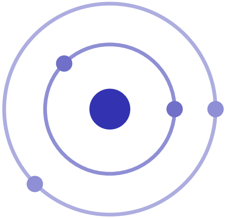
Atomic Structure

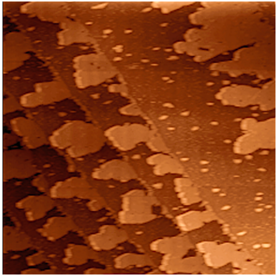
A-Level Chemistry ▪ Topic 1

A-Level Chemistry



What we will cover

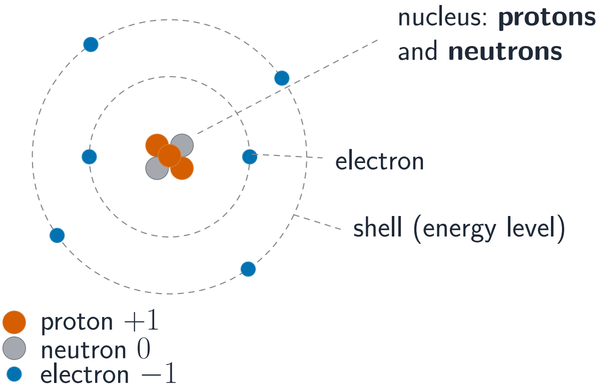
1. Inside the atom
2. Counting particles & radius
3. Isotopes
4. Sub-shells & orbitals
5. Electronic configuration
6. Ionisation energy



real atoms, imaged

1 Inside the atom

Inside the atom



A tiny **nucleus** 原子核 of **protons** 质子 $(+1)$ and **neutrons** 中子 (0) holds nearly all the mass; **electrons** 电子 $(-1, \sim 0$ mass) move in **shells** 壳层.

Relative charge and relative mass

We compare the three particles using **relative charge 相对电荷** and **relative mass 相对质量**.

> These are simple numbers, not real units.

Counting particles

proton number 质子数 | **nucleon number 核子数 A** | neutrons $= A - Z$

Worked example: $^{27}_{13}\mathbf{Al}^{3+}$

13 protons; $27 - 13 = 14$ neutrons; $13 - 3 = 10$ electrons (lost 3 to become $3+$)

A positive **ion** 离子 (**cation** 阳离子) has fewer electrons than protons; a negative ion (**anion** 阴离子) has more.

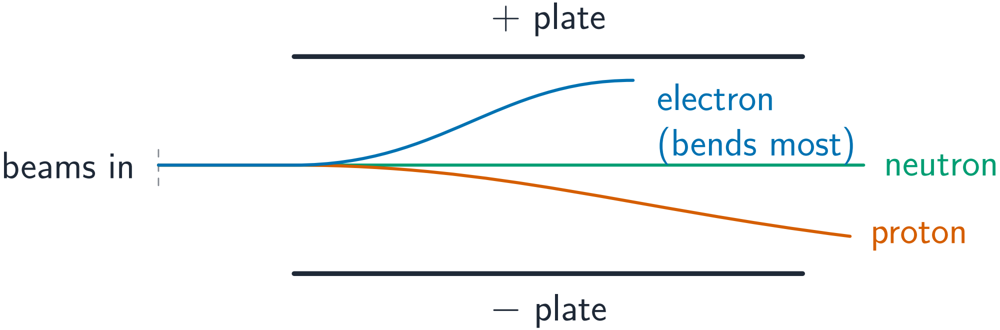
How mass and charge are spread out

Almost all the mass sits in the nucleus, because protons and neutrons are heavy and electrons are very light.

> All the positive charge is in the nucleus (the protons).

