WJEC (Wales) Physics GCSE

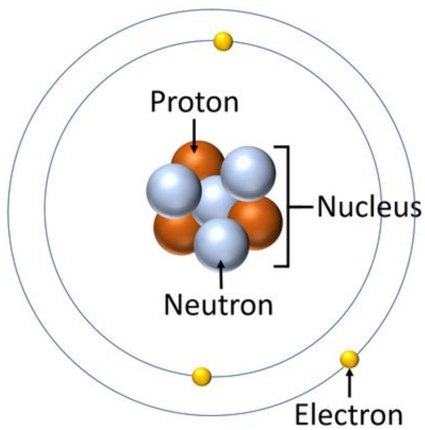
2.7: Types of Radiation

Detailed Notes

(Content in **bold** is for higher tier **only**)

Atomic Structure

Atomic theory developed lots over time as new discoveries were made. Today, the **nuclear model** of the atom is accepted. This describes atoms as consisting of a **central nucleus** of **protons** and **neutrons** and surrounding shells of **orbiting electrons**.



Nuclear model of an atom (keystagewiki.com).

Protons, neutrons and electrons are types of **sub-atomic particle**. They each have characteristic **charges** and **relative masses**:

Sub-atomic Particle	Relative Charge	Relative Mass
Proton (p)	+1	1
Neutron (n)	0	1
Electron (e)	-1	1/1840 (negligible)

This shows how protons and neutrons account for almost all of the mass in an atom. Protons and electrons account for an atom's/ion's charge.

Atomic Number (Z)

Each element has a unique **atomic number** that makes it identifiable. Atomic number is sometimes referred to as **proton number** as it is equal to the **number of protons** present in the nucleus.

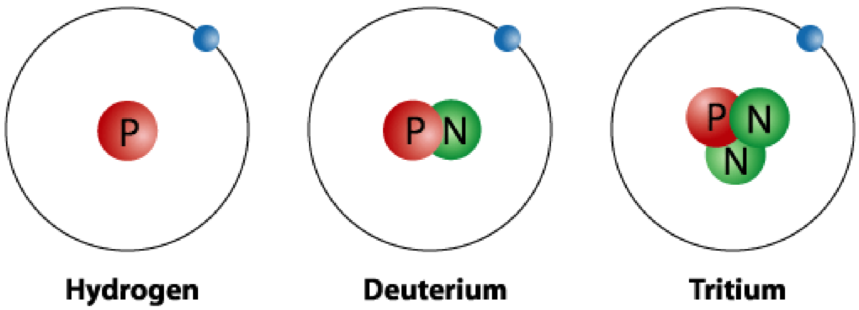
Mass Number (A)

The **mass** of an atom is the **sum of protons and neutrons**. The mass of electrons is so small it is considered to be negligible. Mass number can also be referred to as the **nucleon number** as it is equal to the number of sub-atomic particles in the **nucleus**.

Isotopes

Isotopes are alternative forms of the same element, which necessarily have the **same atomic number**, but have different **mass numbers**. In other words they contain the **same number of protons** in their nucleus but a **different number of neutrons**.

An Element can have **multiple** isotopes but some are more stable than others. **Hydrogen**, for example, has **three** main isotopes: Hydrogen (*H-1*), Deuterium (*H-2*) and Tritium (*H-3*).



The three main isotopes of Hydrogen (memorangapp.com).

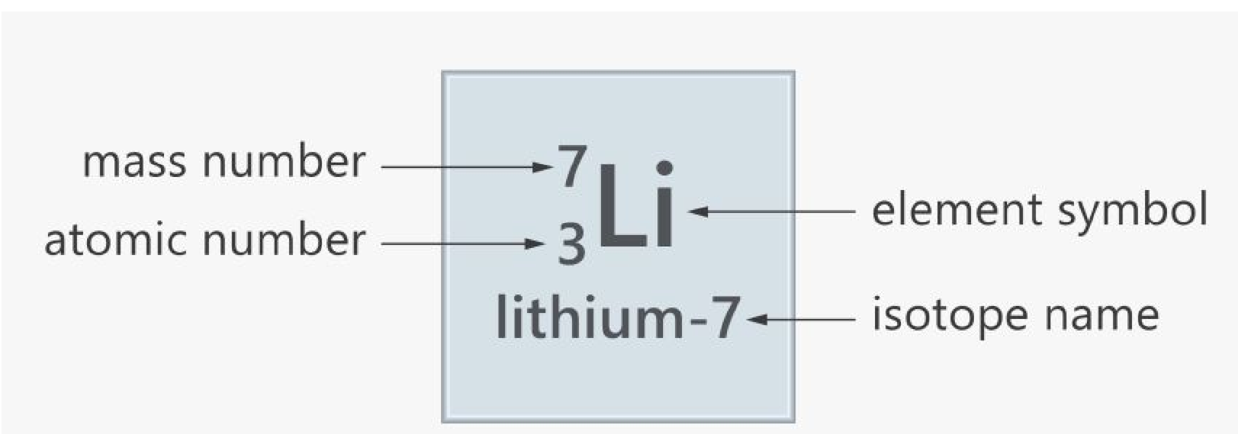
H-1 is the most stable of the three, and is therefore the most abundant.

