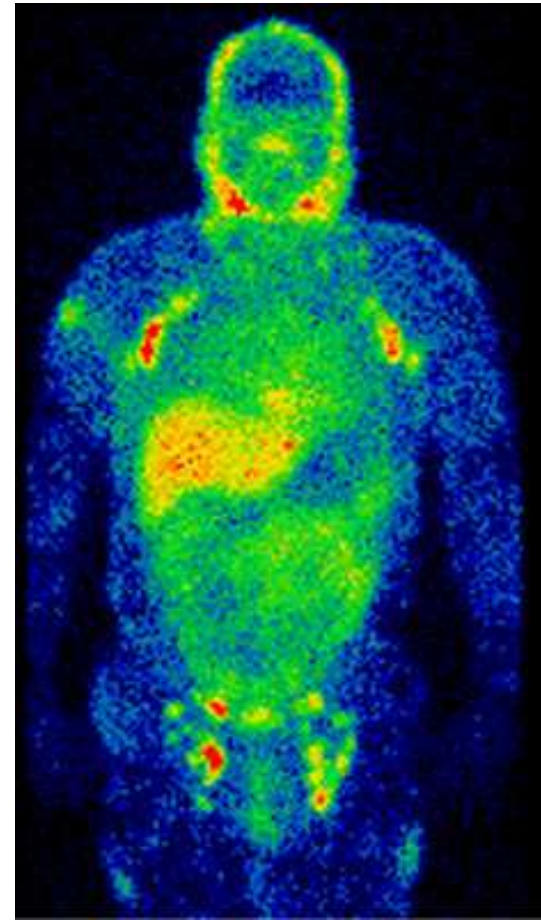


7 Radioactivity and Particles



7 Radioactivity and Particles

7.1 use the following units: becquerel (Bq), centimetre (cm), hour (h), minute (min) and second (s)

7.2 describe the structure of an atom in terms of protons, neutrons and electrons and use symbols such as $^{14}_6\text{C}$ to describe particular nuclei

7.3 know the terms: atomic (proton) number, mass (nucleon) number and isotope

7.4 know that alpha (α) particles, beta (β^-) particles and gamma (γ) rays are ionising radiations emitted from unstable nuclei in a random process

7.5 describe the nature of alpha (α) particles, beta (β^-) particles and gamma (γ) rays, and recall that they may be distinguished in terms of penetrating power and ability to ionise

7.6 practical: investigate the penetration powers of different types of radiation using either radioactive sources or simulations

7.7 describe the effects on the atomic and mass numbers of a nucleus of the emission of each of the four main types of radiation (alpha, beta, gamma and neutron radiation)

7 Radioactivity and Particles

- 7.8 understand how to balance nuclear equations in terms of mass and charge
- 7.9 know that photographic film or a Geiger-Müller detector can detect ionising radiations
- 7.10 explain the sources of background (ionising) radiation from Earth and space
- 7.11 know that the activity of a radioactive source decreases over a period of time and is measured in becquerels
- 7.12 know the definition of the term 'half-life' and understand that it is different for different radioactive isotopes
- 7.13 use the concept of the 'half-life' to carry out simple calculations on activity, including graphical methods
- 7.14 describe uses of radioactivity in industry and medicine
- 7.15 describe the difference between contamination and irradiation
- 7.16 describe the dangers of ionising radiations, including:
 - that radiation can cause mutations in living organisms
 - that radiation can damage cells and tissue
 - the problems arising from the disposal of radioactive waste and how the associated risks can be reduced

7.1 Radioactivity Units

7.1 use the following units: becquerel (Bq), centimetre (cm), hour (h), minute (min) and second (s)

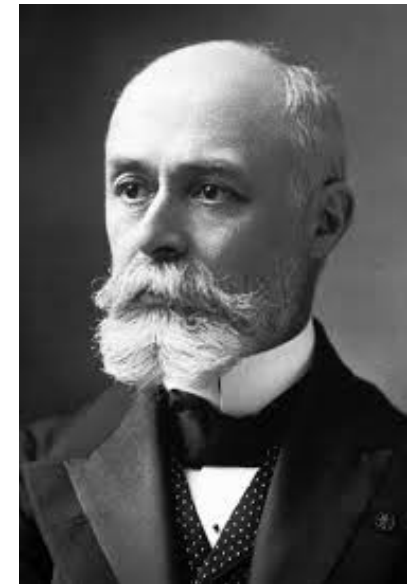
The becquerel (Bq) is the International System (SI) unit of radioactivity.

One becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. It is a measure of the decay rate of a substance.

It is equivalent to s^{-1} , or Hz.

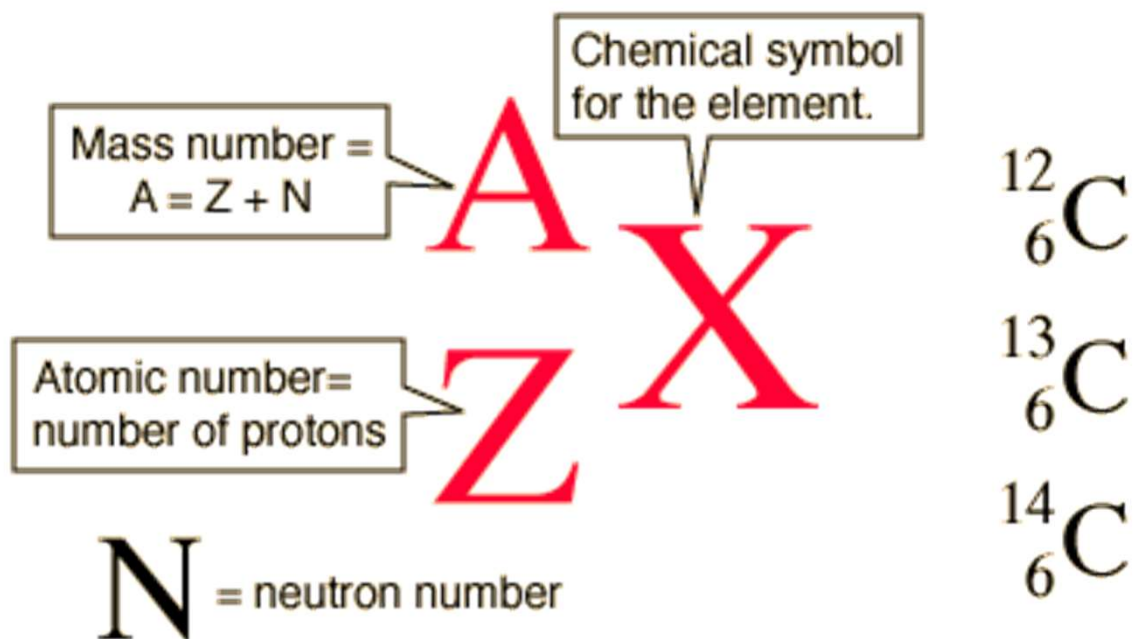
One Becquerel is equal to one nuclear decay per second

It is named after Henri Becquerel a French physicist, and early pioneer in the study of radioactivity



7.2 Nuclear Notation

7.2 describe the structure of an atom in terms of protons, neutrons and electrons and use symbols such as $^{14}_6\text{C}$ to describe particular nuclei

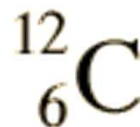
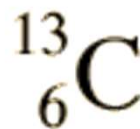
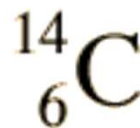


Example: the isotopes of carbon. The element is determined by the atomic number 6.

