Cambridge IGCSE · Physics 0625 · Notes

The nuclear model of the atom

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What you need to know

By the end of this topic you should be able to:

1. **Describe the structure of an atom**: a small, positively charged nucleus in the middle, with negatively charged electrons moving in orbits around it.
2. **Explain how atoms become ions**: an atom that loses electrons becomes a positive ion; an atom that gains electrons becomes a negative ion.
3. **Say what the nucleus is made of**: protons and neutrons.
4. **State the relative charges**: proton $+1$, neutron 0, electron -1.
5. **Define proton number Z and nucleon number A**, and use them to work out the number of neutrons in a nucleus.
6. **Read and write nuclide notation**, ${}^{A}_{Z}\mathrm{X}$.
7. **Explain what an isotope is**, and know that one element can have several isotopes.
8. **Extended only:** describe how the scattering of alpha particles by a thin metal foil supports the nuclear model: it shows that the nucleus is very small with mostly empty space around it, that it holds most of the atom's mass, and that it is positively charged.
9. **Extended only:** describe nuclear fission (a nucleus splitting) and nuclear fusion (nuclei joining), write and balance their nuclide equations, and say in words what happens to mass and energy (no numbers).
10. **Extended only:** link the proton number to the relative charge on a nucleus, and the nucleon number to its relative mass.

Understand it

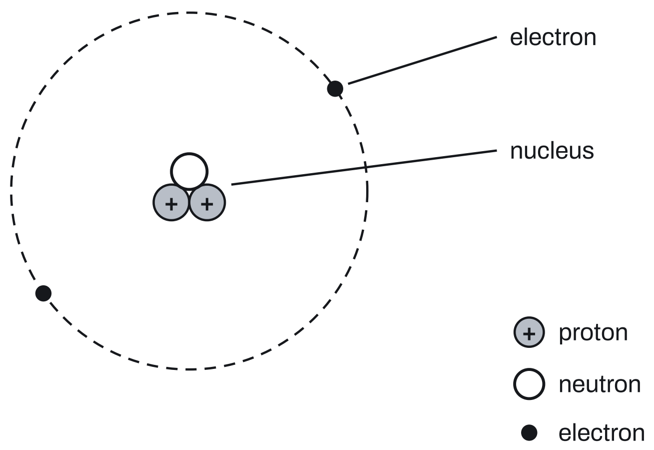
Inside an atom

Everything is made of atoms, and every atom has the same basic plan:

- a tiny **nucleus** at the centre, which is **positively charged**;
- **electrons**, which are **negatively charged**, moving in orbits around the nucleus.

The nucleus is made of two kinds of particle, **protons** and **neutrons**. Both are called **nucleons**, because they live in the nucleus.

Particle	Relative charge	Where it is	Relative mass
proton	$+1$	in the nucleus	about 1
neutron	0 (neutral)	in the nucleus	about 1
electron	-1	outside the nucleus, in orbits	almost 0 (about 2000 times lighter than a proton)



A whole atom has **no overall charge**: it has exactly as many electrons as protons, so the $+1$s and -1s cancel. The helium atom in the diagram has 2 protons ($+2$) and 2 electrons (-2). Its 1 neutron adds mass but no charge.

Ions

Protons are locked inside the nucleus, but the outer electrons can be pulled off or added. A charged atom is called an **ion**.

- **Lose electrons → positive ion.** There are now more protons than electrons. An aluminium atom (13 protons) that loses 3 electrons has 13 protons and 10 electrons, so its charge is $+3$ (written Al^{3+}).
- **Gain electrons → negative ion.** There are now more electrons than protons. A fluorine atom (9 protons) that gains 1 electron has 10 electrons, so its charge is -1 (F^-).

The nucleus does **not** change when an ion forms: an ion is never made by adding or removing protons. To turn a negative ion back into a neutral atom, it must **lose** its extra electrons.

Proton number, nucleon number and nuclide notation

Two numbers describe a nucleus:

- the **proton number** (or atomic number) Z is the number of protons. It decides which element the atom is: every carbon atom has 6 protons, every oxygen atom has 8;
- the **nucleon number** (or mass number) A is the total number of protons **and** neutrons.

So the number of neutrons is $N = A - Z$.