Ions

In an atom, the number of protons will equal the number of electrons so there is **no net atomic charge**. Ions are similar to atoms but have a **net charge**. If an **electron is gained** by an atom, it will become a **negatively** charged ion. If an **electron is lost** by an atom, it will become a **positively** charged ion.

Chemical Symbols

Each element can be represented using **chemical symbols**. These often include its **atomic number**. Different isotopes may possess a different number of neutrons and as a result may have different **mass number**. Therefore, the mass number of the relevant isotope may also be included.



Full chemical symbol for Lithium (pngitem.com).

Using chemical symbols, the number of each sub-atomic particle in an isotope of an element can be calculated (assuming it is neutrally charged).

$$\textit{Atomic Number} = Z = \textit{Protons} = 3$$
$$\textit{Mass Number} = A = \textit{Protons} + \textit{Neutrons} = 7$$

$$\textit{Neutrons} = \textit{Mass Number} - \textit{Atomic Number} = 7 - 3 = 4$$

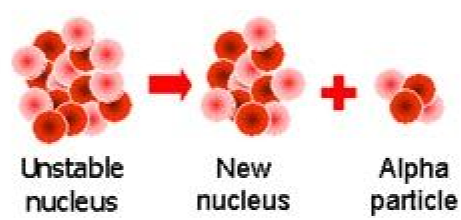
$$=> p = 3$$
$$=> n = 4$$
$$=> e = 3$$

Radioactivity

Atomic nuclei are not always stable, since stability depends on the **ratio of protons and neutrons**. Unstable nuclei emit **ionising radiation** through **radioactive decay** in order to adjust the proton-neutron ratio in the nucleus, and hence become more stable. There are three main types of radioactive emission originating from decay: Alpha, Beta and Gamma.

Alpha Radiation

Alpha particles (α) are emitted as radiation when a nucleus undergoes **alpha decay**. An alpha particle is equivalent to a **helium nucleus ($_2^4He$)**, consisting of two protons and two neutrons.



Alpha decay (adapted from revisionscience.com).

Equations can be written for alpha decay using either $_2^4\alpha$ or $_2^4He^{2+}$. These must be balanced like chemical equations.

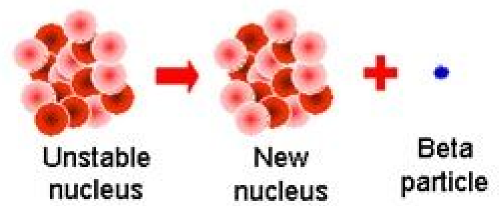
$${}^{235}_{92}U \longrightarrow \underbrace{{}^{4}_{2}He}_{\alpha\ \text{particle}} + {}^{231}_{90}Th$$

Alpha decay equation for Uranium-235 (wou.edu).

Alpha radiation is **slow moving** and **strongly ionising**. Consequently it cannot travel very far through the air so has **low penetrating power**. The range of alpha radiation is **~5 cm** and it can be stopped (absorbed) by **thin paper**.

Beta Radiation

Beta particles (β) are emitted as radiation when a nucleus undergoes **beta decay**. A beta particle is equivalent to a **high energy electron**, with a -1 charge and negligible mass.



Beta decay (adapted from revisionscience.com).

Equations can be written for beta decay using either $_{-1}^{0}\beta$ or $_{-1}^{0}e$. These must be balanced like chemical equations.

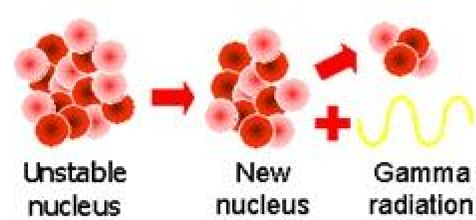
$$^{14}_{6}C \longrightarrow \; ^{14}_{7}N + \underbrace{^{0}_{-1}e}_{\beta\ \text{Particle}}$$

Beta decay equation for Carbon-14 (wou.edu).