Carbon-12 is the common isotope,

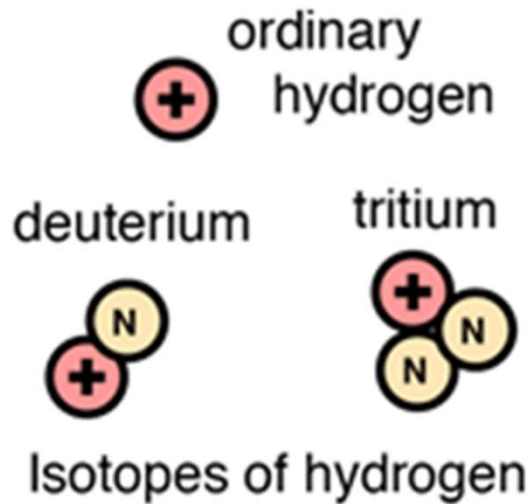
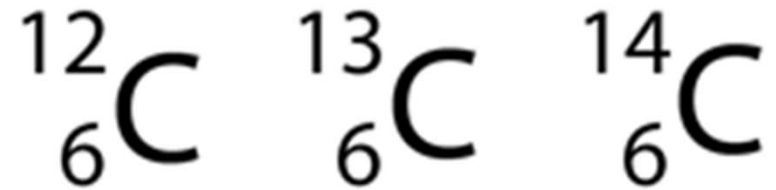
Carbon-13 as another stable isotope which makes up about 1%.

Carbon 14 is radioactive and the basis for carbon dating.



7.3 Nuclear Vocabulary

7.3 know the terms: atomic (proton) number, mass (nucleon) number and isotope



Notation for the different isotopes of the chemical element carbon.

There are about 400 stable isotopes.

The three isotopes of hydrogen change in mass by a factor of three, but their **chemical properties are identical**.

7.3 Nuclear Vocabulary

7.3 know the terms: atomic (proton) number, mass (nucleon) number and isotope

Proton number or charge, Z = the number of protons in a nucleus

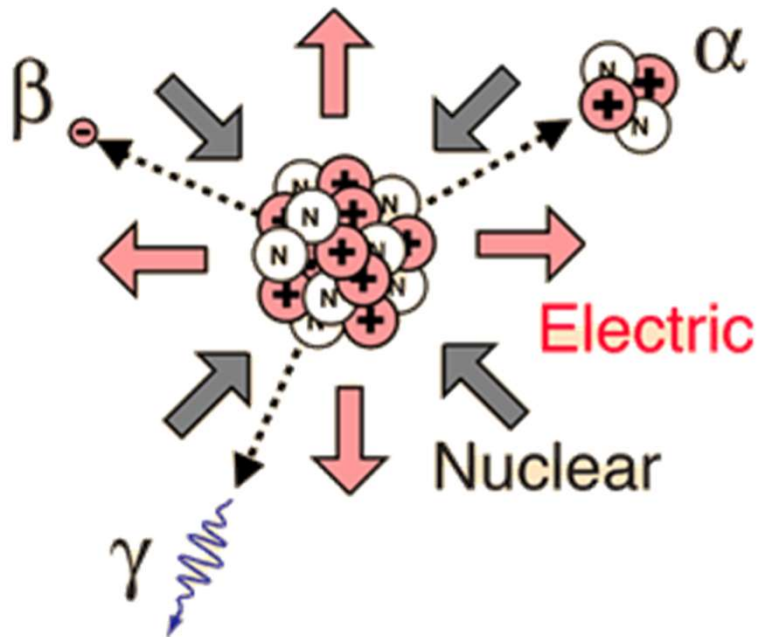
Nucleon number or Mass number, A = the number of protons and neutrons in a nucleus

Neutron number, N = the number of neutrons in a nucleus

Isotopes. Atoms of the same type, they have the same proton no, but different masses due to their having different numbers of neutrons.

7.4 Types of Decay

7.4 know that alpha (α) particles, beta (β^-) particles and gamma (γ) rays are ionising radiations emitted from unstable nuclei in a random process



Nuclear decay arises from an imbalance between the two strongest forces in nature, the nuclear and electromagnetic.

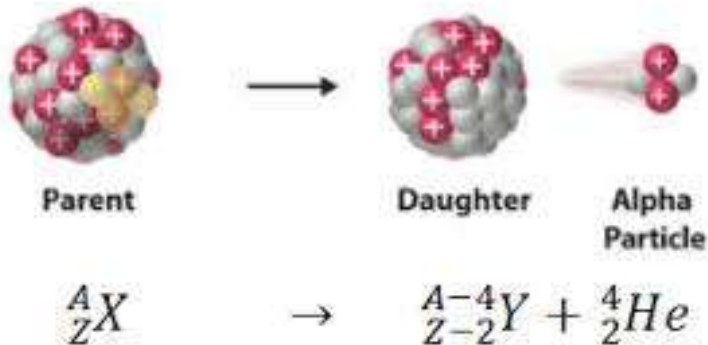
In stable nuclei these forces are balanced; the **electrostatic repulsion** that acts between protons is exactly balanced by the **strong force of nuclear attraction** that acts between all nucleons (protons and neutrons).

