Introduction

Alpha and beta particles may be represented in equations in several different ways.

Different exam boards have their own preference. For example:

Alpha	Beta
$^{4}_{2}He$	$^{0}_{-1}e$
$^{4}_{2}\alpha$	$^{0}_{-1}\beta$
$^{4}_{2}$alpha	$^{0}_{-1}$beta

Despite different ways of writing them, you need to know what each particle **is** in order to make sense of things.

Alpha particles are often called a “helium-4 nucleus” as they are identical to the nucleus of a helium-4 atom (helium’s most common isotope). They consist of **two protons** and **two neutrons**.

Beta particles come in two forms, the one indicated above is a negatively-charged version (or beta-minus particle). There is also a beta-plus form.

Both are quite surprising as, like alpha particles, they come from the nucleus of an unstable radioactive atom.

Beta-minus particles are fast-moving electrons, emitted when a neutron decays into a proton in the nucleus.

Alpha decay

When a radioactive nucleus emits an alpha particle, the decaying nucleus obviously becomes lighter as it loses four particles: two protons and two neutrons.

All alpha decay equations therefore follow this simple pattern: the atomic number (or proton number) reduces by two, the mass number reduces by four (since the nucleus loses two protons **and** two neutrons).

e.g. ${}^{219}_{86}\text{radon} \rightarrow {}^{215}_{84}\text{polonium} + {}^{4}_{2}\text{He}$

Sometimes equations will be written only with the chemical symbols of the atoms, in this case:

$${}^{219}_{86}\text{Rn} \rightarrow {}^{215}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

Notice the reduction in the atomic number from 86 to 84. The two lost protons are of course in the alpha particle (${}^{4}_{2}\text{He}$). Meanwhile, the mass number has dropped by four, from 219 to 215.

For alpha decays, you must remember that the **mass number** must drop **by four** and the atomic number **by two**.

Complete the following equations by writing in the missing numbers:

$${}^{232}_{90}\text{Th} \rightarrow {}^{\_\_}_{\_\_}\text{Ra} + {}^{4}_{2}\text{He} \qquad {}^{224}_{88}\text{Ra} \rightarrow {}^{\_\_}_{\_\_}\text{Rn} + {}^{4}_{2}\text{He}$$

$${}^{216}_{84}\text{Po} \rightarrow {}^{\_\_}_{\_\_}\text{Pb} + {}^{4}_{2}\text{He}$$

Remember to check that things make sense! Like any equation, **things must balance**. So add up the mass numbers on the right, they should equal what you began with. Do the same for the atomic numbers.

Sometimes you will be expected to balance the decay equations “going the other way”. Try these:

$${}^{\_\_}_{\_\_}\text{Bi} \rightarrow {}^{208}_{81}\text{Tl} + {}^{4}_{2}\text{He} \qquad {}^{\_\_}_{\_\_}\text{Ac} \rightarrow {}^{221}_{87}\text{Fr} + {}^{4}_{2}\text{He}$$

$${}^{\_\_}_{\_\_}\text{U} \rightarrow {}^{229}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

You may even have to tackle a **combination** of both:

$${}^{\_\_}_{92}\text{U} \rightarrow {}^{234}_{\_\_}\text{Th} + {}^{\_\_}_{2}\text{He} \qquad {}^{237}_{\_\_}\text{Np} \rightarrow {}^{\_\_}_{91}\text{Pa} + {}^{4}_{\_\_}\text{He}$$

$${}^{213}_{\_\_}\text{Po} \rightarrow {}^{\_\_}_{82}\text{Pb} + {}^{\_\_}_{\_\_}\text{He}$$

Beta decay

When a radioactive nucleus emits a beta particle, the decaying nucleus once again changes, but nowhere near as significantly as during alpha decay. As mentioned before, beta decays come in two types. At GCSE it is usual just to consider beta-minus decay.

Beta-minus decay happens when a neutron changes into a proton in the nucleus, spitting out an electron (the beta particle) in the process. This results in a more stable nucleus. Now you should know that the nucleus only contains protons and neutrons (no neutrons in the case of the lightest isotope of hydrogen). There are, of course, **no electrons in any nucleus**. It is beyond the scope of a GCSE course to go into how a neutron can change into a proton and emit an electron (beta particle). For now, just know that it can happen!

