Chapter 7: Radioactivity 1

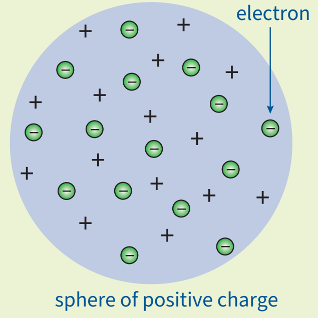
Knowledge organiser

Dalton's model

John Dalton thought the atom was a neutral solid sphere you cannot divide into smaller parts.

Plum pudding model

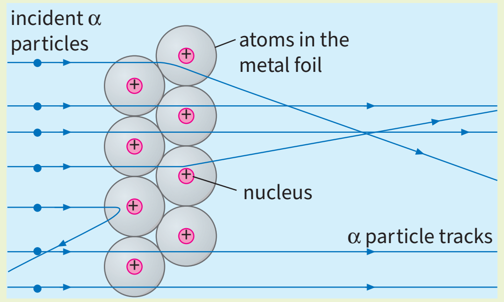
The discovery of negatively charged electrons led to the plum pudding model – a cloud of positive charge with electrons embedded in it.



Alpha scattering experiment

Positively charged alpha particles were fired at a thin sheet of gold foil.

- Most went straight through
- Some were deflected by small amounts
- 1 in 10 0000 deflected through large angles



Nuclear model

To explain the results, scientists deduced that there is a small positively charged nucleus at the centre of the atom where most of the mass is concentrated. The negative electrons orbit the nucleus.

Bohr's model

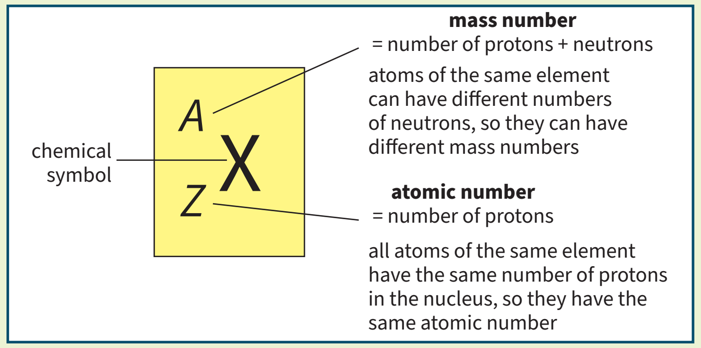
Bohr suggested the electrons orbit at specific distances called energy levels.

Basic structure of an atom

The nucleus, which is 10 000 times smaller than the radius of the atom, consists of two particles:

- positively charged protons
- neutrons which are neutral

An atom is uncharged overall and has equal numbers of protons and electrons.



Isotopes are atoms of the same element, with the same number of protons but a different numbers of neutrons.

Radioactive decay

Radioactive decay is when nuclear radiation is emitted by unstable atomic nuclei so that they become more stable. It is a *random* process. This radiation can knock electrons out of atoms in a process called **ionisation**.

Type of radiation	Change in the nucleus	Ionising power	Range in air	Stopped by	Decay equation
α alpha particle (two protons and two neutrons)	nucleus loses two protons and two neutrons	highest ionising power	travels a few centimetres in air	stopped by a sheet of paper	${}^{A}_{Z}X \rightarrow {}^{(A-4)}_{(Z-2)}Y + {}^{4}_{2}\alpha$
β beta particle (fast-moving electron)	a neutron changes into a proton and an electron	high ionising power	travels ≈ 1 m in air	stopped by a few millimetres of aluminium	${}^{A}_{Z}X \rightarrow {}^{A}_{(Z+1)}Y + {}^{0}_{-1}\beta$
γ gamma radiation (short-wavelength, high-frequency EM radiation)	some energy is transferred away from the nucleus	low ionising power	virtually unlimited range in air	stopped by several centimetres of thick lead or metres of concrete	${}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$

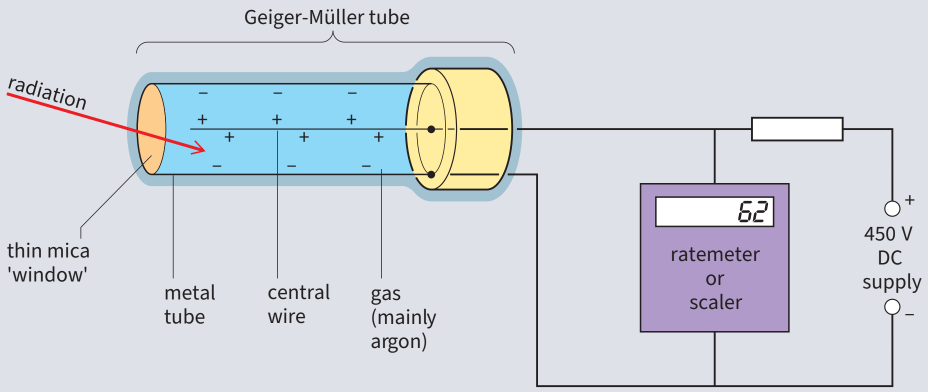
Activity and count rate

The **activity** of a radioactive source is the rate of decay of an unstable nucleus, measured in becquerel (Bq).

1 Bq = 1 decay per second

Detectors (e.g., **Geiger-Müller tubes**) record a **count rate** (number of decays detected per second).

$$\text{count rate after } n \text{ half-lives} = \frac{\text{initial count rate}}{2^n}$$



Half-life

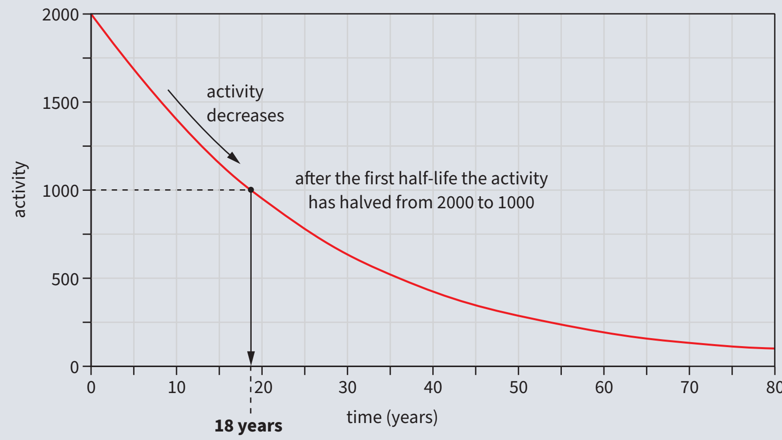
The **half-life** of a radioactive source is the time

- for half the number of unstable nuclei in a sample to decay
- for the count rate or activity of a source to halve.

The half-life of a source can be found from a graph of its count rate or activity against time.

To find the reduction in activity after a given number of half-lives:

1. calculate the activity after each half-life
2. subtract the final activity from the original activity.



The time taken for the activity to halve is 18 years. This is the half-life of this substance.

(HT only) Net decline can be given as a ratio: $\textit{net daecline} = \frac{\text{reduction in activity}}{\text{original activity}}$

Chapter 7: Radioactivity 2

Knowledge organiser

Ionising radiation

Living cells can be damaged or killed by ionising radiation.

The risk depends on the half-life of the source and the type of radiation.

Alpha radiation is very dangerous inside the body because it affects all the surrounding tissue. Outside the body it only affects the skin and eyes because it cannot penetrate further.

Beta and gamma radiation are dangerous outside and inside the body because they can penetrate into tissues.

Radiation dose

Radiation dose, measured in sievert (Sv), measures the health risk of exposure to radiation. It depends on the type and amount of radiation.

Background radiation

Background radiation is radiation that is around us all the time. It comes from:

- natural sources like rocks and cosmic rays
- nuclear weapons and nuclear accidents.

Background radiation is always present but the levels are higher in some locations and in some jobs.

Nuclear waste

When fuel rods are removed from the reactor, they are stored in large tanks in water for up to a year until they cool down.

Machines are then used to open up fuel rods and extract the unused plutonium and uranium. Any material that is left then has to be stored securely as they have lots of radioactive isotopes with long half-lives. This is done to prevent radioactive contamination.

Irradiation versus contamination

irradiation	when an object is exposed to nuclear radiation	cause harm through ionisation	prevented by shielding, removing, or moving away from the source of radiation
contamination	when atoms of a radioactive material are on or in an object		object remains exposed to radiation as long as it is contaminated contamination can be very difficult to remove

Nuclear radiation in medicine

Exploration of internal organs

Gamma-emitting **tracers** are injected or swallowed by a patient. Gamma cameras can then create an image showing where the tracer has gone.

The half-life of the tracer must be short enough so that most of the nuclei will decay shortly after the image is taken to limit the patient's radiation dose (normally about six hours).

Control or destruction of unwanted tissue

1 Narrow beams of gamma radiation can be focused on tumour cells to destroy them. Gamma is used because it can penetrate tumours from outside the body.

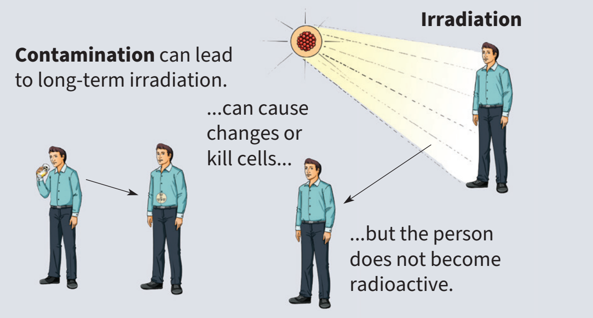
2 Beta- or gamma-emitting implants can be surgically placed inside (or next to) tumours. Their half-lives must be long enough to be effective, but short enough that it does not continue to irradiate the patient after treatment.

Protection against irradiation and contamination

You can protect against irradiation and contamination by:

- maintaining a distance from the radiation source
- limiting time near the source
- shielding from the radiation.

Studies on the effects of radiation should be published, shared with other scientists, and checked by **peer review** as they are important for human health.



Nuclear fission

Nuclear fission is when a large unstable nucleus absorbs an extra neutron and splits into two smaller nuclei of roughly equal size.

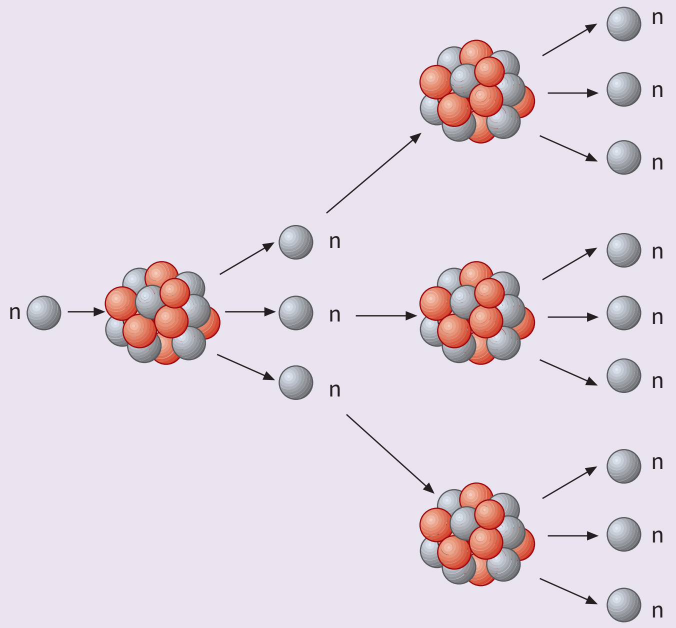
During nuclear fission:

- gamma radiation is emitted and energy is released
- two or three neutrons are emitted that can go on to cause a **chain reaction**.

The chain reaction in a power station reactor is controlled by absorbing neutrons.

Nuclear explosions are uncontrolled chain reactions.

On rare occasions an unstable nucleus splits apart without absorbing a neutron. This is called **spontaneous fission**.



Nuclear fusion

Nuclear fusion is when two light nuclei join to make a heavier one.

Some of the mass is converted to energy and transferred as radiation.

Nuclear fusion in the sun's core releases energy. A fusion reactor has to be at a very high temperature so the nuclei can overcome their repulsion.

Nuclear fusion in the future

Future fusion reactors could meet energy needs for a growing population. This is because:

- The fuel for fusion reactors is easily available as heavy hydrogen is naturally present in sea water.
- The product, helium, is an unreactive gas and non-radioactive so is harmless.
- The energy released could be used to generate electricity in the future.

Key terms

Make sure you can write a definition for these key terms.

atom alpha activity atomic number background radiation beta chain reaction contamination count rate electron fission fusion gamma Geiger-Müller tube half-life ionisation irradiation isotope mass number net decline neutron plum pudding model proton peer review radiation dose radioactive decay spontaneous tracer

Chapter 7: Radioactivity

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P7 questions		Answers
1	Describe the basic structure of an atom.	Put paper here	nucleus containing protons and neutrons, around which electrons orbit in fixed energy levels/shells
2	Describe the plum pudding model of the atom.		sphere of positive charge with negative electrons embedded in it
3	What charges do protons, neutrons, and electrons carry?	Put paper here	protons = positive, neutrons = no charge, electrons = negative
4	Why do atoms have no overall charge?		equal numbers of positive protons and negative electrons
5	What is the radius of an atom?		around 1×10^{-10} m
6	What is ionisation?	Put paper here	process which adds or removes electrons from an atom
7	What is the mass number of an element?		number of protons + number of neutrons
8	Which particle do atoms of the same element always have the same number of?		protons
9	What are isotopes?	Put paper here	atoms of the same element (same number of protons) with different numbers of neutrons
10	What were the two main conclusions from the alpha particle scattering experiment?		• most of the mass of an atom is concentrated in the nucleus • nucleus is positively charged
11	What are the three types of nuclear radiation?	Put paper here	alpha, beta, and gamma
12	Which type of nuclear radiation is the most ionising?		alpha
13	What is the range in air of alpha, beta, and gamma radiation?	Put paper here	a few cm, 1 m, and unlimited, respectively
14	What are the equation symbols for alpha and beta particles?		${}^{4}_{2}\alpha$ and ${}^{0}_{-1}\beta$
15	What is meant by the half-life of a radioactive source?	Put paper here	time taken for half the unstable nuclei to decay or the time taken for the count rate to halve
16	What is radioactive contamination?		unwanted presence of substances containing radioactive atoms on or in other materials
17	Where does background radiation come from?	Put paper here	rocks, cosmic rays, fallout from nuclear weapons testing, nuclear accidents
18	Why are gamma-emitting sources used for medical tracers and imaging?		gamma rays pass through the body without causing much damage to cells
19	What is nuclear fusion?	Put paper here	when two light nuclei join to make a heavier one
20	How does nuclear fission occur?		an unstable nucleus absorbs a neutron, it splits into two smaller nuclei, and emits two or three neutrons plus gamma rays