Nuclide notation puts both numbers on the element's symbol, nucleon number on top and proton number underneath, both on the **left**:

$$^{A}_{Z}\mathrm{X} \qquad \text{for example} \qquad ^{3}_{2}\mathrm{He}$$

$^{3}_{2}\mathrm{He}$ (the atom in the diagram) has 2 protons, 3 nucleons and $3 - 2 = 1$ neutron. A neutral atom of it has 2 electrons, the same as its protons. The top number is the **bigger** one (except for $^{1}_{1}\mathrm{H}$, where they are equal), which helps you spot a swapped pair.

A nuclide is also written with its name and nucleon number, such as "helium-3" or "He-3". The proton number is then found from the element: all helium has $Z = 2$.

The same notation is used for single particles in equations: a neutron is $^{1}_{0}\mathrm{n}$, a proton $^{1}_{1}\mathrm{p}$ (the same as a hydrogen-1 nucleus, $^{1}_{1}\mathrm{H}$), and an alpha particle is a helium nucleus, $^{4}_{2}\mathrm{He}$ or $^{4}_{2}\alpha$ (2 protons and 2 neutrons, relative charge $+2$).

Extended only: the proton number gives the nucleus's **relative charge**: Z protons of $+1$ each make $+Z$ (neutrons add nothing). The nucleon number gives its **relative mass**: each proton and neutron has a relative mass of about 1, so a nucleus has a relative mass of about A. For $^{3}_{2}\mathrm{He}$ the nucleus has relative charge $+2$ and relative mass about 3.

Isotopes

Atoms of the same element always have the same number of protons, but they can have different numbers of neutrons. These different forms are **isotopes**:

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isotopes are atoms of the **same element** (same proton number) with **different numbers of neutrons** (so different nucleon numbers).

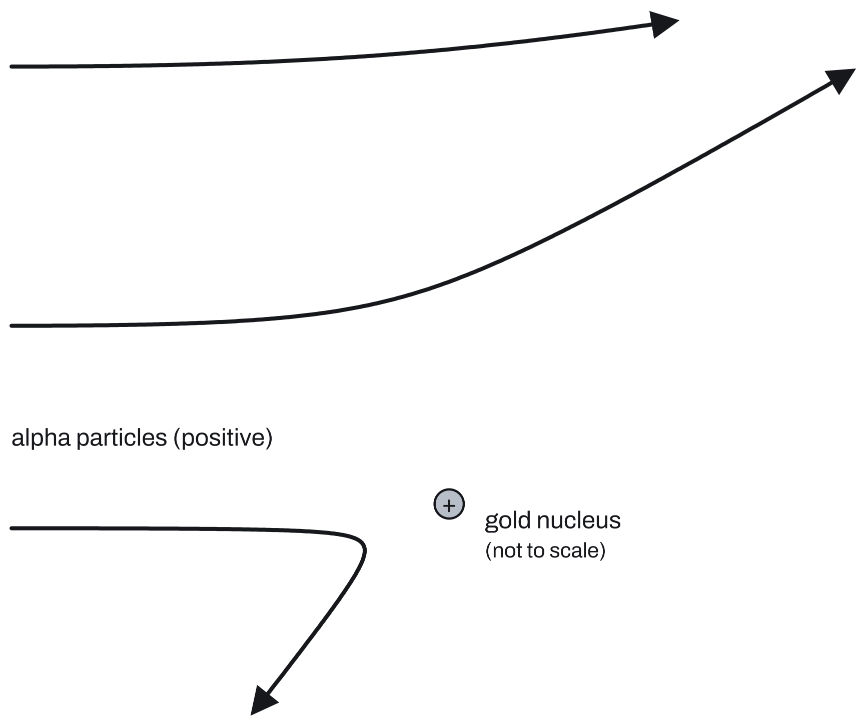
Phosphorus-31 ($^{31}_{15}\mathrm{P}$) and phosphorus-32 ($^{32}_{15}\mathrm{P}$) are isotopes: both have 15 protons, but phosphorus-31 has 16 neutrons and phosphorus-32 has 17. Many elements have more than one isotope.

- Isotopes of one element have the same number of electrons (in a neutral atom), so they behave the same way chemically.
- **Extended only:** their nuclei have the **same charge** ($+Z$) but **different masses** (about A).
- Being an isotope does not mean being radioactive. Phosphorus-31 is stable; phosphorus-32 is radioactive. An unstable isotope often has **too many neutrons** compared with the element's stable isotopes.
- Two nuclides with the **same nucleon number but different proton numbers** (such as $^{32}_{15}\mathrm{P}$ and $^{32}_{16}\mathrm{S}$) are **not** isotopes: they are different elements.

