

BioMedical Admissions Test (BMAT)

Section 2: Physics

Topic P7 - Radioactivity

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Topic P7 - Radioactivity

Atomic Structure

An atom consists of a small dense **nucleus** which contains **protons** and **neutrons**, and **electrons** orbiting the nucleus in diffuse clouds surrounding the nucleus.

- The radius of the nucleus is 100,000 times smaller than the radius of an atom but contains 99.9% of the atom's mass.

The constituents of an atom (protons, neutrons and electrons) have the following **relative** properties:

Type of particle	Relative mass	Relative charge
Proton	1	+1
Neutron	1	0
Electron	1/2000	-1

The repulsion force of positively charged protons packed in the nucleus is overcome by the **strong nuclear force**.

- The number of **protons** in the nucleus of the atom is known as the **atomic number**. In neutral atoms this is also the number of electrons in the atom.
- The number of **protons** and **neutrons** in the nucleus is known as the **mass number** of the atom (also known as the **nucleon** number).
- An **isotope** of an atom contains the same number of protons (so is the same element) but contains a different number of neutrons. Some isotopes of an element are far rarer than other isotopes.

An **ion** is formed when a neutral atom gains or loses electrons to become positively charged (electron loss) or negatively charged (electron gain). This process is known as **ionisation**.

Types of Decay

The atoms of certain elements or isotopes of elements have **unstable nuclei**. This can be for a number of reasons:

- The nucleus is too large
- The number of protons is very different to the number of neutrons
- The nucleus has a lot of energy

In order to stabilise the nuclei, radiation will be emitted.

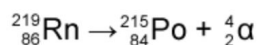




There are three types of radioactive decay each with different characteristics but all three of them produce **ionising radiation** (removes electrons from atoms to create ions):

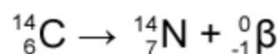
Alpha Decay - occurs when an alpha particle is emitted from the nucleus.

- An alpha particle is made up of two protons and two neutrons (a helium nucleus).
- Due to its relatively large size, alpha decay is highly ionising, slow moving and has a low penetrance (stopped by a few cm of air).
- Due to the loss of two protons and 2 neutrons, the element ejecting the alpha particle is converted to a new element.



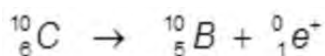
Beta Decay - occurs when a beta particle (a high energy electron) is emitted from the nucleus.

- This happens when a neutron is converted to a proton and an electron which is then emitted.
- Due to the element gaining a proton in beta emission, it is then converted to a new element.



The above is an example of **beta negative decay** as an electron is emitted. It is also possible for a **positron** to be emitted instead of an electron.

- A positron is the positively charged antiparticle of an electron.
- When a positron is emitted, a proton changes into a neutron thereby creating a new element.



As beta particles are smaller than alpha particles, they are moderately ionising, fast moving and have moderate penetrance (can be stopped by aluminium foil).

Exam Tip: the electron is emitted from the nucleus not the electron orbitals in beta decay, so it does not form an ion.

Gamma Decay - occurs when a gamma ray is emitted. A gamma ray is a high energy photon.

- In gamma decay, the mass and atomic number of the element remain unchanged.
- It is weakly ionising but highly penetrating (can only be stopped by thick lead).



Uses and Dangers of Radiation

Alpha Particles:

Use - Smoke alarms. The alpha emitter in the smoke alarm produces alpha particles which ionise air molecules. These ionised molecules carry current and complete a circuit in the smoke alarm. Smoke particles prevent ionisation of air molecules, hence breaking the circuit.

Danger - due to them being highly ionising, alpha particles are very dangerous as they damage DNA of cells and tissues. Fortunately, they have very low penetrance so have to be inhaled or ingested.

Beta Particles:

Uses - Tracers/material quality control. Beta particles are used to measure the thickness of paper/aluminium. If the material gets too thick, fewer beta particles will penetrate. Medical tracers can be used to image certain parts of the body (positron emission tomography).

Danger - beta particles are moderately penetrating so present a hazard if inhaled, ingested or direct exposure without a barrier.

Gamma Particles:

Uses - Sterilising medical equipment/food/radiotherapy. In radiotherapy, multiple angles are used to maximise tumour exposure to gamma rays whilst simultaneously minimising damage to non cancerous tissue.

Danger - due to them being weakly ionising, gamma rays aren't particularly dangerous provided the dose is low enough. However, they are highly penetrating so only thick lead/concrete will prevent exposure.

Half Life

Radioactive decay is a **spontaneous**, random process. Despite this, we know the probability of a certain nucleus decaying and the rate of decay but we cannot say for certain when a nucleus will decay.

The **half life** of a radioactive material is the time taken for 50% of the sample of radioactive material to decay.

- It depends on the decay constant of the element in question (decay constant λ is independent of external factors).
- Decay is measured in **becquerels** using a **geiger counter**.
- One becquerel is one decay per second.

Exam tip - always factor in base level of radiation into count rate questions. There is always a background level of radiation due to radon gas, cosmic rays etc.



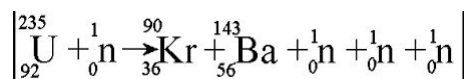


Nuclear Fission

Nuclear fission is a **nuclear reaction** in which a heavy nucleus splits spontaneously into smaller nuclei with the release of energy. This phenomenon is the process by which **energy is released** in nuclear power plants.

In the case of power plants, it is specifically the **fission** of Uranium-235. In a **fission reactor**:

- Uranium-235 absorbs a neutron producing the unstable isotope Uranium-236.
- Once Uranium-236 is made, it splits into two random smaller nuclei releasing neutrons and energy in the process:



- The three neutrons can then be absorbed by other Uranium-235 atoms in a chain reaction that needs to be controlled in a nuclear reactor through the use of **neutron absorbing control rods** to prevent a nuclear explosion.

Nuclear Fusion

Nuclear fusion is a nuclear reaction in which atomic nuclei of low atomic number fuse to form a heavier nucleus with the release of energy.

- Fusion requires an incredible amount of energy to occur as the mutual repulsion of nuclei needs to be overcome.
- This sort of energy is seen in the sun where fusion mainly occurs between hydrogen and deuterium nuclei to produce helium:

