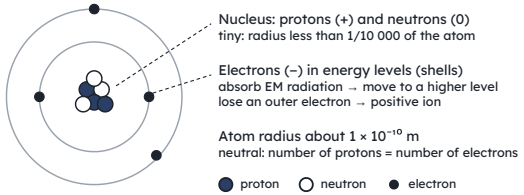
4.4 Atomic structure

THE ATOM



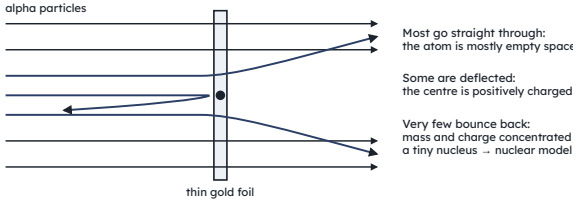
ISOTOPES AND IONS

- Atoms of the same element have the same number of protons (**atomic number**).
- **Mass number** = protons + neutrons.
- **Isotopes:** atoms of the same element with different numbers of neutrons.
- Atoms that lose outer electrons become **positive ions**.

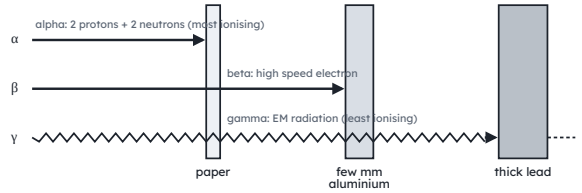
DEVELOPING THE MODEL OF THE ATOM

- Tiny indivisible spheres → **plum pudding** (ball of positive charge with electrons embedded) after the electron was discovered.
- Alpha scattering → **nuclear model** (mass concentrated in a small positive nucleus).
- Bohr: electrons orbit at specific distances. Later: protons, then Chadwick's neutron.
- New evidence changes models.

ALPHA SCATTERING



NUCLEAR RADIATION

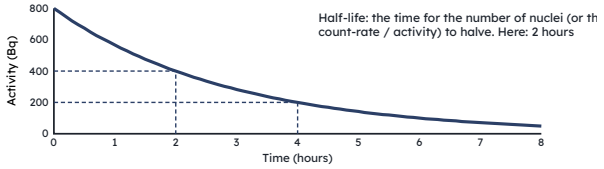


Type	What it is · range in air · ionising
α **alpha**	2 protons + 2 neutrons (helium nucleus) · a few cm · strongly
β **beta**	high speed electron from the nucleus (neutron → proton) · about 1 m · moderately
γ **gamma**	EM radiation from the nucleus · large distances · weakly

NUCLEAR EQUATIONS

- Alpha: $^{219}_{86}Rn \rightarrow {}^{215}_{84}Po + {}^{4}_{2}He$ (mass −4, atomic number −2)
- Beta: $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ (mass same, atomic number +1)
- Gamma: no change to mass or charge. A neutron can also be emitted.

HALF-LIFE

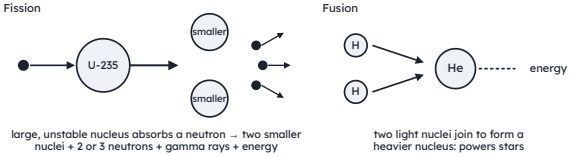


- Decay is **random**. **Activity**: rate of decay, in becquerel (Bq). **Count-rate**: decays recorded each second by a detector (e.g. Geiger-Muller tube).
- (Higher) Net decline: after n half-lives, $(½)^n$ of the original remains.

HAZARDS

- **Contamination:** unwanted presence of materials containing radioactive atoms on other materials. **Irradiation:** exposure to radiation; the object does not become radioactive.
- Results about radiation risks should be shared and **peer reviewed**.
- (PO) **Background radiation**: rocks, cosmic rays, fallout from weapons tests and nuclear accidents. Dose measured in **sieverts (Sv)**.
- (PO) Uses: tracers (short half-life, gamma), radiotherapy; weigh benefits against risks.

FISSION AND FUSION (PO)



- **Fission:** splitting of a large and unstable nucleus (e.g. uranium or plutonium) into two smaller nuclei, roughly equal in size, emitting 2–3 neutrons and gamma rays. A chain reaction is controlled in a reactor.
- **Fusion:** joining of two light nuclei to form a heavier nucleus; some mass may be converted into the energy of radiation.

EXAM TIPS

- Alpha is most ionising but least penetrating; gamma the opposite.
- Short half-life for medical tracers; gamma passes out of the body.