Evidence for the nucleus: alpha-particle scattering

Extended only. How do we know the positive charge is squeezed into a tiny nucleus? The evidence comes from firing a beam of **alpha particles** (small, fast, **positive** particles) at a very thin sheet of gold (or another metal) in a vacuum, and counting where they go:

1. **Almost all go straight through**, with little or no change in direction.
2. **A few are deflected** (turned) through large angles.
3. **A very few bounce back** towards where they came from.



What each observation tells us:

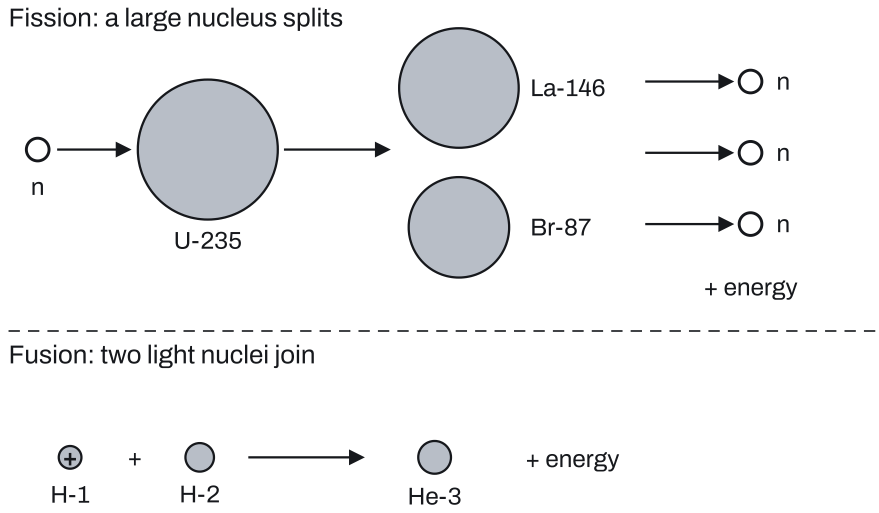
Observation	Conclusion
Most alpha particles go straight through	Most of the atom is **empty space**; the nucleus is **very small** compared with the atom
A few are deflected through large angles	The nucleus is **positively charged**: like charges repel, so it pushes the positive alpha particles away
A very few bounce straight back	The nucleus holds **most of the atom's mass** (and all its positive charge) in a tiny volume; something light could not turn a fast alpha particle round

The closer an alpha particle's path is to a nucleus, the stronger the repulsion and the **more it is deflected**. One heading straight at a nucleus slows down, stops and comes back along its path. Deflected paths **curve smoothly**: the force acts before the particle reaches the nucleus, so the path bends gradually, and it never touches the nucleus.

Why alpha particles? They are **charged**, so the charged nucleus pushes on them; neutrons are uncharged and would not be repelled. The foil must be very thin so that each alpha particle meets only a few atoms. Note that the experiment does **not** show that the nucleus contains protons and neutrons: it shows only that the nucleus is small, massive and positive.

Fission and fusion

Extended only. Some nuclear changes release huge amounts of energy.



Nuclear fission is the **splitting** of a large, heavy nucleus into two smaller nuclei. In a nuclear reactor, a uranium-235 nucleus absorbs a slow-moving **neutron**, becomes unstable and splits into two smaller nuclei (of roughly similar size), releasing **two or three neutrons** and energy. Those neutrons can go on to split more nuclei.

Nuclear fusion is the **joining** of two light nuclei to make one heavier nucleus. Stars such as the Sun are powered by fusion: **hydrogen nuclei join to form helium**, releasing energy. Fusion is hard to make happen on Earth: both nuclei are positive and **repel** each other strongly, so they must be moving extremely fast, which means an **extremely high temperature**, to get close enough to join.

Mass and energy. In both fission and fusion, the total mass of the products is **slightly less** than the total mass of what went in. The "lost" mass has been changed into **energy**, which is released, mostly as kinetic energy of the products. No numbers are needed; say it in words.

Say **nuclei**, not atoms: fission is a nucleus splitting, fusion is nuclei joining.

Nuclide equations

Extended only. A nuclear change is written as an equation in nuclide notation. Two things must balance:

- the **top numbers** (nucleon numbers): total on the left = total on the right;
- the **bottom numbers** (proton numbers, which are the charges): total on the left = total on the right.