Beams in an electric field

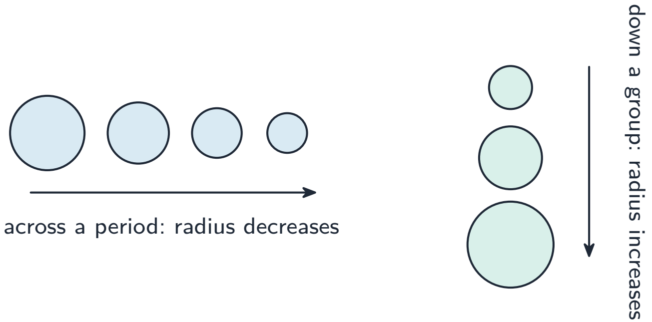
- proton bends to the − plate
- electron bends to the + plate, far more (much lighter)
- neutron goes straight (no charge)



Atomic and ionic radius

- across a **period** 周期 – smaller (stronger **nuclear charge** 核电荷, same shell)
- down a **group** 族 – larger (each step adds a shell)

A cation is smaller than its atom; an anion larger.



Isotopes

$^{35}_{17}\text{Cl}$

17 protons, 18 neutrons

$^{37}_{17}\text{Cl}$

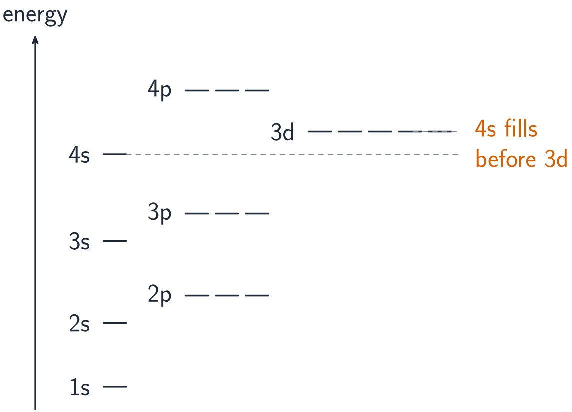
17 protons, 20 neutrons

Isotopes 同位素: same protons, different neutrons. Same chemical properties (same electrons); different physical ones (mass, density).

2

Electrons

Sub-shells and energy order



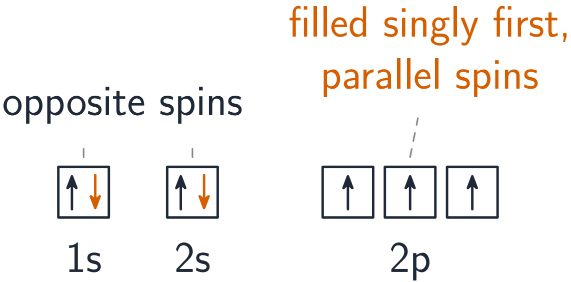
Shells split into **sub-shells** 亚层 s (2), p (6), d (10), made of **orbitals** 轨道 (2 electrons each).

> Fill lowest energy first – note 4s fills before 3d.

Hydrogen emits light only at discrete

Hydrogen emits light only at discrete, characteristic wavelengths – its line emission spectrum.

Electronic configuration



Electronic configuration 电子排布: Fe $= [\text{Ar}]\, 3d^6\, 4s^2$.

- paired electrons have opposite **spin** 自旋
- orbitals fill singly first (less repulsion)

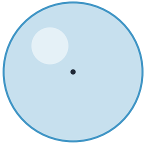
Ions lose 4s before 3d: $Fe^{3+} = [\text{Ar}]\, 3d^5$.

Filling order, shorthand, and the boxes

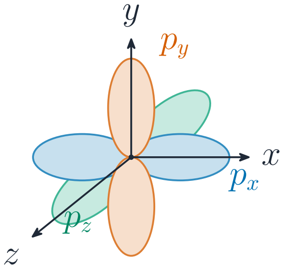
the surprise	4s is slightly lower in energy than 3d, so 4s fills first – and empties first when an ion forms
the order	1s 2s 2p 3s 3p 4s 3d 4p ...
the shorthand	use the nearest **noble gas** 稀有气体 in square brackets – $[\mathrm{Ar}]4s^2$ stands for argon's full configuration plus two 4s electrons
in boxes	within a sub-shell, electrons fill empty orbitals one at a time, with parallel arrows, before any orbital gets a second
why	electrons repel, so they stay apart while they can – Hund's rule
the ground state 基态	the lowest-energy arrangement; anything else is excited

The 4s-before-3d order is why transition metals lose 4s electrons first when they ionise – the point every configuration question in Topic 28 rests on.

