Nuclear equations

6.4.2.2 · Physics · revision notes

How to write and balance nuclear equations for alpha and beta decay, and how alpha, beta and gamma emission change the mass and charge of a nucleus. Expect 'complete the equation' questions and questions asking you to identify the type of decay from the numbers.

Key facts

- Alpha $^{4}_{2}\mathrm{He}$: mass number − 4, atomic number − 2
- Gamma $^{0}_{0}\gamma$: no change to mass number or atomic number
- Top numbers balance; bottom numbers balance
- Beta $^{0}_{-1}\mathrm{e}$: mass number unchanged, atomic number + 1
- Neutron $^{1}_{0}\mathrm{n}$: mass number − 1, atomic number unchanged
- New atomic number = new element

Notes

Symbols in nuclear equations

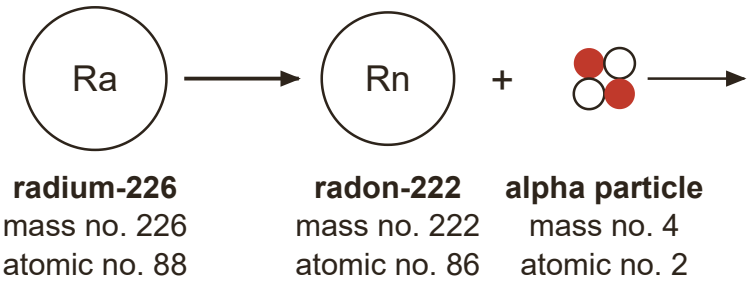
- Each nucleus is written as $^{A}_{Z}\mathrm{X}$: A is the mass number and Z is the atomic number (its charge).
- Alpha particle: $^{4}_{2}\mathrm{He}$ (sometimes written $^{4}_{2}\alpha$).
- Beta particle: $^{0}_{-1}\mathrm{e}$ (sometimes written $^{0}_{-1}\beta$). Mass number 0, charge −1.
- Gamma ray: $^{0}_{0}\gamma$. Neutron: $^{1}_{0}\mathrm{n}$

Balancing rules

- The mass numbers (top numbers) add up to the same total on both sides of the arrow.
- The atomic numbers (bottom numbers) add up to the same total on both sides.
- If the atomic number changes, the element changes. The question gives the symbol of the new element.

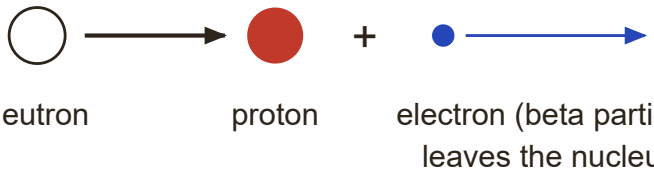
What each type of decay does

- **Alpha decay**: mass number down by 4, atomic number down by 2. Both the mass and the charge of the nucleus decrease. Example: $^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$



Alpha decay: mass numbers 226 = 222 + 4 and atomic numbers 88 = 86 + 2.

- **Beta decay**: mass number unchanged, atomic number up by 1. The mass does not change but the charge increases, because a neutron has become a proton. Example: $^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}\mathrm{e}$



Beta decay: a neutron becomes a proton plus an electron. Mass number unchanged; atomic number up by 1.

- **Gamma emission**: no change to the mass or the charge of the nucleus. The nucleus just gets rid of energy, often straight after an alpha or beta decay.
- **Neutron emission**: the mass number falls by 1 and the atomic number stays the same, so the nucleus becomes a different isotope of the same element. Grade 7+ only

How to answer each type of question

Describe how a decay changes the nucleus 2 marks Grade 5

1. For each decay, say what happens to the mass (mass number).
2. Then say what happens to the charge (atomic number).

Example. Compare the effect on a nucleus of emitting an alpha particle and emitting a gamma ray.

Model answer. Alpha: the mass number decreases by 4 and the atomic number (charge) decreases by 2 (1). Gamma: there is no change to the mass or the charge of the nucleus (1).

Complete a nuclear equation

2 marks | Grade 5

1. Write in the full symbol for the particle emitted, with both numbers.
2. Balance the top numbers.
3. Balance the bottom numbers (remember beta counts as −1).
4. Use the symbol the question gives for the new nucleus.

Example. Polonium-210 decays by emitting an alpha particle. The equation for the decay is
$^{210}_{84}\mathrm{Po} \rightarrow {}^{a}_{b}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$
Determine the values of a and b.

Model answer.

a = 210 − 4 = 206 (1)

b = 84 − 2 = 82 (1)

Identify the type of decay

2 marks | Grade 7

1. Find the change in mass number and in atomic number.
2. Work out the mass number and charge of the missing particle.
3. Name it and give the numbers as your reason.

Example. Thorium-234 decays to protactinium-234:
$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + \mathrm{X}$
Identify X. Explain how you know.

Model answer. X is a beta particle, $^{0}_{-1}\mathrm{e}$ (1). The mass number stays at 234 but the atomic number goes up by 1, so X has mass number 0 and charge −1 (1).

Work through a chain of decays

3 marks | Grade 8

1. Apply each decay in the order given, writing down the new numbers each time.
2. Alpha: − 4 and − 2. Beta: no change and + 1.
3. Check whether the final atomic number matches the starting element.

Example. A uranium-238 nucleus, $^{238}_{92}\mathrm{U}$, emits an alpha particle. The nucleus formed then emits two beta particles, one after the other.
Determine the mass number and atomic number of the final nucleus.

Model answer. After the alpha decay: mass number 234, atomic number 90 (1). After two beta decays: mass number still 234 (1), atomic number 90 + 2 = 92 (1). (The final nucleus is uranium-234, an isotope of the original element.)

Don’t lose marks

- Writing the beta particle as ${}^{0}_{1}\mathrm{e}$ or ${}^{1}_{0}\mathrm{e}$. It is ${}^{0}_{-1}\mathrm{e}$
- Taking 2 off the mass number in alpha decay. It is 4 off the mass number and 2 off the atomic number.
- Keeping the same element symbol after alpha or beta decay. The atomic number has changed, so the element has too.
- Thinking beta decay lowers the atomic number. It raises it by 1.

More tips

Memory tricks

- Alpha: 'minus 4, minus 2'. Beta: 'same, plus 1'. Gamma: 'no change'.
- Check every equation with two quick sums: the top numbers on each side, then the bottom numbers.
- The −1 on the beta particle is why the new nucleus goes UP by 1: the bottom numbers must still add up.

Exam technique

- Write both numbers for every particle in the equation, even if the question only asks for one.
- If a periodic table or list of elements is given, use the new atomic number to choose the symbol.
- When asked to 'describe' the change, use words too: e.g. 'the mass stays the same and the charge increases'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4 — **Recall the symbols for alpha and beta**
Alpha is ${}^{4}_{2}\mathrm{He}$ and beta is ${}^{0}_{-1}\mathrm{e}$

Grade 5 — **State how alpha decay changes a nucleus**
The mass number falls by 4 and the atomic number falls by 2.

Grade 5 — **State how beta decay changes a nucleus**
The mass number stays the same and the atomic number goes up by 1.

Grade 5 — **Explain why gamma emission changes neither number**
Gamma is electromagnetic radiation with no mass and no charge.

Grade 5 — **Complete a nuclear equation**
Make the mass numbers and the atomic numbers balance on both sides of the arrow.

Grade 7 — **Identify the decay type from an equation**
Compare the mass and atomic numbers before and after to see what was emitted.

Grade 8 — **Work through a chain of decays**
Apply several alpha and beta decays in turn to find the final nucleus.

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