WJEC (Wales) Physics A-level

Topic 1.7: Particles and Nuclear Structure

Notes

Quarks and Leptons

All **matter** is made up of two types of particle: **quarks** and **leptons**. These are fundamental particles which means they cannot be broken down any further. An atom is not **fundamental** because it contains smaller particles: protons, neutrons and electrons. Protons and neutrons, unlike electrons, are not fundamental because they contain quarks.

There are three generations (sets) of quarks and three generations (sets) of leptons. However, for your exam only knowledge of the first generations are required.

The first generation of quarks are the **up (u) and down (d)** quarks.

The first generation of leptons are the **electron (e^-) and electron neutrino** (ν_e).

	Leptons		Quarks	
Particle	Electron	Electron neutrino	Up	Down
Symbol	e^-	ν_e	u	d
Charge (e)	-1	0	+2/3	-1/3

(Table adapted from the WJEC Physics A-Level from 2015 specification)

The properties of these particles are given in the table above and must be known for the exam.

For each of the quarks and leptons there exist other particles called **antiparticles**. They have the same mass but **opposite charges**.

	Leptons		Quarks	
Particle	Positron	Electron antineutrino	Anti-up	Anti-down
Symbol	e^+	$\overline{\nu_e}$	$\overline{u}$	$\overline{d}$
Charge (e)	+1	0	-2/3	+1/3

The antiparticles have the same names as their corresponding particles just with the word **anti** in front of them. The exception is for the electron's antiparticle called the **positron**.

To write the symbols for antiparticles, just place a **bar** across the top of the particle symbol.

Annihilation

Particles and their antiparticles can **annihilate** each other. When they meet they disappear and produce two photons (packets of energy) which travel in opposite directions (so that momentum is conserved).

Hadrons

Hadrons are called **composite** particles because they are made up of quarks and so are not fundamental. There are three types of hadrons you should know about:

- Baryons
- Antibaryons
- Mesons

Baryons

Baryons are particles made up of exactly three **quarks**. Examples of baryons include the proton (uud) and the neutron (udd).

Some less well-known baryons are the Δ^{++} (uuu) and the Δ^{-} (ddd). These are types of delta particles. To find other baryons you need to simply use combinations of three quarks that give a particle with an integer charge.

Antibaryons

Antibaryons are particles made up of exactly three **antiquarks**. Examples of antibaryons include the antiproton ($\overline{u}\overline{u}\overline{d}$) and the antineutron ($\overline{u}\overline{d}\overline{d}$).

Mesons

Mesons are particles made up of **quark-antiquark pairs** (a quark and an antiquark).

Pions are types of meson. If we combine and up quark with an anti-down quark we get the positively charged (+1) pion given the symbol π^{+}. Then we can find the **negatively** charged pion because it is the **antiparticle** of the **positively charged pion**. Therefore, the negatively charged (-1) pion is composed of an anti-up quark and a down quark and is given the symbol π^{-}.

Fundamental Interactions

There are **four ways** in which particles can **interact**. These are:

- Gravitational
- Weak
- Strong
- Electromagnetic

Gravitational

The gravitational interaction is the force of attraction between all **matter** with mass. The gravitational force extends to an **infinite distance** but decreases with distance in an inverse square relationship. This interaction is **very weak** – for two electrons, the gravitational force due to their mass is about 10^{-43} times smaller than the electromagnetic force due to their charge.

Weak

The weak force is an interaction experienced by all **leptons and quarks**. As baryons are composed of quarks, they are also affected by the weak force. However, as the name suggests, it is weak compared to the strong force and the electromagnetic force and has a very short range. Therefore, **when the strong and electromagnetic forces are present** it is **not significant**.

Note: The weak interaction is responsible for reactions where neutrinos and quark flavour changes (e.g when a down quark changes to an up quark).

Strong

The strong force is an interaction experienced by **all quarks**. As baryons are composed of quarks, baryons are also affected by the strong force. This force has a short range.

Electromagnetic

The electromagnetic force is a force between all **charged particles**. Like the gravitational force, it also has an **infinite range**. Sometimes it will affect particles that you may not initially expect so be careful. **Neutral hadrons are affected** by the electromagnetic force because they are composed of quarks (charged).

Lepton Number

Each **lepton has a specific number**. The table below gives the lepton number for the first-generation leptons. Anything that isn't a lepton has a lepton number of 0.

Lepton numbers are conserved in interactions.

	Leptons			
Particle	Positron	Electron antineutrino	Electron	Electron neutrino
Symbol	e^+	$\overline{\nu_e}$	e^-	ν_e
Lepton number	-1	-1	+1	+1

Baryon Number

Each baryon has a baryon number given in the table below.

Baryon numbers are conserved in interactions.

Particle	Baryon number
Baryons (e.g. protons and neutrons)	+1
Antibaryons	-1
Other	0

Simple Interactions

You need to know how to apply conservation laws to simple reactions to make sure they are valid. They can also help you write interaction equations because the laws remove possibilities.

Beta-Minus Decay

Three ways of writing beta minus decay are as follows:

$$ZAX \rightarrow Z + 1AX + e^- + \overline{\nu_e} \ (1)$$

$$n \rightarrow p + e^- + \overline{\nu_e} \ (2)$$

$$d \rightarrow u + e^- + \overline{\nu_e} \ (3)$$

In (1), we show a nucleus undergoing beta minus decay. In (2) we show the neutron in that nucleus turning into a proton. In (3) we show the down quark within that neutron turning into an up quark, so it becomes a proton. All three represent the same process.

To make sure the equations are all valid we need to check for the conservation of:

- Charge
- Lepton number
- Baryon number

In equation (1):

- The total charge before the reaction is Z and the total after is $(Z+1) + (-1) = Z$. Hence **charge is conserved**.
- The total lepton number before is zero as there are no leptons present. Afterwards, the total lepton number is $(+1) + (-1) = 0$. Hence **lepton number is conserved**.
- The total baryon number before is A and after it is A and hence **baryon number is conserved**.

In equation (2):

- The total charge before the reaction is 0 and the total after is $(+1) + (-1) = 0$. Hence **charge is conserved**.
- The total lepton number before is zero as there are no leptons present. Afterwards, the total lepton number is $(+1) + (-1) = 0$. Hence **lepton number is conserved**.
- The total baryon number before is 1 and after it is 1 and hence **baryon number is conserved**.

In equation (3):

- The total charge before the reaction is $-\frac{1}{3}$ and the total after is $(+\frac{2}{3}) + (-1) = -\frac{1}{3}$. Hence **charge is conserved**.
- The total lepton number before is zero as there are no leptons present. Afterwards, the total lepton number is $(+1) + (-1) = 0$. Hence **lepton number is conserved**.
- The total baryon number before is 0 and after it is 0 and hence **baryon number is conserved**.