Beta radiation is **faster moving** than alpha and **less strongly ionising**. This means it travels **further** and requires a tougher material to be stopped as it is a more effective **penetrator**. The range of beta radiation is **~1 m** and can be stopped (absorbed) by **thin metal**.

Gamma Radiation

Gamma radiation is not a particle but a type of **electromagnetic (EM) radiation (γ)** and is emitted when a nucleus undergoes **gamma decay**. As a wave, gamma radiation has **no mass** and **no charge**.



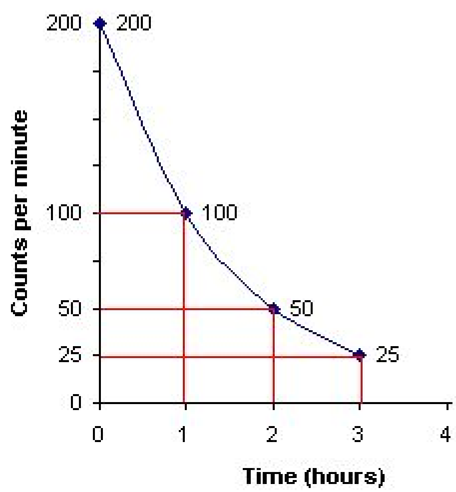
Beta decay (adapted from revisionscience.com).

Gamma radiation **travels quickly** (speed of light) and is **weakly ionising**. Gamma rays are **highly penetrating** and can therefore travel **long distances**. The range of gamma radiation is much greater than 1 m and a **thick lead** block is required to stop (absorb) it.

Random Decay Nature

Radioactive decay is **random** in nature meaning it is **not possible to predict** when a specific **individual atom** will decay. However it is possible to predict the number of atoms in a population that will undergo decay, in a given time-period. Such predictions rely on the fact that a population undergoing decay will follow a negatively exponential function. Such a function can be described using the concept of a **half-life**.

A half-life is the time it takes for the **number of radioactive nuclei** to **halve** in number. This is the same as the time it takes for the rate at which decay events take place, sometimes called the **count-rate**, to **halve**. The half-life of each radioactive element is **unique** and can range from a few minutes to millions of years.



Count rate - time graph for a radioactive element with a half-life of 1 hour (darvill.clara.net).

Half-life can be found **experimentally** but many **repeat readings** are required over a long period of time to calculate an accurate estimate.

Background Radiation

There is radiation all around us from lots of different sources. These sources can be **natural** or **man-made**.

Natural Sources	Man-made Sources
Cosmic Rays *(radiation remaining from the Big Bang that reaches Earth from space)*	X-Rays *(radiation used to image inside the body and present high in the atmosphere when flying)*
Rocks *(certain rock types such as granite are radioactive and some even emit radon gas which itself is radioactive)*	Nuclear Power Stations *(these release radiation into the air and also produce highly radioactive nuclear waste)*

Living Things *(Plants absorb radiation from the ground which is then passed along the food chain)*	Nuclear Weapons *(man-made bombs and missiles containing radioactive material release radiation into the air upon impact)*

Natural sources, especially rocks and cosmic rays, are the **biggest contributors** to background radiation for the average person. **Man-made** sources account for **~15%** of the average person's background radiation but it is increasing as medical and power sources become more common. This is dangerous as there are links between **radiation exposure** and **cell mutation** diseases, such as **cancer**.