When these forces are **unbalanced**, the nucleus is said to be radioactive and can **spontaneously** and **randomly** decay.

There are four mechanisms of decay, alpha, beta, gamma, and neutron decay.

The first three are directly ionising, the fourth is electrically neutral and is not.

7.4 Alpha Decay - α

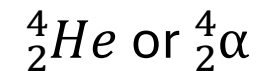


Composed of two protons and two neutrons, the alpha particle is a **nucleus** of the element helium.

It has the following properties:

Proton no.	$Z = 2$
Neutron no.	$N = 2$
Nucleon no.	$A = 4$

It is represented as:



It occurs when a radioactive nucleus has **too many protons** and the electrostatic repulsion is greater than the strong nuclear attraction.

7.4 Beta Decay - β

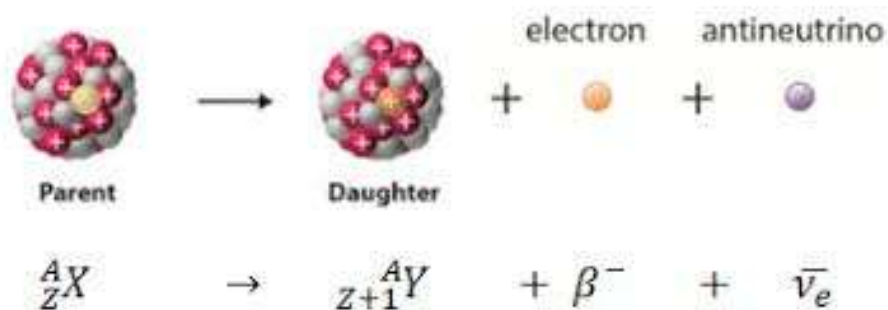
Composed of a single fast-moving electron.

It has the following properties:

Proton no.	$Z = -1$
Neutron no.	$N = 0$
Nucleon no.	$A = 0$

It is represented as:

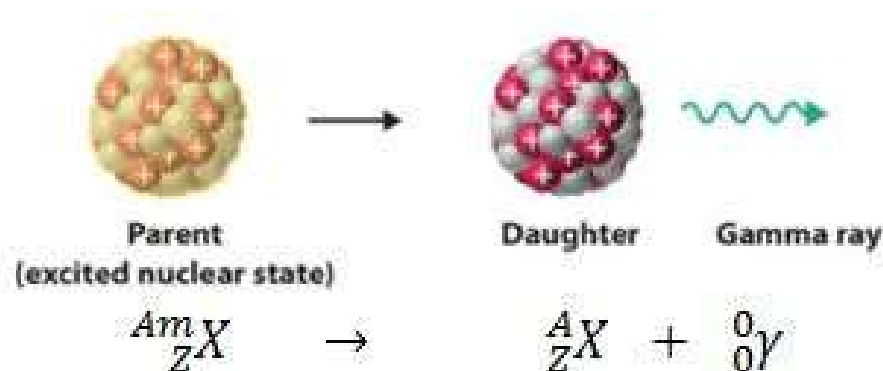
$${}_{-1}^0\beta \text{ or } {}_{-1}^0e$$



N.B. You do not need to know about neutrinos for this course, but they are there!

It occurs when a radioactive nucleus has **too many neutrons** and the strong nuclear attraction is greater than the electrostatic repulsion.

7.4 Gamma Decay - γ



Composed of small amount of electromagnetic radiation, in the form of a high frequency electromagnetic wave.
A gamma ray.

It has the following properties:

Proton no.	$Z = 0$
Neutron no.	$N = 0$
Nucleon no.	$A = 0$

It is represented as:



It occurs when a nucleus is in an excited state, the protons and neutrons are arranged unevenly.

7.4 Neutron Decay - n

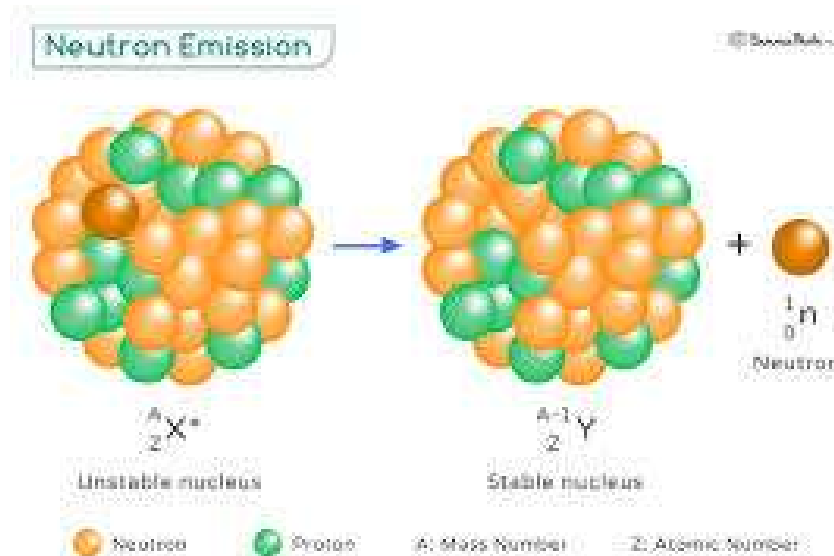
Neutron emission is a mode of radioactive decay in which one or more neutrons are ejected from a nucleus.

It occurs in the most neutron-rich/proton-deficient nuclides, and also from excited states of other nuclides.

As only a neutron is lost by this process

The number of protons remains unchanged,

The atom does not become an atom of a different element, but a different isotope of the same element.



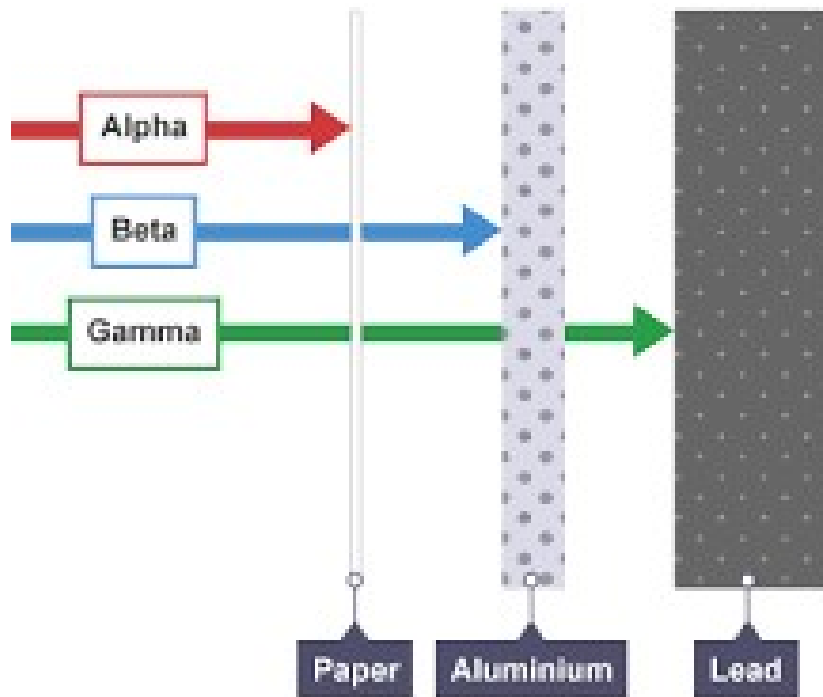
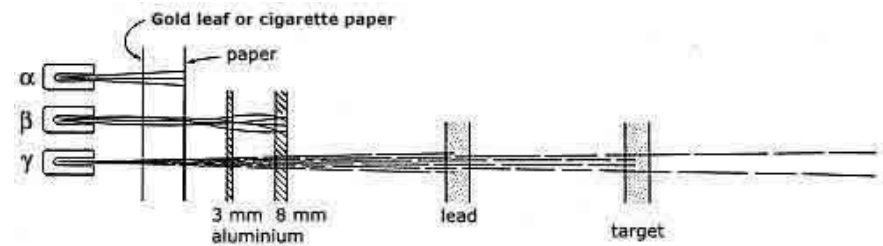
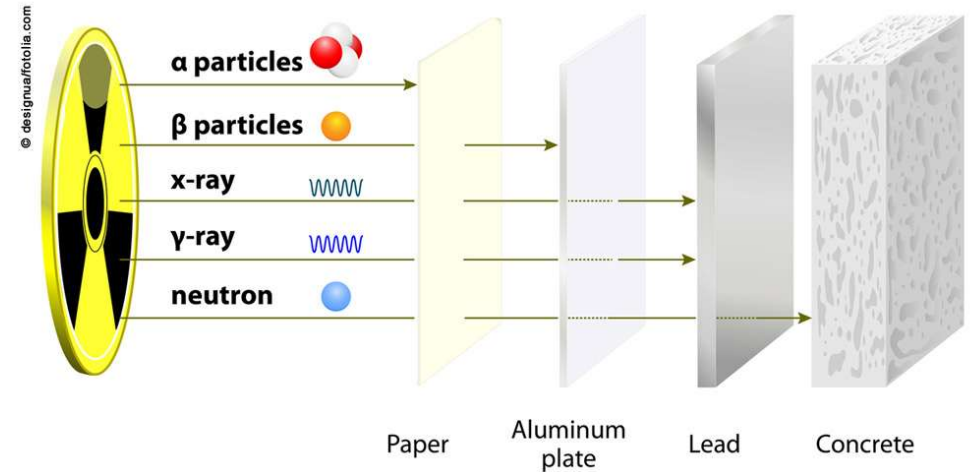
7.5 Properties of Decay

