matter with negative electrons dispersed throughout them. This was named the **plum pudding model** by Thompson.
- Later, it was discovered in 1911 by Rutherford that atoms were mostly empty space, had a small dense nucleus and had **electrons orbiting them**.
- Then in 1913 it was discovered these **electrons orbit in shells** and emit EM radiation when they move between them.
 - 1919, the **proton** was discovered, followed by the **neutron**.
- Now, we believe that electrons exist in **subshells** and that the nucleons are made up of **quarks** - this is referred to as quantum mechanics.

Plum Pudding Model

Thomson's Plum Pudding Model was the accepted model of the atom prior to experiments such as Rutherford's Alpha Scattering experiment, which disproved it. The model described the atom to be a ball of **positive charge**, with **negatively charged** electrons **evenly distributed** throughout it.



Rutherford Scattering

This experiment provided evidence to support the currently accepted Bohr model of the atom, and discounted the then believed Plum Pudding model.

Alpha particles were fired at a thin sheet of gold foil. If the plum pudding model was true, the particles were expected to pass through with only slight deflections. However, in reality:

- Most passed through with no deflection, suggesting that the atom is **mostly empty space** and that the nucleus is **very small**
- Some were deflected by large angles, suggesting that there is a **positively charged nucleus** that repels the positive alpha particles
- A few were deflected by more than 90 degrees, suggesting that the central nucleus was very small, but also **very dense** since it changed the direction of the very fast moving alpha particles.

Investigating the nucleus

Nucleon number: The number of neutrons and protons in the nucleus

Proton number: The number of protons in the nucleus

High energies are required to investigate the structure of nucleons due to their small size. This is because the higher the energy of matter (such as electrons), the smaller their De Broglie wavelength, and so they are more suitable for investigating smaller objects (as the resolution increases).

Fundamental Particles and Quarks

Fundamental particles are particles that cannot be broken down into any smaller constituent parts. Most types of matter however are not fundamental and can be broken down into quarks.

Quarks come in **three** main types:

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

Quarks can only ever be found in threes or in an quark and antiquark pair. Quarks can never exist alone, due to a principle known as **quark confinement**.

Quark-Lepton Particle Model

The quark-lepton model splits particles into **four** main categories:

1. **Baryons** consist of **three quarks** and both protons and neutrons are types of baryons. You should know that the only stable baryon is the proton, so all other baryons eventually decay into the proton.
2. **Mesons** consist of a **quark and an antiquark pair** and include pions which are the exchange particle for the strong nuclear force. Kaons are a heavier form of meson, which decay into pions.
3. **Leptons** are **fundamental** particles and include the electron. They only interact in the weak nuclear force

4. Photons

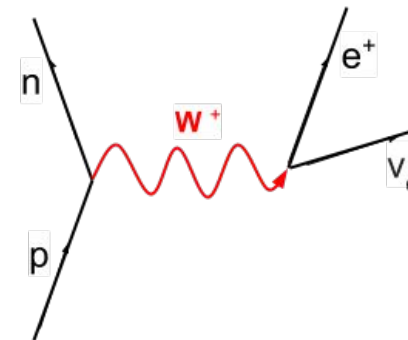
Another term that you should be aware of is hadrons. **Hadrons** are the wider particle group that contains both baryons and mesons. All hadrons interact through the strong nuclear force and are made up of quarks.

Particle Interactions

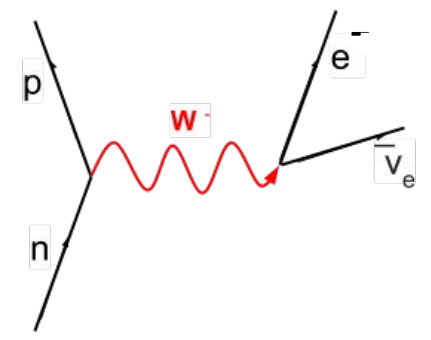
Exchange particles are the **force carriers** for the fundamental forces. They transfer energy, momentum, force and sometimes charge. The **size** of the exchange particle determines the **range** of the force; the bigger the particle, the shorter the range.

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

Conservation

The following properties are always conserved:

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^0 are +1, K^- and anti- K^0 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 appropriate values for all the particles.

Antimatter

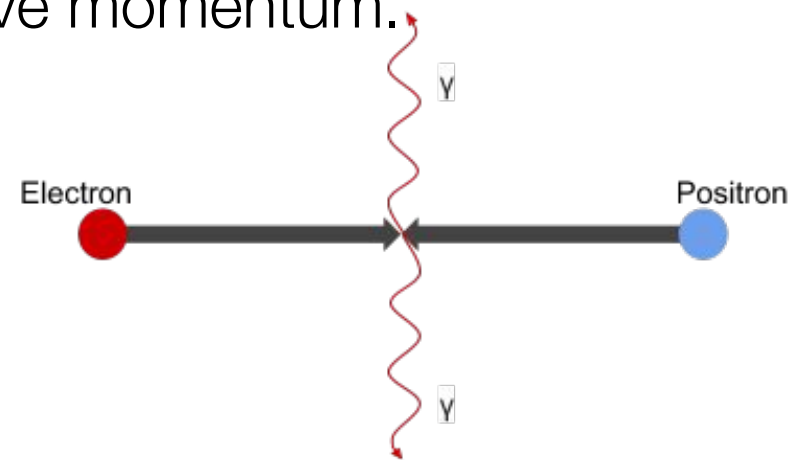
Every particle has an antiparticle. Antiparticles have the **same mass/rest energy** but **opposite charges and opposite quantum numbers** compared to their normal matter counterparts.

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

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

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

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



Einstein's Energy Equation

The **mass-energy equivalence** is the concept that mass and energy are interchangeable. This can be expressed as the following equation:

$$E = mc^2$$

You can use the above equation to calculate the energy transferred when a particle and antiparticle are produced or annihilated, by substituting their collective mass with the m in the equation.

Thermionic Emission

An easy method of producing an electron beam is through **thermionic emission**. This is when a metal is **heated**, resulting in **free electrons** inside the metal gaining **sufficient kinetic energy** to leave the metal's surface. The most common method of achieving this is with a **wire filament**:

- A current is passed through the filament
 - The filament heats up, and free electrons gain kinetic energy
- Electrons that gain sufficient kinetic energy are released from the surface

To **accelerate** the electrons that are released, and to produce a beam, an **anode** is placed opposite the filament. There is a **vacuum** between the filament and the anode, which allows the electrons to be accelerated across the gap, due to the electric field between them. There is a **small hole** in the anode that the electrons then pass through.

If you know the accelerating voltage, it is possible to **calculate** the **speed** of the electrons as they pass through the hole. All the **kinetic energy** that electrons have, comes from the **work done** by the potential difference, and so:

$$eV = \frac{1}{2} m v^2$$

Deflection in a Magnetic Field

In a magnetic field, moving charged particles will experience a magnetic force **perpendicular** to their motion. This magnetic force acts as a centripetal force and so the particles will follow a circular path. The radius of their path can be calculated by using the equation derived below.

The **magnetic force** on the particles is the **centripetal force** causing their circular motion and so:

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

$$r = \frac{mv}{BQ}$$

$$r = \frac{p}{BQ}$$

Cyclotron

An application of the circular deflection of charged particles in a magnetic field is a type of particle accelerator called a **cyclotron**.

A cyclotron is formed of two semi-circular electrodes, with a **uniform magnetic field** acting perpendicular to the plane of the electrodes, and an **alternating voltage** applied between the electrodes. The charged particles move from the centre of one of the electrodes, and are deflected in a circular path by the magnetic field.

Once the particles reach the edge of the electrode they begin to move across the gap between the electrodes, where they are **accelerated** by the electric field, meaning the **radius** of their circular path will increase as they move through the second electrode. This process repeats several times until the required speed is reached by the particles and they exit the cyclotron.

