AQA Physics A-level

Topic 8: Nuclear Physics

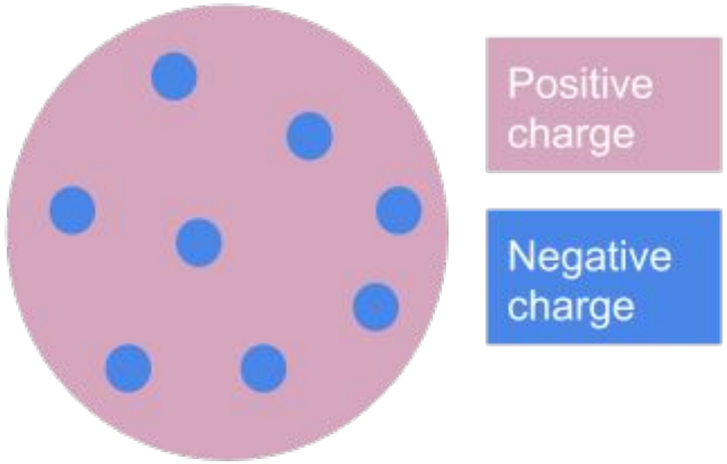
Key Points

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 in them, named the **plum pudding model** by Thompson.
- Later it was discovered in 1911 by Rutherford that atoms were mostly empty space, and actually 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.



Plum pudding model

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.

Alpha Radiation

An alpha particle consists of **two protons and two neutrons**, the same as a **helium nucleus**. Alpha radiation is:

- Strongly ionising
- Slow moving
- Stopped by a few centimeters of air or paper
- Positively charged
- Deflected in a magnetic field

It is used in **smoke detectors**. Alpha particles **ionise** the air particles between two metal plates, allowing a current to flow between them. However, when smoke enters the detector, the alpha particles are restricted from ionising the air, resulting in the current flow decreasing. This **current reduction** triggers the alarm.

Beta Radiation

Beta-minus radiation consists of an **electron** and **Beta-plus** radiation consists of a **positron**. Beta radiation is:

- Mildly ionising
- Fast moving
- Stopped by a few millimetres of aluminium
- Negatively charged
- Deflected in a magnetic field

It is used in **thickness monitors**. Beta particles are **emitted** on one side of the material, and **detected** on the other. If the material is too thick, the number of beta particles detected will be too low, and will trigger the machine to reduce the material thickness.

Gamma Radiation

Gamma radiation is a form of **electromagnetic radiation**. It is very high frequency and is:

- Weakly ionising
- Travels at the speed of light
- Stopped by a few several centimetres of lead or a few metres of concrete
- Chargeless
- Unaffected by magnetic and electric fields

It is used to **sterilise** medical equipment and **kill cancerous cells**, as well as being used as a **medical tracer** in diagnosis.

Safe Use of Radiation

When carrying out experiments with radioactive sources, a number of procedures **must** be followed:

- Never directly **handle** the source
- Use **long-armed tongs** to increase your distance from the source
- Display **signage** warning others that radioactive sources are in use
- Keep the **time** that the source is being used to a **minimum**
- Store in an appropriate **lead box** when not in use

Background Radiation

Background radiation is always present and originates from:

- Radon Gas
- Rocks
- Cosmic Radiation
- Nuclear Weapon Testing
- Nuclear Disasters

It is only present in **very small quantities** and so **isn't harmful,** but it must be corrected for when carrying out **experiments**. You should always take a background count reading and **subtract** this from any further measurements you take.

Radioactive Decay

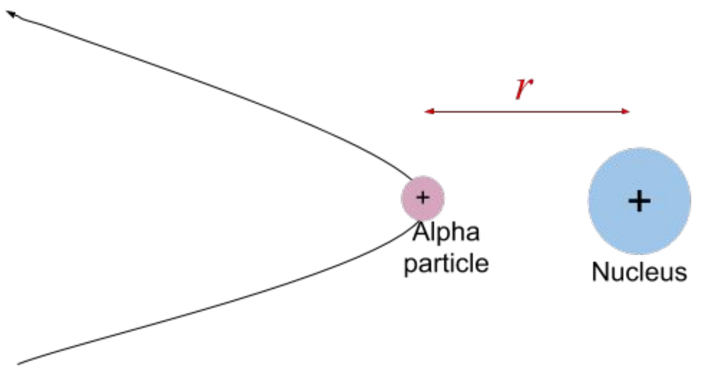
Radioactive decay is a **random process**. **Which** nucleus nucleus will decay, and **when** it will happen, is **unpredictable** and determined only by **chance**. The key terms that you need to know are:

- **Activity**: The number of nuclei that decay per second, measured in Becquerels.
- **Half-Life**: The time it takes for the number of radioactive nuclei to halve, for a given isotope.
- **Decay Constant**: The probability of a decay occurring in a unit time.

Distance of Closest Approach

The first method to calculate an approximation for nuclear radius, is by calculating the distance of closest approach.

When you fire an alpha particle at a gold nucleus, as it approaches, **kinetic energy** is converted to **electric potential energy**. At the point where it turns around, the potential energy is equal to the initial kinetic energy, and the distance the particle is from the nucleus is the **distance of closest approach**. Using the equation for electrical potential, you can calculate this distance. It will always be an **overestimate** for the nuclear radius since the particle will never reach the nucleus.



Electron Diffraction

A more accurate method of determining nuclear radius is by using electron diffraction:

- **High speed electrons** are fired at a thin sheet of material
- As they pass through the atoms, they diffract
- A diffraction pattern consisting of **concentric circles** is formed on a screen behind the material
- The nuclear radius can be calculated using measurements from the pattern

Electrons are **leptons**, and so aren't affected by the **strong nuclear force**. This means they can pass through the nucleus unaffected and the value calculated is **more accurate**.

Nuclear Fission

Nuclear fission is the splitting of a large nucleus to produce two smaller nuclei, two or three neutrons, and energy.

- **Spontaneous fission** is rare, a fissile nuclei normally need to absorb a thermal neutron to induce fission
- **A thermal neutron** is a slow moving neutron that can induce fission
- A commonly used fissile isotope is **Uranium-235**
- If uncontrolled, **chain reactions** occur, which is when the neutrons produced in a fission reaction, go on to induce further fission reactions
- **Critical mass** is the minimum amount of a fissile substance needed to maintain a steady flow of fission reactions

Nuclear Reactors

You need to know the roles of the key constituents of a fission reactor:

- **Control rods** absorb neutrons to prevent them going on to induce further fission - the lower the rods are inserted, the more neutrons that are absorbed and so the fewer the number of fission reactions that occur
- **The moderator** is responsible for slowing down the neutrons released in fission reactions so that they are at the speed of a thermal neutron and can go on to induce further fission
- **Fuel rods** consist of a fissile material - each rod contains less than the critical mass so that the reactions don't become uncontrolled
- **Coolant** carries away the thermal energy produced by fission reactions to generate steam and turn generators

Nuclear Waste

You also need to know how the nuclear waste produced by nuclear reactors should be safely dealt with:

- Waste should be cooled in **cooling ponds** to reduce the temperatures to safe levels
- High-level waste should then be stored in **thick concrete containers underground** for hundreds of years
- When being transported, it should be stored in **reinforced containers** in case of accidents, and if possible it should be processed as **close** to the plant as possible, to reduce the risks of transporting it
- All handling of waste should be done **remotely** from a distance

Nuclear Fusion

Nuclear fusion is the fusing of two smaller nuclei, to form a single large nuclei and produce large quantities of energy.

- Nuclear fusion produces much **larger quantities** of energy per unit of fuel than nuclear fission
- Common nuclei used are **deuterium** and **tritium**
- The conditions required for fusion include **very high temperatures** and **pressures** - this means that it is currently a challenging and **unsustainable** form of energy production

Mass Defect and Binding Energy

A key idea used in nuclear fission and fusion is the **mass-energy equivalence**. You should be able to carry out energy calculations and understand that:

- **Binding Energy** is the energy required to split up the nucleus into its individual nucleons. The greater the binding energy per nucleon the more stable the nucleus.
- **Mass Defect** is the difference between the mass of the nucleus and its individual constituents.
- **The Atomic Mass Unit** is the average mass of a nucleon, 1/12 the mass of Carbon-12.

$$E = mc^2$$