The Complete GCSE Guide to Radioactivity

Introduction:

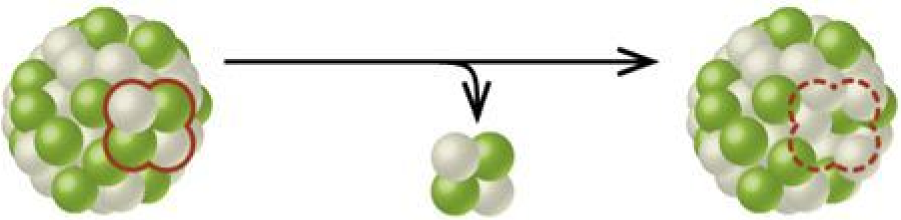
Radioactivity occurs when an unstable atom emits particles or waves in order to become more stable. Radioactivity can occur when an atom has too many or too few neutrons to balance out the repulsive positive charges of protons in the nucleus.

Types of Radioactivity:

There are four types of radioactivity emitted by an unstable nucleus, alpha particles, beta particles, gamma waves and neutron emission.

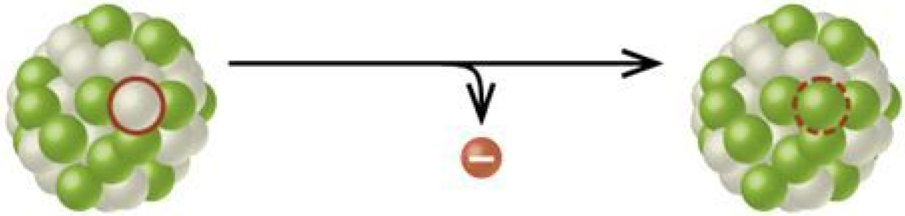
Alpha Particles:

Alpha particles consist of two protons and two neutrons (a helium nucleus) and have a charge of 2+. They can be represented in two ways: ${}^{4}_{2}He^{2+}$ and ${}^{4}_{2}\alpha^{2+}$ (where α is the Greek symbol alpha). A nucleus with too few neutrons will emit alpha particles to become stable. This causes the mass number of an atom to decrease by four whilst the atomic number decreases by two.



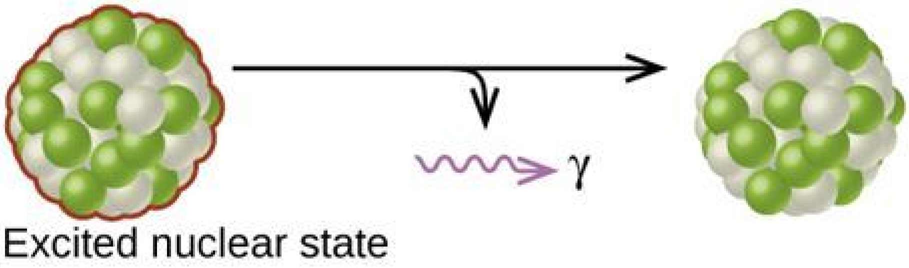
Beta Particles:

Beta particles are high-speed electrons and thus have a charge of 1-. They are also represented in two ways: ${}^{0}_{-1}e^{-}$ and ${}^{0}_{-1}\beta^{-}$ (where β is the Greek symbol beta). In a nucleus with too many neutrons, a neutron will change into a proton and an electron, emitting the electron as a beta particle. This causes the atomic number to increase by one whilst the mass number remains unchanged.



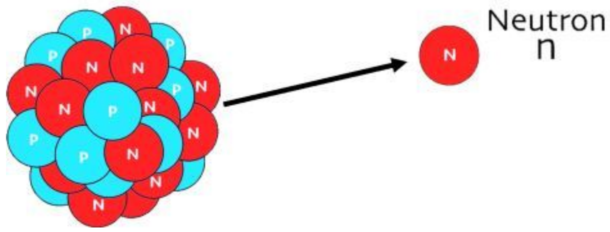
Gamma Waves:

Gamma waves are a form of electromagnetic (EM) radiation that do not have mass or charge. They fall on the far left of the EM spectrum with the shortest wavelength and highest energy of all waves. They are represented with the following symbol: ${}^{0}_{0}\gamma$ (where γ is the Greek symbol gamma). Gamma waves are emitted following alpha or beta decay due to an excess of energy remaining after the initial decay. This causes no change to the mass or atomic numbers of the atom.