In the process of beta decay, only the tiny beta particle is emitted from the nucleus, no protons or neutrons leave. This means **the mass number of the nucleus before and after beta decay remains exactly the same**. This is clearly worth remembering!

For beta decays, you must remember that **mass number** is **unchanged** after the decay.

Meanwhile, since a neutron changes into a proton, the proton number (atomic number) must increase by one. Again, you need to remember this – and it will always be the same for beta-minus decay.

e.g. $^{14}_{6}\text{carbon} \rightarrow {}^{14}_{7}\text{nitrogen} + {}^{0}_{-1}\text{e}$ or $^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e}$

Notice that the mass number (top row) is unchanged and the atomic number (bottom row) goes up by one. The beta particle (electron) is shown as having a **negative** proton number because it has the opposite electric charge. As with alpha decay equations, notice that the top row adds up to the same thing on both sides of the equation.

For beta(-minus) decays, remember only that the **atomic (proton) number increases by one** after the decay.

Complete the following equations by writing in the missing numbers:

$^{64}_{29}\text{Cu} \rightarrow {}^{\_\_}_{\_\_}\text{Ni} + {}^{0}_{-1}\text{e}$ $^{25}_{11}\text{Na} \rightarrow {}^{\_\_}_{\_\_}\text{Mg} + {}^{0}_{-1}\text{e}$

$^{56}_{25}\text{Mn} \rightarrow {}^{\_\_}_{\_\_}\text{Fe} + {}^{0}_{-1}\text{e}$

As with alpha decay equations, always check that the mass numbers and proton numbers add up on the top and bottom rows.

Now try these:

$${}^{\_\_}_{\_\_}\mathrm{Be} \rightarrow {}^{10}_{5}\mathrm{B} + {}^{0}_{-1}\mathrm{e} \qquad {}^{\_\_}_{\_\_}\mathrm{F} \rightarrow {}^{20}_{10}\mathrm{Ne} + {}^{0}_{-1}\mathrm{e}$$

$${}^{\_\_}_{\_\_}\mathrm{Br} \rightarrow {}^{83}_{36}\mathrm{Kr} + {}^{0}_{-1}\mathrm{e}$$

And then these:

$${}^{125}_{\_\_}\mathrm{Sb} \rightarrow {}^{\_\_}_{52}\mathrm{Te} + {}^{0}_{-1}\mathrm{e} \qquad {}^{\_\_}_{87}\mathrm{Fr} \rightarrow {}^{222}_{\_\_}\mathrm{Ra} + {}^{\_\_}_{-1}\mathrm{e}$$

$${}^{237}_{\_\_}\mathrm{U} \rightarrow {}^{\_\_}_{93}\mathrm{Np} + {}^{\_\_}_{\_\_}\mathrm{e}$$

Finally, write the **full decay equations** for the following:

1. ${}^{222}_{88}$Ra into Rn by alpha decay.

2. ${}^{199}_{79}$Au into Hg by beta decay.

3. ${}^{215}_{83}$Bi into Po by beta decay, which then, in turn, alpha decays into Pb.

Answers

Alpha:

$^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^{4}_{2}He$ $^{224}_{88}Ra \rightarrow ^{220}_{86}Rn + ^{4}_{2}He$ $^{216}_{84}Po \rightarrow ^{212}_{82}Pb + ^{4}_{2}He$

$^{212}_{83}Bi \rightarrow ^{208}_{81}Tl + ^{4}_{2}He$ $^{225}_{89}Ac \rightarrow ^{221}_{87}Fr + ^{4}_{2}He$ $^{233}_{92}U \rightarrow ^{229}_{90}Th + ^{4}_{2}He$

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$ $^{237}_{93}Np \rightarrow ^{233}_{91}Pa + ^{4}_{2}He$ $^{213}_{84}Po \rightarrow ^{209}_{82}Pb + ^{4}_{2}He$

Beta:

$^{64}_{29}Cu \rightarrow ^{64}_{30}Ni + ^{0}_{-1}e$ $^{25}_{11}Na \rightarrow ^{25}_{12}Mg + ^{0}_{-1}e$ $^{56}_{25}Mn \rightarrow ^{56}_{26}Fe + ^{0}_{-1}e$

$^{10}_{4}Be \rightarrow ^{10}_{5}B + ^{0}_{-1}e$ $^{20}_{9}F \rightarrow ^{20}_{10}Ne + ^{0}_{-1}e$ $^{83}_{35}Br \rightarrow ^{83}_{36}Kr + ^{0}_{-1}e$