MODEL EXPLANATIONS (GRADE 7+ ANSWERS)

Explain why the plum pudding model was replaced.
A few alpha particles were deflected through large angles or bounced back. This showed the mass and positive charge are concentrated in a tiny nucleus. The plum pudding model has positive charge spread out, so it predicted that all the alpha particles would pass straight through.

Explain why gamma sources are used as medical tracers rather than alpha sources. (Physics only)
Gamma passes out of the body to the detector; alpha would be absorbed inside the body. Gamma is weakly ionising, so it causes less damage to cells; a short half-life means the activity falls quickly after the scan.

Explain the difference between contamination and irradiation.
Contamination is the unwanted presence of materials containing radioactive atoms on or in other materials. Irradiation is exposing an object to nuclear radiation; it does not become radioactive. Contamination is more dangerous because the source stays with you and keeps decaying; irradiation stops when you move away from the source.

4.4 Atomic structure

NUCLEAR EQUATIONS

- Alpha: $^{219}_{86}Rn \rightarrow {}^{215}_{84}Po + {}^{4}_{2}He$ (mass number −4, atomic number −2)
- Beta: $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ (mass number same, atomic number +1)
- Gamma: no change to mass or charge.
- Mass numbers and atomic numbers must balance on both sides.

KEY WORDS

Isotopes: atoms of the same element with the same number of protons but different numbers of neutrons.
Atomic number: the number of protons. Mass number: protons + neutrons.
Activity: the rate at which a source of unstable nuclei decays, in becquerel (Bq).
Count-rate: the number of decays recorded each second by a detector (e.g. Geiger-Muller tube).
Half-life: the time for the number of nuclei of the isotope in a sample to halve, or for the count-rate (or activity) to fall to half its initial level.
Contamination: the unwanted presence of materials containing radioactive atoms on other materials.
Irradiation: exposing an object to nuclear radiation; the object does not become radioactive.
Nuclear fission (PO): the splitting of a large and unstable nucleus into two smaller nuclei, roughly equal in size.
Nuclear fusion (PO): the joining of two light nuclei to form a heavier nucleus.

WORKING SCIENTIFICALLY

- Radioactive decay is random: measure count-rate over a longer time and subtract background radiation.
- Half-life from a graph: read the time for the activity to fall to half; repeat from another starting value.
- Peer review checks findings on radiation risk before they're accepted.

MISCONCEPTIONS

× **Irradiated food becomes radioactive.**	✓ Irradiation doesn't make things radioactive; contamination is the problem.
× **Gamma is the most dangerous everywhere.**	✓ Inside the body, alpha is most dangerous because it's most ionising.
× **Half-life is half the time a sample lasts.**	✓ It's the time for the activity (or number of nuclei) to halve.

AIM FOR GRADE 7+

- Balance nuclear equations: mass and atomic numbers must add up on both sides.
- Choose a medical isotope: type of radiation and half-life, with reasons.
- Explain how the model of the atom changed with new evidence.

COMMAND WORDS

State	a short answer, no explanation
Describe	say what happens, in order
Explain	say what and why: use "because" and "so"
Calculate	equation, substitution, answer, unit
Evaluate	both sides, then a justified conclusion

QUICK-FIRE QUIZ: COVER THE ANSWERS

Radius of an atom?	**About 1×10^{-10} m**
Most penetrating radiation?	**Gamma**
Most ionising radiation?	**Alpha**
Who discovered the neutron?	**James Chadwick**
Fusion joins what?	**Two light nuclei → a heavier nucleus**
Half-life of a sample: random or predictable?	**Each decay is random; half-life is predictable**

UNITS AND PREFIXES

giga (G)	$\times 10^{9}$
mega (M)	$\times 10^{6}$
kilo (k)	$\times 10^{3}$
centi (c)	$\times 10^{-2}$
milli (m)	$\times 10^{-3}$
micro (μ)	$\times 10^{-6}$
nano (n)	$\times 10^{-9}$

Convert to the base unit (m, kg, s, J, W) before you calculate.

PRACTICAL LANGUAGE

Accurate: close to the true value. **Precise:** measurements close to each other. **Repeatable:** same person, same method, similar results. **Reproducible:** similar results by another person or method.
Resolution: smallest change an instrument can show.
Random error: unpredictable scatter; reduce by repeating and averaging. **Systematic error:** every reading out by the same amount, e.g. a **zero error**.