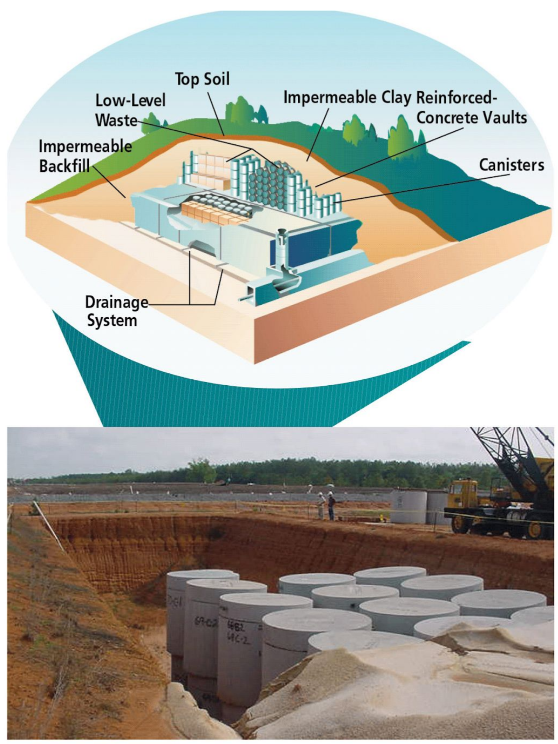
Nuclear Waste

Nuclear power stations are used to generate **electricity** and are considered to be fairly 'green' as they produce **no greenhouse gases** such as CO_2. However a major downside of nuclear power is the nuclear waste produced from the radioactive material. This waste remains **radioactive** for many years after removal from the station and is **very dangerous** if not disposed of correctly.

Some nuclear waste is more dangerous than others, so the waste is **rated** and disposed of in different ways.

Low Level Waste

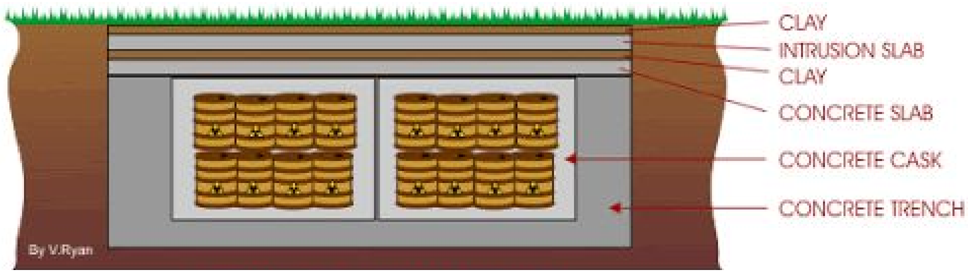
This includes protective clothing, equipment or material that is contaminated. Low level waste can be disposed of in **landfill** by surrounding it in **concrete** in large **disposal drums**.



Low level nuclear waste disposal in buried drums (nrc.gov).

Intermediate Level Waste

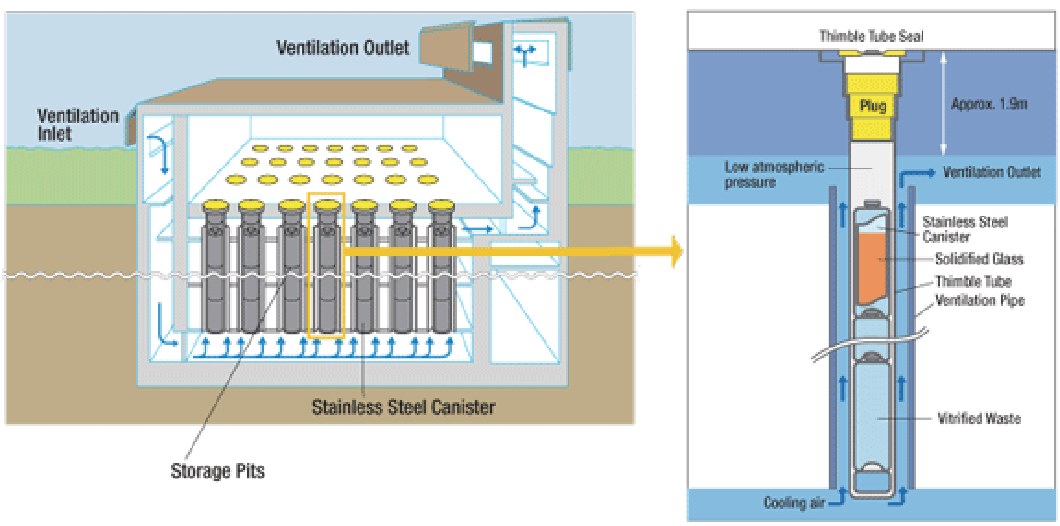
This includes radioactive sources from smaller medical settings and components from nuclear reactors. Intermediate level waste can be disposed of by mixing it with **concrete** in large **steel disposal drums** which are then buried in **purpose-built stores**.



Intermediate level nuclear waste disposal bunkers (technologystudent.com).

High Level Waste

This includes chemicals from nuclear reactors and nuclear fuels. High level waste has to be stored in **underwater pools** for **over 20 years**. Within these pools the waste is held in **casks**. **Air circulation** has to be created to help remove any **heat** generated by the still decaying material. High level waste can take **thousands of years** to decay to safer levels.



HIgh level nuclear waste disposal (trex17153.wixsite.com).