

Atomic Structure, Isotopes & Mass Spectra

IB / A Level Chemistry Exam Preparation Notes

Structure 1.2 - How do the nuclei of atoms differ?

Core topics

Atomic model • protons, neutrons and electrons • nuclear symbols • ions • isotopes • relative atomic mass • HL mass spectra

Guiding question

How do the nuclei of atoms differ? In exams, the answer usually links the number of protons to atomic identity and the number of neutrons to isotopes and mass number.

1. Specification checklist

Use this page as a revision tracker. Tick each skill only when you can explain it, apply it to unfamiliar species, and answer exam-style questions without notes.

Level	You should be able to...
Core / SL	Describe the atom as a tiny dense positive nucleus surrounded by electrons.
Core / SL	Recall relative masses and charges of protons, neutrons and electrons.
Core / SL	Use nuclear symbols to deduce protons, neutrons and electrons in atoms and ions.
Core / SL	Explain cations and anions in terms of electron loss or gain.
Core / SL	Define isotopes and compare their chemical and physical properties.
Core / SL	Calculate relative atomic mass from isotope mass and abundance data.
HL	Interpret simple mass spectra to identify isotopes and their relative abundance.
HL	Use isotope abundances to predict molecular ion patterns such as Cl ₂ .

Exam focus

Most marks come from accurate particle counting, clear definitions, and weighted-average calculations. HL questions often test whether you understand what the peaks in a mass spectrum represent.

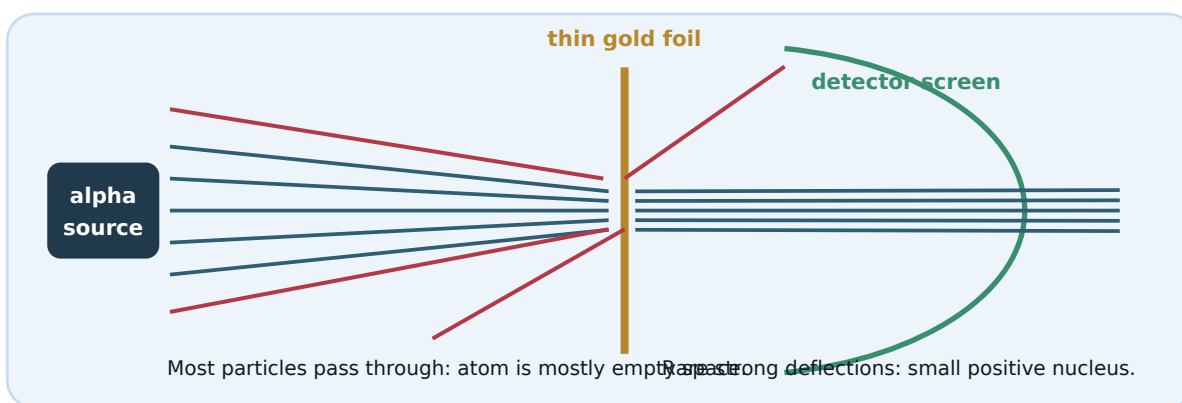
2. One-page overview

Key term	Essential meaning
Atomic number, Z	Number of protons in the nucleus. Defines the element.
Mass number, A	Number of protons + neutrons. Also called nucleon number.
Neutral atom	Number of protons = number of electrons.
Positive ion	Has lost electrons, so electrons = protons - charge.
Negative ion	Has gained electrons, so electrons = protons + charge size.
Isotopes	Atoms of the same element with different numbers of neutrons.
Relative atomic mass, A _r	Weighted mean mass of atoms of an element compared with 1/12 of carbon-12.
Mass spectrum (HL)	Shows m/z on the x-axis and relative abundance on the y-axis.

3. Development of the atomic model

Atomic models changed as new evidence became available. You do not need long historical essays, but you should be able to connect each model to the evidence that supported or replaced it.

Model	Main idea	Evidence / exam link
Dalton	Atoms are tiny indivisible particles; atoms of different elements differ; atoms combine in fixed ratios.	Explained fixed composition in compounds, such as water forming from hydrogen and oxygen in a constant ratio.
Thomson	The atom contains negative electrons in a spread-out positive region, often called the plum pudding model.	Cathode ray experiments showed that metals release the same negative particles.
Rutherford	The atom is mostly empty space with a tiny dense positive nucleus.	Alpha-particle scattering: most passed through gold foil, but a few were strongly deflected.
Bohr	Electrons occupy shells or energy levels around the nucleus.	Useful for simple atoms and later work on electron arrangement.



How to write Rutherford explanations

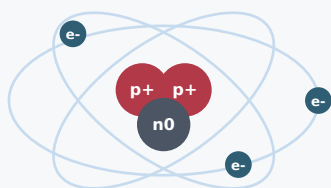
Observation: most alpha particles passed straight through the foil. Conclusion: atoms are mostly empty space.

Observation: a small number were deflected or bounced back. Conclusion: positive charge and most mass are concentrated in a very small, dense nucleus.

Nature of Science link

Atomic theory is a model: it is not a direct photograph of atoms in the usual sense, but an evidence-based explanation that predicts observations. Better technology, such as vacuum tubes, alpha sources, detectors and mass spectrometers, allowed scientists to test and refine the model.

4. The nuclear atom



Modern nuclear model

- Tiny dense nucleus contains protons and neutrons.
- Electrons occupy the space outside the nucleus.
- Most of the atom is empty space.
- Atomic identity is fixed by the number of protons.

The modern model used at this level describes atoms as a dense positive nucleus made from protons and neutrons, with electrons occupying the surrounding space. Protons and neutrons are called nucleons. The nucleus is tiny compared with the whole atom but contains almost all of the mass.

Subatomic particles

Particle	Relative mass	Relative charge	Location	Exam importance
Proton	1	+1	In nucleus	Determines atomic number and element identity.
Neutron	1	0	In nucleus	Changes mass number and affects isotope stability.
Electron	0.0005 (often negligible)	-1	Outside nucleus	Responsible for chemical reactions and ion formation.

Common trap

Atomic number is defined by the number of protons, not electrons. Electrons can change when ions form; protons do not change in ordinary chemical reactions.

Why are neutrons important?

In nuclei with more than one proton, the positive protons repel each other. Neutrons help stabilize the nucleus because the strong nuclear force acts between nucleons. If the neutron-to-proton balance is unsuitable, the isotope may be radioactive.

5. Nuclear symbols and particle counting

A nuclear symbol summarizes the composition of an atom or ion. The top number is the mass number, and the bottom number is the atomic number.

Nuclear symbol

A/Z X or mass number over atomic number

Use A for mass number and Z for atomic number.

Core equations

protons = Z neutrons = A - Z electrons = Z (neutral atom)

For ions, adjust electrons using the charge.

Ion electron rules

Species type	Meaning	Electron rule
Cation, e.g. Al ³⁺	Atom has lost electrons.	electrons = protons - charge size
Anion, e.g. O ²⁻	Atom has gained electrons.	electrons = protons + charge size

Worked examples

Species / information	Counting method	Answer / interpretation
${}_{13}^{27}\text{Al}$	p = 13; n = 27 - 13 = 14; e = 13	neutral atom
${}_{13}^{27}\text{Al}^{3+}$	p = 13; n = 14; e = 13 - 3 = 10	positive ion formed by electron loss
${}_{8}^{16}\text{O}^{2-}$	p = 8; n = 16 - 8 = 8; e = 8 + 2 = 10	negative ion formed by electron gain
Species with 19p, 20n, 18e	Z = 19 = K; A = 39; charge = +1	${}_{19}^{39}\text{K}^{+}$

Marking guidance

Show the method. A correct final answer may not receive full marks if the examiner cannot see how you found protons, neutrons and electrons.

6. Atoms, ions and isoelectronic species

Ions form when atoms gain or lose electrons. The nucleus does not change during ion formation, so the atomic number and mass number stay the same.

Comparing atoms and ions

Example	Particle count	Important comparison
Sodium atom, Na	11 protons, 11 electrons	Neutral; highly reactive metal atom.
Sodium ion, Na ⁺	11 protons, 10 electrons	Positive ion; present in sodium chloride.
Chlorine atom, Cl	17 protons, 17 electrons	Neutral atom.
Chloride ion, Cl ⁻	17 protons, 18 electrons	Negative ion; present in sodium chloride.

Isoelectronic species

Isoelectronic species have the same number of electrons. They do not have to be the same element or have the same charge.

Species	Protons	Electrons	Why isoelectronic?
Ar	18	18	Neutral argon has 18 electrons.
K ⁺	19	18	Potassium loses one electron.
Ca ²⁺	20	18	Calcium loses two electrons.
Cl ⁻	17	18	Chlorine gains one electron.

Common trap

Species with the same number of electrons can have very different chemical properties because they have different nuclear charges and often different ionic radii.

Exam technique: charge from particle counts

To deduce the charge, compare protons and electrons. If there are more protons, the species is positive. If there are more electrons, the species is negative.

Charge rule

$$\text{charge} = \text{number of protons} - \text{number of electrons}$$

Example: 19 p and 18 e gives +1.

7. Isotopes

Isotopes are atoms of the same element with different numbers of neutrons. Because they have the same number of protons, they have the same atomic number and occupy the same place in the periodic table.

Example: chlorine isotopes

Isotope	Protons	Neutrons	Electrons in neutral atom	Mass number
$^{35}_{17}\text{Cl}$	17	18	17	35
$^{37}_{17}\text{Cl}$	17	20	17	37

Chemical versus physical properties

Property type	Comparison	Reason
Chemical properties	Usually the same or extremely similar.	They have the same electron arrangement because they have the same number of protons and electrons.
Physical properties	Can differ slightly.	Different neutron numbers give different masses, affecting properties such as density, rate of diffusion, melting point or boiling point.
Nuclear stability	Can differ greatly.	Some isotope nuclei are unstable and radioactive.

Precise definition

Best exam definition: isotopes are atoms of the same element with the same number of protons but different numbers of neutrons. Do not define isotopes only as atoms with different mass numbers; that is incomplete.

Isotope tracers

Radioactive isotopes behave chemically like non-radioactive isotopes of the same element, but can be detected from the radiation they emit. This allows scientists to follow atoms through biological systems, environmental processes or reaction mechanisms.

8. Relative atomic mass and isotopic abundance

The relative atomic mass shown in the periodic table is usually not a whole number because it is a weighted mean of all naturally occurring isotopes of an element.

Weighted mean formula

$$A_r = \frac{\text{sum}(\text{isotope mass} \times \text{relative abundance})}{\text{sum}(\text{relative abundances})}$$

If abundances are percentages, the denominator is 100.

Worked example: chlorine

Chlorine has two common isotopes: chlorine-35 and chlorine-37. If 75% is chlorine-35 and 25% is chlorine-37:

$$A_r = [(35 \times 75) + (37 \times 25)] / 100 = 35.5$$

The answer is closer to 35 than 37 because chlorine-35 is more abundant.

Worked example: finding an unknown abundance

Boron has isotopes ^{10}B and ^{11}B . If $A_r = 10.81$, let x be the percentage abundance of ^{10}B . Then ^{11}B has abundance $100 - x$.