Neutron Emission:

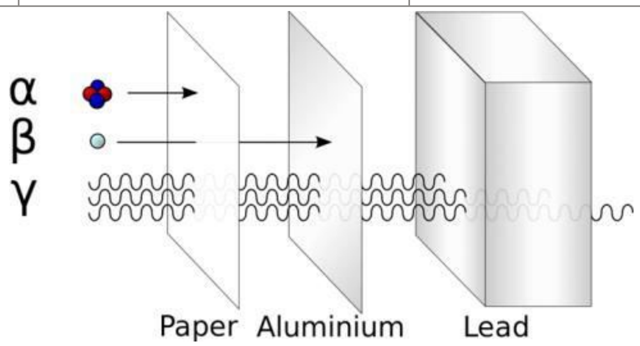
During neutron emission, a nucleus with too many neutrons releases a high-energy neutron. This usually occurs when particles collide, for example when a Beryllium nucleus collides with alpha particles. The symbol for this type of decay is as follows: ${}^{1}_{0}n$.



Radiation Properties:

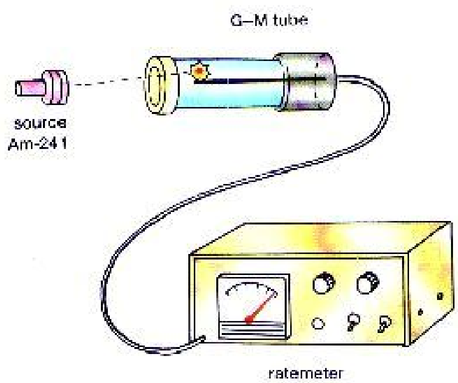
Different forms of radiation have different properties due their differing compositions. We can split these into penetrating power (or how far radiation can travel into objects), ionising power (or how easily the radiation can cause atoms to form ions by losing electrons) and range in air (or how far they travel in air). The properties can be found in the table below:

Radiation	Penetrating Power	Ionising Power	Range in Air
Alpha (α)	Skin/Paper	High	< 5 cm
Beta (β)	3 mm of Aluminium Foil	Low	≈ 1 m
Gamma (γ)	Lead/Concrete	Very Low	> 1 km



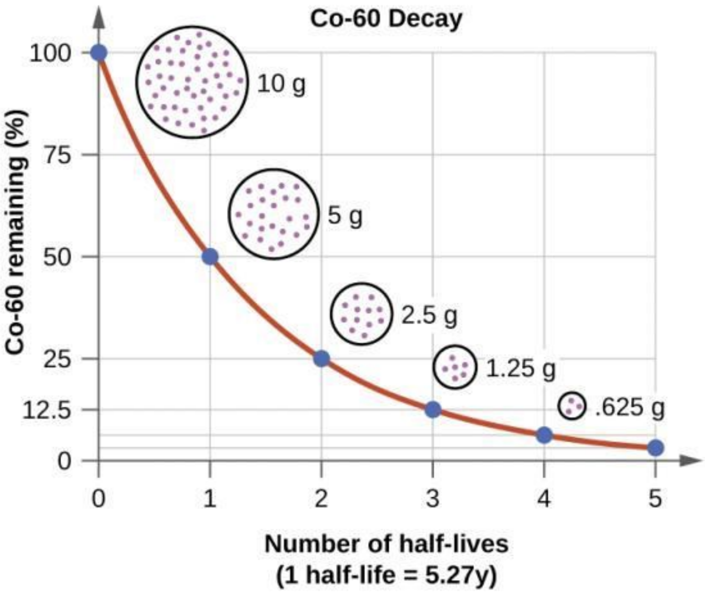
Detecting Radiation:

A Geiger-Muller tube can be used to measure the rate of radioactive decay in counts per second - how much radiation hits the detector in one second. When detecting radiation, it is important to remember that radioactive sources emit radiation in all directions whilst detectors can only detect radiation from a single direction.



Half-Life:

Due to the random nature of radioactive decay, scientists use a measurement called half-life to make predictions about radioactive atoms. The half-life is the time it takes for half of the radioactive atoms within a sample to decay.



The graph above shows the relationship between the half-life of Co-60 (cobalt-60) and the percentage of the original number of atoms remaining. After one half-life, half of the original atoms remain.

Half-Life Calculations:

We can calculate the amount of atoms remaining in a sample if we know the original number and the number of half-lives that have passed as with every half-life the original number of atoms halves so after two half-lives there will be $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ of the original number of atoms remaining as a half of a half is one quarter.

For example, in the Co-60 graph above after three half-lives there is 12.5% of the original number of atoms remaining as $\frac{1}{2}^3 = \frac{1}{8} = 0.125 = 12.5\%$.

Nuclear Equations:

We can express the changes in the nucleus that occur during radioactive decay as equations. In alpha decay, the nucleus loses two protons and two neutrons, decreasing the atomic number by two and the mass number by four. This can be seen in the following equation:

$$^{219}_{86}Rn \rightarrow {}^{215}_{84}Po + {}^{4}_{2}\alpha$$

In beta decay, the atomic number increases by one, whilst the mass number remains unchanged. This can be seen in the following equation:

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

Gamma radiation is not represented using an equation as there are no changes to the mass or atomic numbers.

Irradiation:

Exposing objects to radiation is known as irradiation. Irradiation causes damage to living tissue - this is both a hazard and a useful property of radiation. Irradiation does not cause an object to become radioactive.

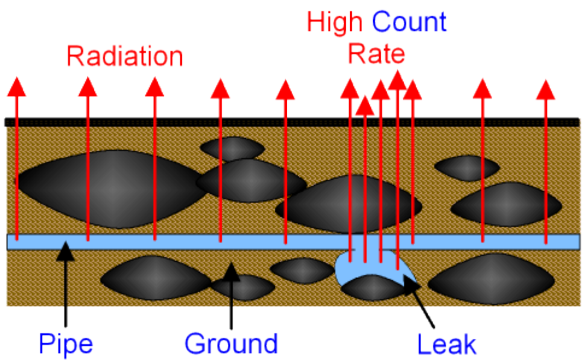
For example, food is often irradiated using cobalt-60. The gamma radiation emitted kills microorganisms and bacteria living on the food whilst causing no damage to the food itself.

Food irradiation enables sterilisation (the killing of microorganisms) without the need for high temperatures such as in cooking meaning that uncooked food can stay fresh for longer. It also works on food that would melt at high temperatures. However, it may not kill all of the bacteria and microorganisms on food and must be completed in a safe area without people nearby that would also be harmed by the radiation.

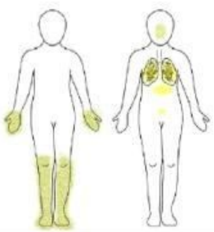
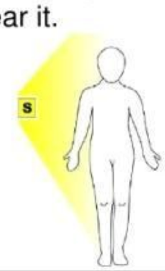
Contamination:

When an object comes into contact with a radioactive material it is contaminated as the object will continue to emit radiation once the radioactive material has been removed.

Contamination is used in the water industry to test for leaks within pipes. A source of gamma radiation is introduced to the pipe and will cause a build-up of emissions in an area with a leak as the water will seep out of the pipe and into the ground. The gamma radiation can then be detected and the leak location discovered.



The isotope used for this purpose must be a gamma emitter, have a half-life of at least a couple of days (to allow for the leak to be found), and not be poisonous to humans who will drink the contaminated water.

Contamination	Irradiation
This is when the source is inside the body, or on your skin and will affect you all of the time. 	This is when a source outside the body affects you – but only when you are near it. 

Effects on the Body:

Radiation can have many hazardous effects on the body as it can ionise chemicals - convert atoms to ions - and release large amounts of energy into the body.

Within the body, the ionisation of DNA can cause dangerous mutations and cell death, even leading to cancer. This classes radiation as a carcinogen (substance that causes cancer).

Repeated exposure to radiation increases the risk of cell damage occurring and thus cancers forming. To reduce the risk, we can store radioactive sources within lead-lined boxes when not used, wear protective clothing, limit exposure time and distance from the source, and handle sources with tongs.

Radiation Use in Industry:

Within industry, radiation has many different uses due to its useful range of properties. More obvious uses include cancer treatment and food irradiation (see Irradiation above).

However, there are also less obvious cases, such as water pipe leak testing (see Contamination above) and aluminium foil production.

In aluminium foil production, beta radiation is directed at the foil surface and the amount of radiation that passes through is measured to determine the thickness of foil so that equipment can be adjusted to produce the correct thickness.