7.5 describe the nature of alpha (α) particles, beta (β^-) particles and gamma (γ) rays, and recall that they may be distinguished in terms of penetrating power and ability to ionise

Type of decay	Penetrating ability	Ionising Ability
Alpha Decay	Weakly penetrating, absorbed by a few cm of air or a sheet of paper.	Most ionising, has a +2 charge
Beta Decay	Moderately penetrating, absorbed by a thin sheets of aluminium.	Moderately ionising, has a charge of -1.
Gamma Decay	Strongly Penetrating, absorbed by several centimetres of lead, or metres of concrete	Least ionising as has to 'knock off' an electron from an atom after colliding with it.
Neutron Decay	Extremely penetrating, only stopped by metres of concrete	Neutral, very unlikely to ionise, unless absorbed by a nucleus, and inducing a subsequent beta decay.

7.6 Radioactivity Properties - Practical

7.6 practical: investigate the penetration powers of different types of radiation using either radioactive sources or simulations



7.6 Radioactivity Properties - Practical

Practical Method: Investigating Absorption of Radiation

This experiment determines the type of radiation being emitted by checking which material stops it.

Equipment Needed:

Radioactive sources (Alpha, Beta, and Gamma)

Geiger-Müller (GM) tube and counter

Set of absorbers: Paper/Cardboard, Aluminum foil (approx. 3-5mm), Lead block (thick)

Tongs (for safety)

Method/Procedure:

Measure Background Count: Turn on the GM counter without any source present and record the count rate for 5 minutes.

This must be repeated, averaged and then subtracted from all measurements.

Setup the Source: Using tongs, place the radioactive source (e.g., Americium-241 for Alpha, Strontium-90 for Beta, Cobalt-60 for Gamma) about 3-5 cm from the GM tube.