$$10.81 = [10x + 11(100 - x)] / 100$$

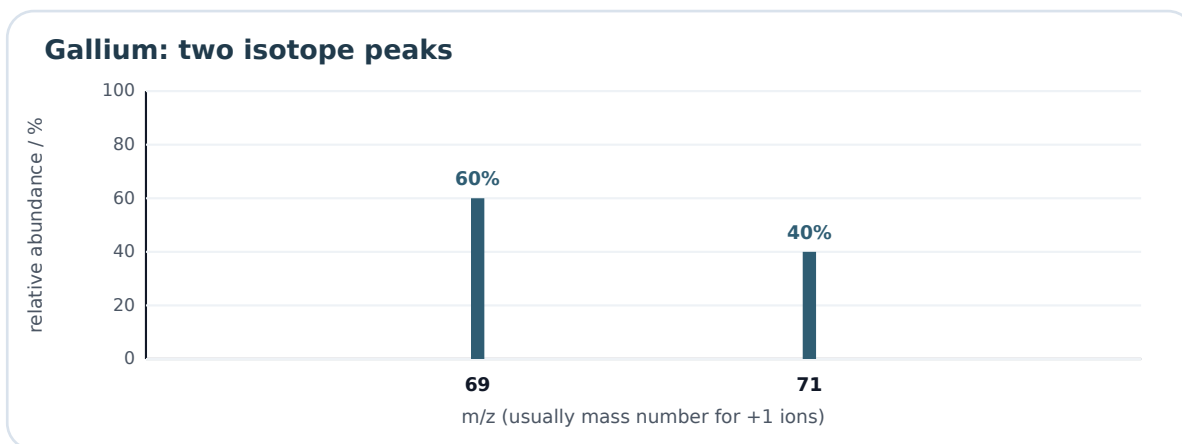
$1081 = 1100 - x$, so $x = 19$. Therefore $^{10}\text{B} = 19\%$ and $^{11}\text{B} = 81\%$.

Calculator advice

Keep one or two extra decimal places during working, then round only at the end. In abundance questions, check that your percentages add to 100%.

9. HL: Mass spectra of elements

A mass spectrometer can measure the mass and relative abundance of isotopes. You do not need to describe operational details in depth, but you should understand what the axes and peaks mean.



Interpreting a mass spectrum

Feature	Meaning
Number of peaks	Number of isotopes detected, unless fragmentation or multiple charges complicate the spectrum.
x-axis, m/z	Mass-to-charge ratio. For +1 ions, m/z equals the isotope mass number approximately.
y-axis	Relative abundance of the ions. This can be given as percentages or relative peak heights.
Peak at m/z 69	Represents ions of gallium-69, usually written $^{69}\text{Ga}^+$.
Weighted mean	Use peak masses and abundances to calculate A_r .

Worked example: gallium

If gallium has 60% of mass 69 and 40% of mass 71:

$$A_r = [(69 \times 60) + (71 \times 40)] / 100 = 69.80$$

HL exam trap

When naming the particles in a mass spectrum, include the positive charge: e.g. $^{69}\text{Ga}^+$, not just Ga.

10. HL: Molecular isotope patterns

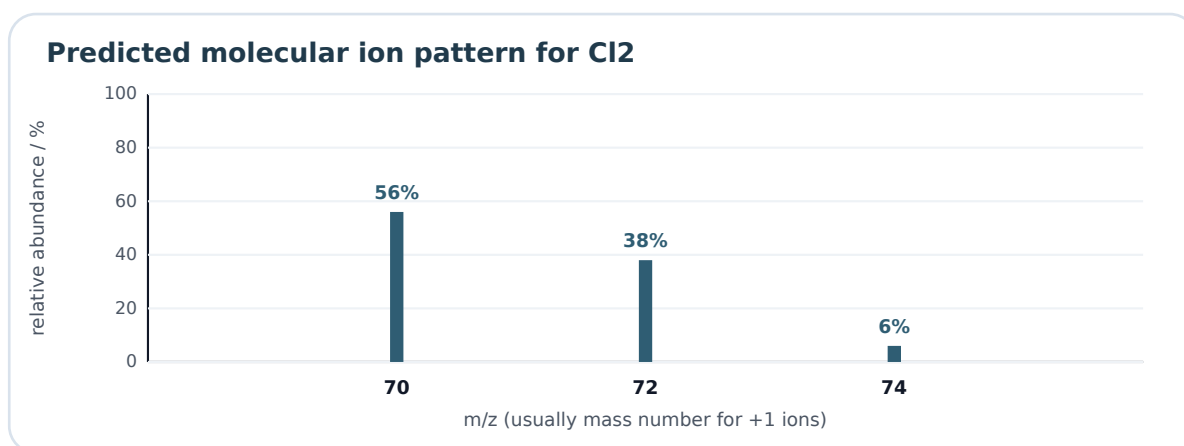
When a molecule contains atoms that have isotopes, different combinations of isotopes can produce different molecular ion peaks.