For the fission in the diagram:

$$^{1}_{0}\mathrm{n} + ^{235}_{92}\mathrm{U} \rightarrow ^{146}_{57}\mathrm{La} + ^{87}_{35}\mathrm{Br} + 3\,^{1}_{0}\mathrm{n}$$

Top: $1 + 235 = 236$ and $146 + 87 + 3 \times 1 = 236$. Bottom: $0 + 92 = 92$ and $57 + 35 + 0 = 92$. A number in front, such as $3\,^{1}_{0}\mathrm{n}$, means three particles, so multiply both its numbers by 3.

For the fusion in the diagram (one of the steps by which the Sun turns hydrogen into helium):

$$^{1}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He}$$

Top: $1 + 2 = 3$. Bottom: $1 + 1 = 2$.

Once the bottom number of a missing nucleus is known, it tells you the element, because each element has its own proton number (the question gives you the symbols or proton numbers you need).

Key facts and formulas

There is no formula sheet for 0625: every relationship must be learnt.

Formula	Status
Relative charges: proton $+1$, neutron 0, electron -1	Learn it
Nuclide notation $^{A}_{Z}\mathrm{X}$: A = nucleon number (top), Z = proton number (bottom)	Learn it
Number of neutrons $N = A - Z$	Learn it
Neutral atom: number of electrons $= Z$	Learn it
Ion: charge $=$ protons $-$ electrons (lose electrons → positive, gain → negative)	Learn it
Isotopes: same Z, different A (different number of neutrons)	Learn it
Extended: relative charge on a nucleus $= +Z$; relative mass of a nucleus $\approx A$	Learn it
Extended: neutron $^{1}_{0}\mathrm{n}$, proton $^{1}_{1}\mathrm{p}$ or $^{1}_{1}\mathrm{H}$, alpha particle $^{4}_{2}\mathrm{He}$, beta particle $^{0}_{-1}\mathrm{e}$	Learn it
Extended: in a nuclide equation, top numbers balance and bottom numbers balance	Learn it
Extended: fission and fusion: products have less mass than reactants; the lost mass is released as energy	Learn it

How to do it

In the Paper 1–4 questions we have tagged for this topic (146 questions, 129 of them different, 2021–2025), the types came up this often. 21 of the questions mix types, so the counts add up to 175, more than 146. Half-life, background radiation and penetration parts of the same questions belong to Radioactivity.

Question type	Questions
Read nuclide notation: count protons, neutrons, electrons, nucleons	47
Describe the atom: particles, charges, locations	34
Alpha-particle scattering: observations, conclusions, paths	23
Explain, identify or compare isotopes	20
Describe fission and fusion	18
Complete or check a nuclide equation	14
Explain how atoms form ions, or identify an ion	11
Write nuclide notation from particle numbers	8

1. Read nuclide notation: count protons, neutrons, electrons, nucleons (47 questions)

1. **Find A and Z.** Top number $= A$ (nucleons), bottom number $= Z$ (protons). If only a name is given ("arsenic-75"), A is the number in the name and Z comes from the question.
2. **Protons** $= Z$.
3. **Neutrons** $= A - Z$. Write the subtraction: $^{75}_{33}\mathrm{As}$ has $75 - 33 = 42$ neutrons.
4. **Electrons** in a neutral atom $= Z$ (33 for arsenic). They are **outside** the nucleus.
5. **Nucleons** $= A$ (75).

Variations you will meet:

- **"State what the numbers represent."** Top: nucleon number (the number of protons and neutrons). Bottom: proton number (the number of protons). Don't call the top number the neutron number.
- **Counting from a diagram of an atom.** Count each kind of particle; Z = protons, A = protons + neutrons.
- **A table of nuclides.** "Which two have the same number of nucleons?": compare the top numbers. "Which has the most neutrons?": work out $A - Z$ for **each** one and show the subtractions; the biggest top number does not always win.
- **Relative charge on the nucleus** (Extended): $+Z$. For $^{208}_{82}\mathrm{Pb}$ it is $+82$, not $+208$ or $+126$.
- **Comparing two nuclides with the same A** (Extended), such as $^{36}_{16}\mathrm{S}$ and $^{36}_{17}\mathrm{Cl}$: chlorine-36 has one more proton (17), one fewer neutron (19 instead of 20) and (as a neutral atom) one more electron. Give the numbers.
- **"Describe the composition of a neutral atom"** (Extended): give the number of protons and neutrons in the nucleus and the number of electrons orbiting outside it, with their charges.

2. Describe the atom: particles, charges, locations (34 questions)

1. **Nucleus** at the centre: protons (charge $+1$) and neutrons (charge 0).
2. **Electrons** (charge -1) orbit **outside** the nucleus.
3. In a neutral atom, number of electrons = number of protons.