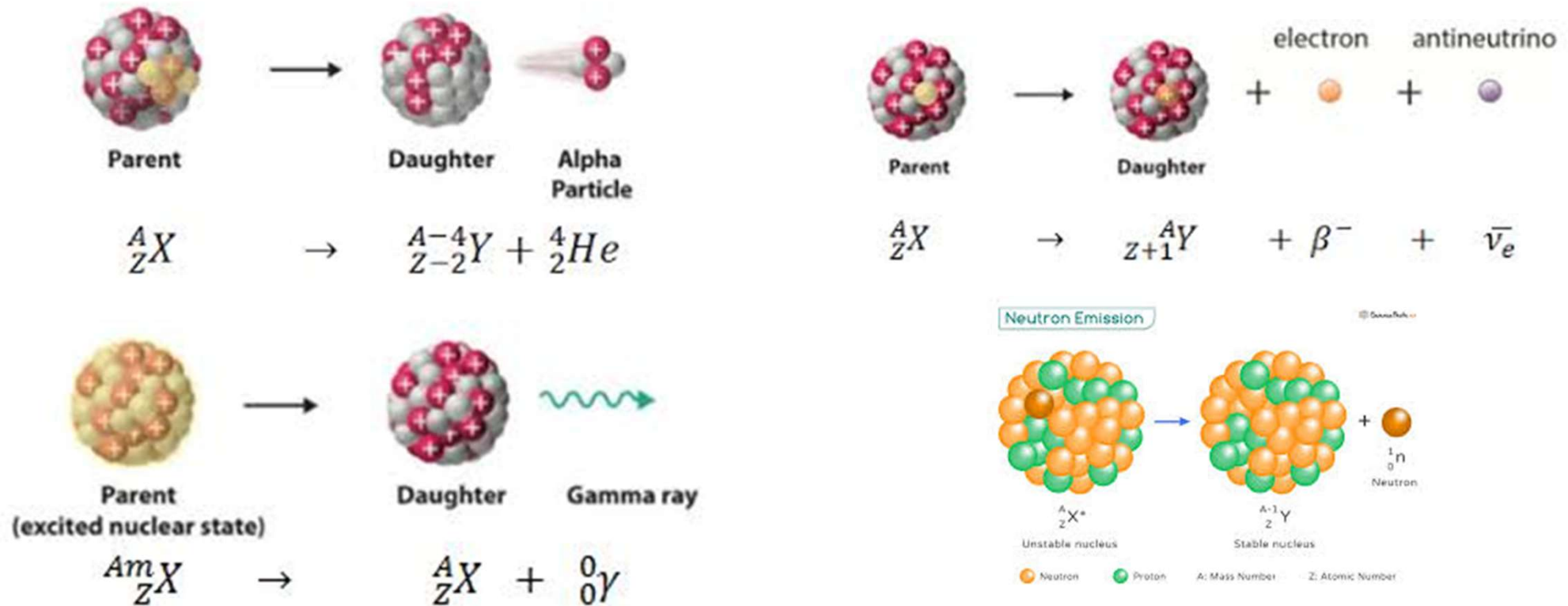
Test with Paper: Place a sheet of paper between the source and the tube. If the count rate drops to background levels, the source is alpha.

Test with Aluminum: If the count remains high, replace the paper with aluminum foil. If the count drops significantly, the source is beta.

Test with Lead: If the count still remains, place a thick lead block in front of the source. A significant decrease in the count suggests gamma radiation.

7.7 Decay Equations 1

7.7 describe the effects on the atomic and mass numbers of a nucleus of the emission of each of the four main types of radiation (alpha, beta, gamma and neutron radiation)



7.8 Decay Equations 2

There are some fundamental conservation laws that are never violated, these are:

- Conservation of Mass/Energy
- Conservation of Charge
- Conservation of Momentum

The first two are maintained by balancing radioactive decay equations;