Example: chlorine gas, Cl₂

Chlorine is approximately 75% chlorine-35 and 25% chlorine-37. A Cl₂ molecule can contain two ³⁵Cl atoms, one of each isotope, or two ³⁷Cl atoms.

Combination	Molecular ion m/z	Probability	Relative abundance
³⁵ Cl- ³⁵ Cl	70	$0.75 \times 0.75 = 0.5625$	56.25%
³⁵ Cl- ³⁷ Cl or ³⁷ Cl- ³⁵ Cl	72	$2 \times 0.75 \times 0.25 = 0.375$	37.5%
³⁷ Cl- ³⁷ Cl	74	$0.25 \times 0.25 = 0.0625$	6.25%

So the molecular ion peaks appear at m/z 70, 72 and 74 in an approximate 9 : 6 : 1 ratio.



Why the middle peak is larger than expected

There are two ways to make mass 72: ³⁵Cl-³⁷Cl and ³⁷Cl-³⁵Cl. Always count all possible combinations.

11. Common mistakes and how to avoid them

Mistake	Better exam answer
Calling isotopes different elements	Isotopes are the same element because they have the same number of protons.
Using electrons to define atomic number	Atomic number is the number of protons. Electrons only equal protons in neutral atoms.
Forgetting ion charge when counting electrons	For Al^{3+} , subtract 3 electrons. For O^{2-} , add 2 electrons.
Saying isotopes have different chemical properties	They usually have the same chemical properties because electron arrangement is the same.
Confusing mass number and relative atomic mass	Mass number applies to one isotope; A_r is a weighted mean for an element.
Averaging isotope masses without abundances	Use weighted mean, not simple mean, unless abundances are equal.
For mass spectra, omitting charge	Write isotope ions as X^+ in HL mass spectrum explanations.
Using all digits too early	Round final answers only; do not round intermediate calculations too aggressively.

Command words

Command word	What the examiner expects
Deduce	Use given data to work out a value or identity. Show the logical steps.
Explain	Give a reason, often linking particle structure to the observation.
Compare	State similarities and differences.
Calculate	Write the formula/substitution and give a final numerical answer with suitable rounding.
Justify	Support your answer using evidence from the table, graph or spectrum.

12. Rapid revision cards

Atomic number Number of protons in the nucleus; defines the element.	Mass number Number of protons plus neutrons.
Nucleons Particles in the nucleus: protons and neutrons.	Cation Positive ion formed when electrons are lost.
Anion Negative ion formed when electrons are gained.	Isotopes Same protons, different neutrons.
Same chemical properties? Isotopes have the same electron arrangement, so their chemical properties are very similar.	Different physical properties? Different masses can affect density, diffusion rate and boiling/melting points.
Ar Weighted average mass of atoms relative to carbon-12.	Mass spectrum Peaks show m/z and relative abundance of ions.
Rutherford evidence Most alpha particles pass through; few deflect strongly.	Empty space Rutherford concluded atoms are mostly empty space.

10-second isotope test

Same atomic number? If yes, same element. Different mass number? If yes, isotopes. Different electron number? Then one or both may be ions.

13. Exam practice - Core / SL / AS

Answer these without notes. Then check the marking guidance on the next pages.

1. State the relative mass and relative charge of a proton, neutron and electron. (3)
2. Explain why Rutherford concluded that the atom is mostly empty space. (2)
3. Deduce the numbers of protons, neutrons and electrons in ${}^{56}_{26}\text{Fe}^{3+}$. (3)
4. A species contains 17 protons, 18 neutrons and 18 electrons. Identify the species using a nuclear symbol and charge. (3)
5. Define isotopes. (2)
6. Explain why isotopes of the same element usually have the same chemical properties. (2)
7. Chlorine exists as 75% chlorine-35 and 25% chlorine-37. Calculate its relative atomic mass. (2)
8. Explain why the relative atomic mass of an element may not be a whole number. (2)
9. Compare ${}^{14}_6\text{C}$ and ${}^{14}_7\text{N}$ in terms of protons, neutrons and electrons. (3)
10. Calcium forms Ca^{2+} . Explain, using electrons, how this ion forms. (2)

