

Unstable nuclei, decay and half-life

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Worksheet answers

Each answer gives the reasoning, the substitution and the result with units in bold. For half-life questions the number of half-lives is shown first and then the halving steps. Keep intermediate values unrounded and round only the final answer.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS1-8, GCSE P4

Problem 1 Which radiation?

1. **Alpha.**
2. **Beta.**
3. **Gamma.**
4. **Alpha:** it ionises most strongly because it has a large mass and a +2 charge.

Problem 2 Inside a carbon-14 atom

1. The atomic number is the number of protons: **6**.
2. Neutrons = mass number – atomic number = $14 - 6 = \mathbf{8}$.
3. A neutral atom has equal numbers of protons and electrons: **6**.
4. They have the **same number of protons** (6) but different numbers of neutrons (6 and 8).

Problem 3 Halving the activity

1. One half-life: $640 \div 2 = \mathbf{320\ Bq}$.
2. Two half-lives: **160 Bq**.
3. $6.0 \div 2.0 = 3$ half-lives: $640 \rightarrow 320 \rightarrow 160 \rightarrow \mathbf{80\ Bq}$.

Problem 4 Units of radiation

1. $3.2 \times 1000 = \mathbf{3200\ Bq}$.
2. $1.5 \times 24 = \mathbf{36\ hours}$.
3. $0.5 \times 1000 = \mathbf{500\ \mu Sv}$.
4. $45 \div 60 = \mathbf{0.75\ hours}$.

Problem 5 Handling sources safely

1. Keep the **time** of exposure short, keep as far away as possible, point the source away from people, and never touch it or eat or drink nearby.
2. Lead **absorbs the radiation**, so the dose to people near the box is reduced.

3. **Irradiation** is exposure to radiation from an outside source. **Contamination** is when radioactive atoms get on or inside the body.

Problem 6 Subtracting the background

- Any two: radon gas, rocks and soil, cosmic rays, food, medical scans.
- Corrected rate = $58 - 12 = \mathbf{46 \text{ counts per minute}}$.
- The detector also counts background radiation, so subtracting it gives only the counts **from the source**.

Problem 7 An alpha decay equation

- $210 - 4 = \mathbf{206}$.
- $84 - 2 = \mathbf{82}$.
- Lead-206**.

Problem 8 Beta decay equations

- Mass number stays **24**; atomic number $11 + 1 = \mathbf{12}$, so the new nucleus is **magnesium-24**.
- Mass number **131**; atomic number $53 + 1 = \mathbf{54}$.
- A **neutron changes into a proton** and a fast electron (the beta particle) is emitted.

Problem 9 Half-life from a table

- The rate falls from 800 to 400 in 20 minutes, so the half-life is **20 minutes** (200 at 40 minutes agrees).
- $60 \div 20 = 3$ half-lives: $800 \rightarrow 400 \rightarrow 200 \rightarrow \mathbf{100 \text{ counts per minute}}$.
- $800 \rightarrow 400 \rightarrow 200 \rightarrow 100 \rightarrow 50$ takes 4 half-lives: $4 \times 20 = \mathbf{80 \text{ minutes}}$.

Problem 10 Reading a decay graph

- The activity falls from 1600 Bq to 800 Bq at 8 days, so the half-life is **8 days**.
- 16 days is 2 half-lives: $1600 \rightarrow 800 \rightarrow \mathbf{400 \text{ Bq}}$.
- At 12 days the graph reads about **570 Bq**, between 800 Bq at 8 days and 400 Bq at 16 days ($1600 \times 0.5^{1.5} = 566 \text{ Bq}$).
- Each half-life removes only half of what is left, so some nuclei always remain and the activity gets smaller without reaching zero.

Problem 11 Which radiation does it emit?

- Subtract 10: **400, 398, 130 and 2** counts per minute.
- No alpha**: paper does not change the count rate (400 to 398), and alpha would be stopped by paper.
- Beta and gamma**. Aluminium cuts the rate from 398 to 130, which shows beta is

absorbed. The remaining 130 is absorbed by lead (2), which shows gamma.