Nucleon No – conserves mass

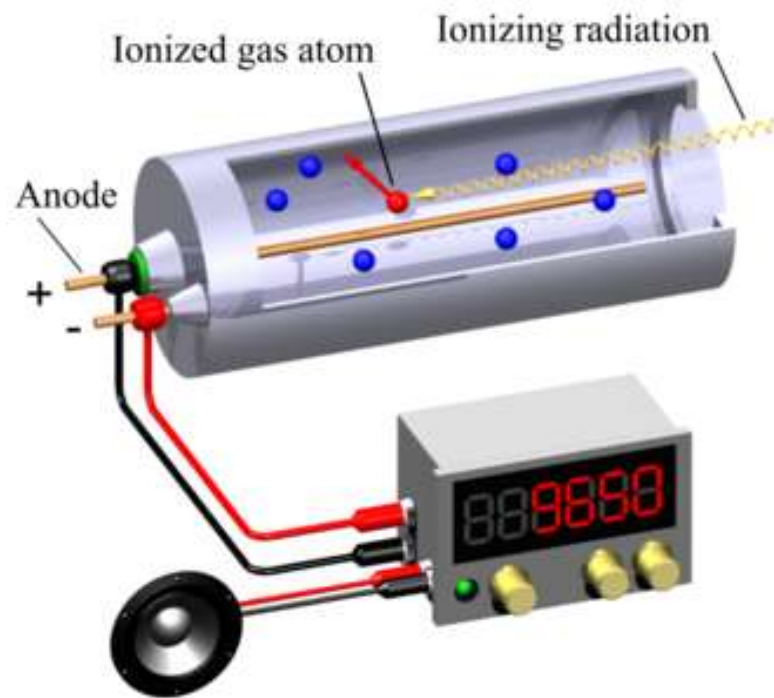
Proton No – conserves charge

The relative direction and speed of the particles before and after the decay conserves momentum.

In practice the sum of each of these numbers on either side must be equal.

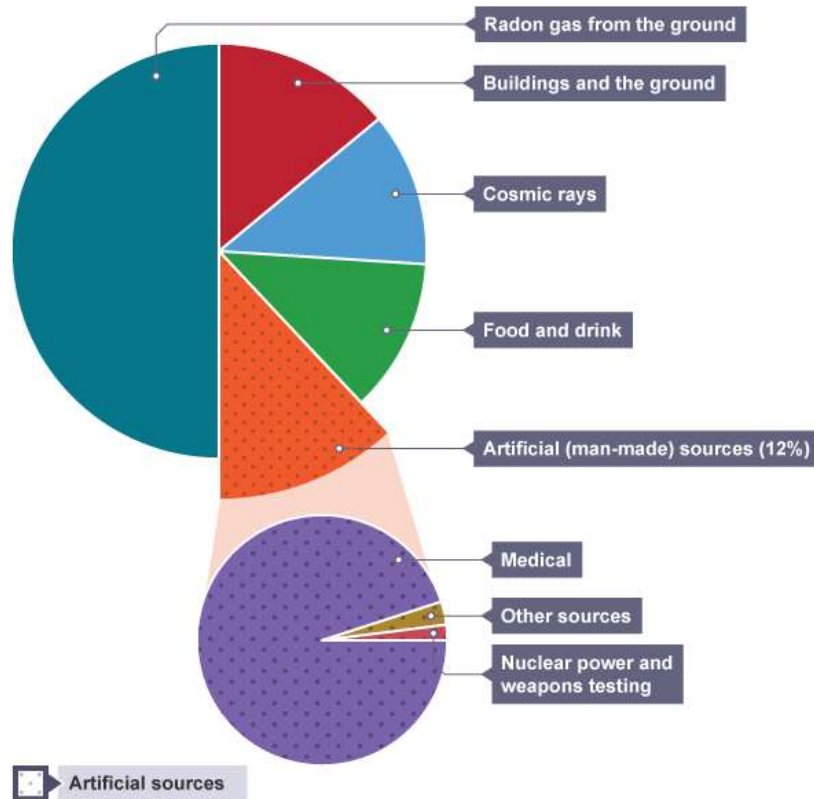
7.9 Detecting Radioactivity

7.9 know that photographic film or a Geiger-Müller detector can detect ionising radiations



7.10 Background Radiation

7.10 explain the sources of background (ionising) radiation from Earth and space



Eating a banana that contains radioactive potassium	0.000000098 Sv	0.000098 mSv
Exposure for cabin crew on airliners (per year)	0.0016 Sv	1.6 mSv
6 months on the International Space station	0.08 Sv	80 mSv
Highest dose to a worker during Fukushima disaster	0.67 Sv	670 mSv
Typical fatal dose	10 Sv	10,000 mSv

<https://remap.jrc.ec.europa.eu/Atlas.aspx>