14. Exam practice - HL mass spectra

11. Gallium has two isotopes, ^{69}Ga and ^{71}Ga , with abundances 60% and 40%. Calculate A_r for gallium. (2)
12. A mass spectrum shows two peaks at m/z 85 and 87 with relative abundances 77% and 23%. Calculate the relative atomic mass. (2)
13. Explain why the x-axis of a mass spectrum is labelled m/z rather than mass. (2)
14. Bromine has two isotopes, ^{79}Br and ^{81}Br , in equal abundance. Predict the m/z values and relative ratio of molecular ion peaks for Br_2 . (3)
15. Chlorine gas has molecular ion peaks at m/z 70, 72 and 74. Explain why there are three peaks, and why the peak at 72 is not the smallest. (3)
16. Magnesium has three isotopes: ^{24}Mg , ^{25}Mg and ^{26}Mg . ^{24}Mg has abundance 78.90%, and $A_r = 24.31$. If x is the percentage abundance of ^{25}Mg , form an equation that could be solved to find x . (2)

Teacher / student use

These questions are deliberately compact. They are intended for quick recall practice before moving on to full past-paper questions.

15. Answer key and marking guidance

Q	Answer / marking points
1	Proton: relative mass 1, charge +1. Neutron: relative mass 1, charge 0. Electron: relative mass about 0.0005 or negligible, charge -1.
2	Most alpha particles passed through the foil with little or no deflection, showing that most of the atom contains no concentrated mass or charge. Therefore the atom is mostly empty space.
3	Fe has $Z = 26$. Protons = 26; neutrons = $56 - 26 = 30$; electrons = $26 - 3 = 23$.
4	$Z = 17$, so the element is chlorine. $A = 17 + 18 = 35$. There is one extra electron, so charge is -1. Answer: ${}^{35}_{17}\text{Cl}^-$.
5	Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons.
6	Chemical properties depend mainly on electron arrangement. Isotopes of the same element have the same number of protons and, as neutral atoms, the same number of electrons, so their electron arrangement is the same.
7	$\text{Ar} = [(35 \times 75) + (37 \times 25)] / 100 = 35.5$.
8	The value is a weighted average of the masses of all isotopes, taking their relative abundances into account. It is not usually the mass of one actual atom.
9	Carbon-14: 6p, 8n, 6e. Nitrogen-14: 7p, 7n, 7e. They have the same mass number but different atomic numbers, so they are different elements.
10	A calcium atom loses two electrons. It then has two more protons than electrons, forming Ca^{2+} .

16. HL answer key and marking guidance

Q	Answer / marking points
11	$Ar = [(69 \times 60) + (71 \times 40)] / 100 = 69.80$.
12	$Ar = [(85 \times 77) + (87 \times 23)] / 100 = 85.46$.
13	The mass spectrometer separates ions according to mass-to-charge ratio. For ions with charge +1, m/z is approximately equal to the mass number, but this is not true for ions with different charges.
14	Br ₂ molecular ion peaks: 158 from ⁷⁹ Br- ⁷⁹ Br, 160 from mixed ⁷⁹ Br- ⁸¹ Br, and 162 from ⁸¹ Br- ⁸¹ Br. With equal abundance, the ratio is 1 : 2 : 1.
15	Three peaks occur because Cl ₂ can contain ³⁵ Cl- ³⁵ Cl, ³⁵ Cl- ³⁷ Cl, or ³⁷ Cl- ³⁷ Cl. The m/z 72 peak has two possible combinations, so it is larger than the 74 peak.
16	Let ²⁵ Mg = $x\%$. Then ²⁶ Mg = $100 - 78.90 - x = 21.10 - x$. Equation: $24.31 = [24(78.90) + 25x + 26(21.10 - x)] / 100$.

Final quick check

- Can you identify the element from the number of protons?
- Can you calculate neutrons using $A - Z$?
- Can you adjust electron counts correctly for positive and negative ions?
- Can you explain why isotope chemistry is similar but physical properties can differ?
- Can you calculate Ar from isotope abundances and interpret mass spectrum peaks?