Variations you will meet:

- **Complete a table** of name, charge and location. For the neutron, "0", "zero" or "neutral" all work. For the electron's location, write "outside the nucleus" or "orbiting the nucleus".
- **Label a diagram** of an atom, or **draw** one: put the right number of protons and neutrons together in the middle and the right number of electrons in orbits around them. Get the numbers from the nuclide notation.
- **Multiple choice**: pick the diagram with the positive particles in the centre and the negative ones outside, or the statement "negative electrons surround a positive nucleus". Wrong options put electrons in the nucleus, make the nucleus neutral or negative, or give electrons a positive charge.
- **"Describe the structure of an atom"** (Extended, often several marks): each separate correct point scores, so list them: a nucleus; containing protons and neutrons, with their numbers; protons positive, neutrons neutral; electrons orbit outside the nucleus, with their number; electrons negative.
- The charge on a proton may be written e instead of $+1$: then the electron is $-e$ and the neutron 0.

3. Alpha-particle scattering: observations, conclusions, paths (23 questions)

Extended only.

1. **Link each observation to its conclusion** using the table in "Understand it":
   - most pass straight through → most of the atom is empty space, the nucleus is very small;
   - a few deflected through large angles → the nucleus is positive (it repels the positive alpha particles);
   - a very few bounce back → most of the mass is concentrated in the tiny nucleus.
2. **If asked to "explain"**, give the reason as well as the conclusion, for example "the nucleus is positively charged, because like charges repel and the alpha particles are positive".

Variations you will meet:

- **Complete the paths** of alpha particles near nuclei: a path far from every nucleus continues straight; a path passing near a nucleus curves smoothly **away** from it; a path aimed at the centre of a nucleus turns back. The closer the path, the bigger the bend. Draw each path all the way on, starting to bend **before** it reaches the nucleus, never through the nucleus.
- **Which conclusion does NOT follow?** "The nucleus is made of protons and neutrons": the experiment tells us nothing about neutrons.
- **Why alpha particles and not neutrons?** Alpha particles are charged (positive), so they are repelled by the nucleus.
- **The charge on an alpha particle**: positive $(+2)$.

- **Matching results and conclusions** in a table: "most pass straight through" goes with "most of the atom is empty space", not with "the nucleus is very large".

4. Explain, identify or compare isotopes (20 questions)

1. **Definition** (two marks): atoms of the **same element**, with the **same number of protons** (same proton number) but a **different number of neutrons** (different nucleon number).
2. **Identify isotopes**: look for the same bottom number (same Z) and different top numbers.

Variations you will meet:

- **Pick isotopes from a table** of proton and nucleon numbers, or of proton and neutron numbers: same number of protons, different number of neutrons.
- **"How does one isotope differ from another?"** For neon-22 and neon-20: neon-22 has 2 more neutrons in the nucleus ($22 - 20$), and the same number of protons and electrons.
- **Compare the nuclei** of two isotopes (Extended): same charge, different mass.
- **"Only one isotope of this element occurs naturally"**: so every natural atom of it has the same number of neutrons.
- **Stable versus unstable isotope** (Extended): the unstable (radioactive) one usually has **more neutrons**; a stable isotope of the same element has fewer.
- Wrong options: "isotopes are radioactive" or "isotopes have different numbers of protons".

5. Describe fission and fusion (18 questions)

Extended only.

1. **Fission**: a large nucleus (such as uranium-235) **absorbs a neutron** and **splits** into two smaller nuclei, releasing neutrons and energy.
2. **Fusion**: two light nuclei (such as hydrogen nuclei) **join** to form a heavier nucleus, releasing energy. It happens in stars: hydrogen fuses to helium.
3. **Mass and energy**: in both, the products have **less total mass** than the starting nuclei; the missing mass is released as **energy**.

Variations you will meet:

- **Which particle causes fission?** A neutron.
- **Sizes**: both nuclei made in fission are smaller than the original nucleus.
- **Which is fission, which is fusion?** from equations: one big nucleus on the left splitting into two medium ones is fission; small nuclei on the left making a bigger one is fusion.
- **Why fusion needs a very high temperature**: the nuclei are both positive and repel, so they need very high speeds (kinetic energy) to get close enough to join.
- **One difference** between fission and fusion: fission splits a heavy nucleus; fusion joins light nuclei.

6. Complete or check a nuclide equation (14 questions)

Extended only.

1. Write every particle in nuclide notation, including neutrons ${}^{1}_{0}\mathrm{n}$ and alpha particles ${}^{4}_{2}\mathrm{He}$.
2. **Top numbers**: add them up on each side; the missing nucleon number makes them equal.
3. **Bottom numbers**: do the same for the proton numbers.
4. Use the missing proton number to name the element if the question asks.

Variations you will meet:

- **How many neutrons are released in fission?** Neutrons have bottom number 0, so only the top numbers give the count. For ${}^{1}_{0}\mathrm{n} + {}^{239}_{94}\mathrm{Pu} \to {}^{134}_{53}\mathrm{I} + {}^{103}_{41}\mathrm{Nb} + x\,{}^{1}_{0}\mathrm{n}$: $1 + 239 = 134 + 103 + x$, so $x = 3$. Check the bottom numbers too: $94 = 53 + 41$.
- **Fusion of hydrogen isotopes.** The hydrogen nuclei go on the **left**; don't write them again as products. Work out the product's top number from the sum rather than assuming helium is always ${}^{4}_{2}\mathrm{He}$. For ${}^{3}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \to {}^{A}_{Z}\mathrm{He} + 2\,{}^{1}_{0}\mathrm{n}$: top $3 + 3 = A + 2$, so $A = 4$; bottom $1 + 1 = Z + 0$, so $Z = 2$.
- **Alpha and beta decay equations** appear in the same questions (they are part of Radioactivity) and balance the same way: an alpha particle is ${}^{4}_{2}\mathrm{He}$, a beta particle ${}^{0}_{-1}\mathrm{e}$. For ${}^{24}_{11}\mathrm{Na} \to {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}\mathrm{e}$: top $24 = 24 + 0$, bottom $11 = 12 + (-1)$.

7. Explain how atoms form ions, or identify an ion (11 questions)

1. **Positive ion**: the atom **loses** one or more electrons.
2. **Negative ion**: the atom **gains** one or more electrons.
3. The number of protons (the nucleus) stays the same.

Variations you will meet:

- **Identify an ion in a diagram**: count protons and electrons. More electrons than protons means a negative ion; fewer means a positive ion; equal means a neutral atom.
- **Size of the charge**: a $2+$ ion (such as Ca^{2+}) has lost two electrons; a $1-$ ion (such as F^{-}) has gained one.
- **A negative ion becoming neutral** loses its extra electrons.
- **"State how a neutral atom becomes a positive ion"**: "it loses an electron". Adding a proton is always wrong.

8. Write nuclide notation from particle numbers (8 questions)

1. **Nucleon number** A = protons + neutrons. **Proton number** Z = protons.
2. Write A at the **top left** and Z at the **bottom left** of the symbol.

For a polonium nucleus with 84 protons and 126 neutrons: $A = 84 + 126 = 210$, so ${}^{210}_{84}\mathrm{Po}$.

Variations you will meet:

- **From a diagram of an atom**: count protons and neutrons, then write the notation.
- **From a name and proton number**, such as bismuth-209 with proton number 83: $^{209}_{83}\mathrm{Bi}$.
- **Multiple choice**: reject symbols with the numbers swapped, with the neutron number on top, or with the numbers on the right.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.
- **C1** compensatory mark: earned for working even though the final answer is wrong.

Example 1

A nuclide of potassium is represented by $^{39}_{19}\mathrm{K}$.

(a) State the number of protons and the number of neutrons in a nucleus of potassium-39. **[2]**

(b) A neutral atom of potassium-39 loses one electron. State the number of electrons in the particle formed, and the name for a charged particle like this. **[2]**

(c) Potassium-40 is another isotope of potassium. State how a nucleus of potassium-40 differs from a nucleus of potassium-39. **[1]**

(a) Protons $= Z = 19$. **B1**

Neutrons $= A - Z = 39 - 19 = 20$. **B1**

(b) A neutral atom has 19 electrons; after losing one it has $19 - 1 = 18$. **B1**

It is a (positive) **ion**. **B1**

(c) Potassium-40 has **one more neutron** (21 instead of 20); the number of protons is the same. **B1**

Example 2

Extended. In an alpha-particle scattering experiment, a detector counts alpha particles after they pass a very thin sheet of gold in a vacuum. Out of every 1 000 000 alpha particles (numbers simplified), 999 850 are deflected by less than 10°, 125 are deflected by between 10° and 90°, and 25 are deflected by more than 90°.

(a) Calculate the percentage of the alpha particles that are deflected by more than 90°. **[2]**

(b) State what the number deflected by less than 10° shows about atoms. **[1]**

(c) Explain what the alpha particles deflected by more than 90° show about the nucleus of a gold atom. **[2]**

(d) A student says the results show that the nucleus contains protons and neutrons. Explain why the student is wrong. **[1]**

(a) $\frac{25}{1\,000\,000} \times 100$ **C1** $= 0.0025\%$ **A1**

(b) Most of an atom is empty space (the nucleus is very small compared with the atom). **B1**

(c) The nucleus is **positively charged**: it repels the positive alpha particles, since like charges repel. **B1** The nucleus holds **most of the mass** of the atom in a tiny volume: only something very massive and concentrated could turn a fast alpha particle back, and so few are turned back because the nucleus is so small. **B1**

(d) The experiment shows only where the charge and mass are (a small, massive, positive nucleus); it tells us nothing about neutrons, which are uncharged and do not repel the alpha particles. **B1**

Example 3

Extended. In a nuclear reactor, a uranium-235 nucleus absorbs a neutron and splits into a tellurium nucleus, a nucleus of element X and two neutrons:

$$^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{135}_{52}\text{Te} + {}^{A}_{Z}\text{X} + 2\,{}^{1}_{0}\text{n}$$

Element	strontium (Sr)	yttrium (Y)	zirconium (Zr)	niobium (Nb)
Proton number	38	39	40	41

(a) Name this process. **[1]**

(b) Determine the values of A and Z. **[2]**

(c) Use the table to identify element X. **[1]**

(d) Describe the changes in mass and energy that take place in this process. **[2]**

(a) Nuclear fission. **B1**

(b) Top numbers: $1 + 235 = 135 + A + 2 \times 1$, so $A = 236 - 137 = 99$. **B1**

Bottom numbers: $0 + 92 = 52 + Z + 0$, so $Z = 40$. **B1**

(c) Proton number 40: zirconium, so the nucleus is $^{99}_{40}\text{Zr}$. **B1**

(d) The total mass of the products is less than the total mass of the neutron and uranium nucleus. **B1** The lost mass is released as energy (mostly kinetic energy of the products). **B1**

Example 4

Extended. In an experimental reactor, a nucleus of hydrogen-2 fuses with a nucleus of helium-3. A helium-4 nucleus and one other particle X are produced.

(a) Using nuclide notation, write the equation for this reaction. **[3]**

(b) Identify particle X. **[1]**

(c) Explain why the reaction only happens at an extremely high temperature. **[2]**

(a) Left side: ${}^{2}_{1}\mathrm{H} + {}^{3}_{2}\mathrm{He}$. **B1**

Top: $2 + 3 = 4 + A$, so $A = 1$. Bottom: $1 + 2 = 2 + Z$, so $Z = 1$. **C1** for balancing both.

$${}^{2}_{1}\mathrm{H} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{p}$$

A1

(b) $A = 1$ and $Z = 1$: one proton (a hydrogen-1 nucleus). **B1**

(c) Both nuclei are positively charged, so they repel each other strongly. **B1** Only at an extremely high temperature do they move fast enough (have enough kinetic energy) to get close enough to join. **B1**

Common mistakes

- **Calling the top number the neutron number.** In ${}^{127}_{53}\mathrm{I}$, 127 is the nucleon number; the neutrons are $127 - 53 = 74$. Examiners see the top number given as the number of neutrons every year.
- **Swapping the numbers, or putting them on the right.** In nuclide notation both numbers go on the **left** of the symbol, the larger (nucleon) number on top. Writing the neutron number underneath instead of the proton number is another common slip.
- **Choosing the nuclide with the biggest top number when asked for the most neutrons.** Work out $A - Z$ for every nuclide; with different proton numbers the order can change.
- **Vague isotope definitions.** "Isotopes are elements with different numbers of neutrons" is not enough. Say they are atoms of the **same element**, with the **same number of protons** and a **different number of neutrons**.
- **Thinking ions form by changing protons.** Positive ions form by **losing electrons**, never by gaining protons. Many candidates also forget that losing a negative electron leaves the atom positive.
- **Putting electrons in the nucleus**, or saying the nucleus is neutral or negative. The nucleus is positive; electrons orbit outside it.
- **Adding a conclusion the scattering experiment can't support.** It does not show that the nucleus contains protons and neutrons. It shows a small, positive nucleus holding most of the mass.
- **Drawing scattered paths badly.** Paths must carry on after passing a nucleus, bend smoothly away from it (never towards it), and start bending before they reach it. Many candidates stop the path at the nucleus.
- **Giving the alpha particle's charge as just "+".** Its charge is $+2$ (and its numbers are 4 and 2).

