Edexcel Physics A-level

Topic 11: Nuclear Radiation

Key Points

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 a sheet of paper
- Positively charged
- Deflected in a magnetic field

It is used in **smoke detectors**. Alpha particles sit between two metal plates, and since they are charged can carry a current between the plates. However, if smoke enters the detector, the particles can no longer travel (due to their **low penetrating power**), so the current flow is stopped and the alarm sounds.

Beta Radiation

Beta-minus radiation consists of a high-energy **electron** and **Beta-plus** radiation consists of a high-energy **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 has a very high frequency and is:

- Weakly ionising
- Travels at the speed of light
- Stopped by 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.

Radioactive Decay

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

- **Activity (A)**: The number of nuclei that decay per second, measured in Becquerels (Bq).
- **Half-Life ($T_{1/2}$)**: The time it takes for the number of radioactive nuclei to halve, for a given isotope. This can be calculated graphically.
- **Decay Constant (λ)**: The probability of a decay occurring in a unit time.

Equations for Radioactive Decay

You should be familiar with the following equations for radioactive decay and where appropriate, be able to derive the corresponding log equations.

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

$$N = N_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

Nuclear Fission

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

- **Spontaneous fission** is rare, a fissile nuclei usually needs 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**
- In fission, **chain reactions** can 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 reactions - the further 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 reach thermal speeds and can go on to induce further fission reactions
- **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 to generate electricity

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 its temperature to safe levels
- High-level waste should then be stored in **thick steel containers underground** in geologically stable areas 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 risk of transporting it
- All handling of waste should be done **remotely** to reduce exposure

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 (u)** is the average mass of a nucleon, 1/12 the mass of Carbon-12, 1.661×10^{-27} kg.

$$E = mc^2$$