Problem 12 Alpha inside and outside

1. Ionising radiation **knocks electrons off atoms**, producing ions.
2. Alpha travels only a few centimetres in air and cannot pass through the sealed case or the skin, so it is safe outside the body.
3. Inside the body all of the strongly ionising alpha energy is absorbed by nearby cells, causing serious **damage**.

Problem 13 Choosing an isotope

1. The **gamma emitter with a 6-hour half-life**: gamma passes out of the body to be detected, and the short half-life means it soon decays away.
2. The **430-year alpha emitter**: alpha is stopped by the casing and the source lasts for decades.
3. A tracer should leave the patient's body quickly with little dose, while a smoke detector must keep working for many years without replacement.

Problem 14 Balancing fission

1. Left: $1 + 235 = 236$. Right: $141 + 92 + 3 = 236$, so the mass numbers **balance**.
2. Left: $0 + 92 = 92$. Right: $56 + 36 + 0 = 92$, so the atomic numbers **balance**.
3. The neutrons released split other nuclei, which release more neutrons, so the reaction **keeps itself going and speeds up**.
4. Control rods **absorb neutrons** so the reaction rate stays steady.

Problem 15 Fission or fusion?

1. Fission: **large nuclei** such as uranium-235. Fusion: **light nuclei** such as hydrogen isotopes.
2. Fission is used in **nuclear power stations**. Fusion occurs in **the Sun and other stars**.
3. The nuclei are positively charged and repel one another, so they need very high speed (very high temperature) to get close enough to join.

Problem 16 A hospital dose

1. 09:00 to 03:00 is 18 h = 3 half-lives. $600 \rightarrow 300 \rightarrow 150 \rightarrow$ **75 MBq**.
2. $600 \div 2^n$ below 10: $n = 5$ gives 18.75, $n = 6$ gives 9.375 MBq, so **6 half-lives**.
3. $6 \times 6.0 = 36$ hours after 09:00, which is **21:00 on the next day**.
4. The activity (and so the dose to the patient) falls quickly after the scan, with little long-term radiation.

Problem 17 Dating an old wooden bowl

1. $3.75 \div 15.0 = \mathbf{1/4}$ (0.25).
2. $1/4 = (1/2)^2$, so **2 half-lives**.
3. $2 \times 5730 = \mathbf{11\ 460\ years}$.
4. $7.5 \div 15.0 = 1/2$, so 1 half-life: **5730 years**.
5. Decay is random so counts fluctuate, and the original ratio in the living wood may have changed over time.

Problem 18 Spot the errors

1. After two half-lives **one quarter** remains; the activity falls by half each time but never reaches exactly zero.
2. In alpha decay the atomic number goes down by **2**, and the mass number by 4.
3. Gamma rays only pass through the food; they do not make it radioactive. This is irradiation, not contamination, so the food is **not** radioactive afterwards.

Problem 19 Radiographer's dose

1. $4.0 \times 1800 = 7200\ \mu\text{Sv} = \mathbf{7.2\ mSv}$.
2. $7.2 \div 20 \times 100 = \mathbf{36\ \%}$ of the limit.
3. 20 mm = 4 layers of 5 mm: $4.0 \rightarrow 2.0 \rightarrow 1.0 \rightarrow 0.50 \rightarrow \mathbf{0.25\ \mu\text{Sv per hour}}$.
4. $0.25 \times 1800 = \mathbf{450\ \mu\text{Sv}}$.
5. Spend less time near the source and stand further away; wear a dosimeter badge to monitor the dose.

Problem 20 Mass turned into energy

1. $E = mc^2 = 1.0 \times 10^{-3} \times (3.0 \times 10^8)^2 = 1.0 \times 10^{-3} \times 9.0 \times 10^{16} = \mathbf{9.0 \times 10^{13}\ J}$.
2. $t = E \div P = 9.0 \times 10^{13} \div 1.0 \times 10^9 = \mathbf{9.0 \times 10^4\ s}$.
3. $90\ 000 \div 3600 = \mathbf{25\ hours}$.
4. Because c^2 is enormous, a tiny loss of mass releases a huge amount of energy, so the fuel's mass hardly changes.