- **Explaining fusion as "fusing" or "joining atoms".** Say **nuclei join**. For fission, say a **nucleus splits**, not atoms, isotopes or elements.
- **Unbalanced nuclide equations.** Common errors: a product's nucleon number guessed instead of worked out from the sums, forgetting the neutron's $^{1}_{0}$, writing the reactants again as products, or writing "N" or "neutron" instead of $^{1}_{0}\mathrm{n}$.

How to get the marks

- **"State"** needs only the answer: a number, a name, a word such as "ion" or "isotopes". **"Describe"** needs the features in order. **"Explain"** needs a reason: add "because...".
- **Numbers of particles**: write the subtraction ($A - Z$) as well as the answer. Keep the three answers (protons, neutrons, electrons) in the order the question lists them.
- **Tables**: one mark is usually for each row or cell, so fill every one. "Neutral", "zero" and "0" are all accepted for the neutron's charge.
- **"Describe the structure (or composition) of an atom"**: each correct fact earns a mark, so list separate points with numbers: protons and neutrons in the nucleus (how many of each), electrons outside it (how many), and their charges.
- **Isotope definitions** usually carry two marks: one for the same proton number, one for a different number of neutrons (or nucleon number). Use both terms.
- **Scattering conclusions**: link each conclusion to the right observation, and when asked to explain, mention that the alpha particles and the nucleus are both positive and repel.
- **Nuclide equations**: each correct pair of numbers usually earns its own mark, so balance the top and bottom separately and check each one.
- **Fission and fusion**: use the words **nucleus**/**nuclei**, **splits**/**joins**, and say that **energy is released**. For the mass change, say the products have **less** mass and this mass becomes energy.
- **Multiple choice**: read the options for swapped numbers and swapped signs; they are the usual traps.

Quick check

1. For the nuclide $^{55}_{25}\mathrm{Mn}$, state the number of protons, neutrons and electrons in a neutral atom, and the relative charge on its nucleus.
2. A neutral sulfur atom has 16 protons. It gains 2 electrons. State the number of electrons in the particle formed and its charge.
3. Four nuclei have these compositions: W (12 protons, 12 neutrons), X (12 protons, 14 neutrons), Y (13 protons, 11 neutrons), Z (13 protons, 14 neutrons). Which two pairs are isotopes? Which two nuclei have the same nucleon number?
4. Extended. Two alpha particles with the same speed pass the same gold nucleus. Alpha particle P passes much closer to the nucleus than alpha particle Q. State which one is deflected more, explain why, and describe the shape of its path near the nucleus.
5. Extended. Find the missing numbers in the fission equation $^{1}_{0}\mathrm{n} + ^{235}_{92}\mathrm{U} \rightarrow ^{132}_{50}\mathrm{Sn} + ^{A}_{Z}\mathrm{Mo} + 2\,^{1}_{0}\mathrm{n}$.

Answers

1. Protons $= 25$; neutrons $= 55 - 25 = 30$; electrons $= 25$; relative charge on the nucleus $= +25$.
2. Electrons $= 16 + 2 = 18$. It has 16 protons and 18 electrons, so its charge is $16 - 18 = -2$: a negative ion, S^{2-}.
3. Isotopes: W and X (both 12 protons, different neutrons), and Y and Z (both 13 protons). Nucleon numbers: W $= 24$, X $= 26$, Y $= 24$, Z $= 27$, so W and Y have the same nucleon number (but they are different elements, not isotopes).
4. P is deflected more. Both alpha particles and the nucleus are positive, so the nucleus repels them; P comes closer, so the repulsion on it is stronger. Its path curves smoothly away from the nucleus: the force acts all the time it is approaching and leaving, so the direction changes gradually (no sharp corner), and it never touches the nucleus.
5. Top: $1 + 235 = 132 + A + 2$, so $A = 236 - 134 = 102$. Bottom: $92 = 50 + Z$, so $Z = 42$.

Past questions to try

- **0625/42/M/J/22 Q11**: completing alpha-particle paths past gold nuclei, then counting particles in gold-198.
- **0625/41/O/N/21 Q9**: the composition of a uranium atom, comparing isotopes and completing a fission equation.
- **0625/32/O/N/23 Q11**: nuclide notation from a diagram of a beryllium atom, isotopes and ions.
- **0625/42/F/M/23 Q9**: what fission is, then a fusion equation for two deuterium nuclei.