$^{125}_{51}Sb \rightarrow ^{125}_{52}Te + ^{0}_{-1}e$ $^{222}_{87}Fr \rightarrow ^{222}_{88}Ra + ^{0}_{-1}e$ $^{237}_{92}U \rightarrow ^{237}_{93}Np + ^{0}_{-1}e$

Unguided:

1. $^{222}_{88}Ra \rightarrow ^{218}_{86}Rn + ^{4}_{2}He$

2. $^{199}_{79}Au \rightarrow ^{199}_{80}Hg + ^{0}_{-1}e$

3. $^{215}_{83}Bi \rightarrow ^{215}_{84}Po + ^{0}_{-1}e$ then $^{215}_{84}Po \rightarrow ^{211}_{82}Pb + ^{4}_{2}He$

Teaching notes

This worksheet is designed to give you further practice on the completion and writing of both alpha and beta radioactive decay equations. It assumes you have been given a reasonable introduction into both processes by your teacher or through personal study using a textbook or website.

The last page is a compilation of the practice equations from the worksheet.

Complete the following equations.

${}^{232}_{90}\text{Th} \rightarrow {}^{\_\_}_{\_\_}\text{Ra} + {}^{4}_{2}\text{He}$

${}^{224}_{88}\text{Ra} \rightarrow {}^{\_\_}_{\_\_}\text{Rn} + {}^{4}_{2}\text{He}$

${}^{216}_{84}\text{Po} \rightarrow {}^{\_\_}_{\_\_}\text{Pb} + {}^{4}_{2}\text{He}$

${}^{64}_{29}\text{Cu} \rightarrow {}^{\_\_}_{\_\_}\text{Ni} + {}^{0}_{-1}\text{e}$

${}^{25}_{11}\text{Na} \rightarrow {}^{\_\_}_{\_\_}\text{Mg} + {}^{0}_{-1}\text{e}$

${}^{56}_{25}\text{Mn} \rightarrow {}^{\_\_}_{\_\_}\text{Fe} + {}^{0}_{-1}\text{e}$

${}^{\_\_}_{\_\_}\text{Bi} \rightarrow {}^{208}_{81}\text{Tl} + {}^{4}_{2}\text{He}$

${}^{\_\_}_{\_\_}\text{Ac} \rightarrow {}^{221}_{87}\text{Fr} + {}^{4}_{2}\text{He}$

${}^{\_\_}_{\_\_}\text{U} \rightarrow {}^{229}_{90}\text{Th} + {}^{4}_{2}\text{He}$

${}^{\_\_}_{92}\text{U} \rightarrow {}^{234}_{\_\_}\text{Th} + {}^{\_\_}_{2}\text{He}$

${}^{237}_{\_\_}\text{Np} \rightarrow {}^{\_\_}_{91}\text{Pa} + {}^{4}_{\_\_}\text{He}$

${}^{213}_{\_\_}\text{Po} \rightarrow {}^{\_\_}_{82}\text{Pb} + {}^{\_\_}_{\_\_}\text{He}$

${}^{\_\_}_{\_\_}\text{Be} \rightarrow {}^{10}_{5}\text{B} + {}^{0}_{-1}\text{e}$

${}^{\_\_}_{\_\_}\text{F} \rightarrow {}^{20}_{10}\text{Ne} + {}^{0}_{-1}\text{e}$

${}^{\_\_}_{\_\_}\text{Br} \rightarrow {}^{83}_{36}\text{Kr} + {}^{0}_{-1}\text{e}$

${}^{125}_{\_\_}\text{Sb} \rightarrow {}^{\_\_}_{52}\text{Te} + {}^{0}_{-1}\text{e}$

${}^{\_\_}_{87}\text{Fr} \rightarrow {}^{222}_{\_\_}\text{Ra} + {}^{\_\_}_{-1}\text{e}$

${}^{237}_{\_\_}\text{U} \rightarrow {}^{\_\_}_{93}\text{Np} + {}^{\_\_}_{\_\_}\text{e}$

4. ${}^{222}_{88}\text{Ra}$ into Rn by alpha decay.

5. ${}^{199}_{79}\text{Au}$ into Hg by beta decay.

6. ${}^{215}_{83}\text{Bi}$ into Po by beta decay, which then, in turn, alpha decays into Pb