Shapes of orbitals



s orbital
(sphere)



p orbitals
(two lobes each)

- an **s orbital** s 轨道 is a **sphere** 球形
- a **p orbital** p 轨道 is a dumbbell; the three point along *x*, *y*, *z*

A **free radical** 自由基 has an unpaired electron.

Free radicals

A **free radical 自由基** is a species with one or more **unpaired electrons 未成对电子**.

3 Ionisation energy

First ionisation energy

First ionisation energy 第一电离能: $X(g) \rightarrow X^{+}(g) + e^{-}$.

- rises across a period (more nuclear charge)
- dips at Al ($3p < 3s$) and S (**spin-pair repulsion** 自旋成对排斥)

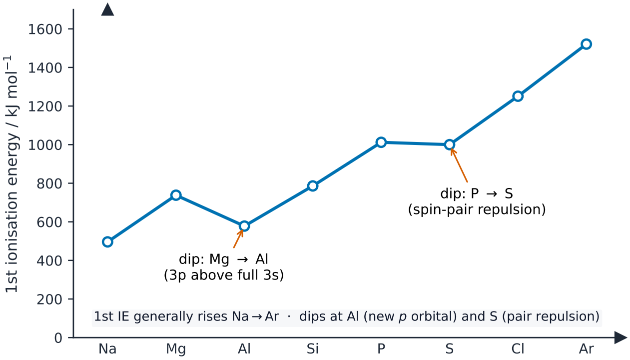
The dips are evidence for sub-shells.

Defining first ionisation energy exactly

the definition	the energy to remove one electron from each atom in one mole of gaseous atoms
why gaseous	so there are no forces between the particles to include in the measurement
the equation	$\mathrm{X(g)} \rightarrow \mathrm{X^{+}(g)} + e^{-}$
the unit	kJ mol^{-1}
what it depends on	nuclear charge, **atomic radius** 原子半径, and shielding by inner shells
the trend	increases across a period, decreases down a group – with the small drops that reveal sub-shell structure

The state symbols (g) are part of the definition, not decoration. Omitting them loses the mark even when the words are right.

First ionisation energy, in detail



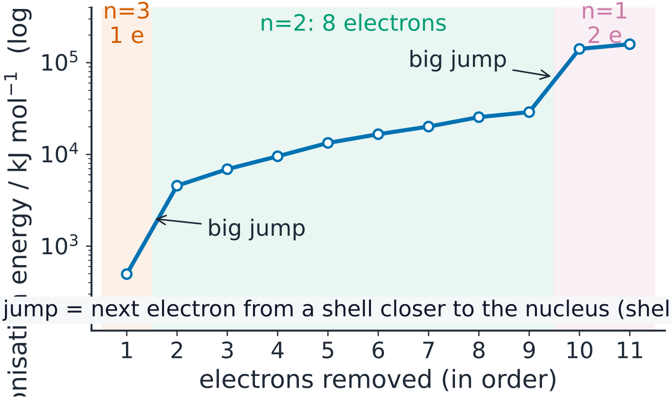
First ionisation energy rises across Period 3 but dips at Al and at S – evidence that sub-shells exist

Successive ionisation energies

Each **successive ionisation energy** 逐级电离能 is larger (a more positive ion).

> Big jumps reveal the shells: sodium's $2, 8, 1$ pattern. Electrons removed before the first jump $=$ the group number.

Successive ionisation energies, in detail

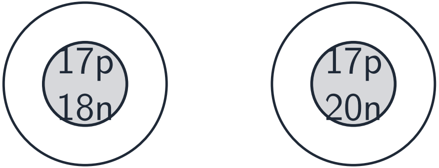


big jump = next electron from a shell closer to the nucleus (shell structure)

Each **successive ionisation energy** 逐级电离能 is larger (a more positive ion).

Isotopes, continued

same protons, different neutrons



$^{35}_{17}\mathrm{Cl}$ $^{37}_{17}\mathrm{Cl}$

> Two chlorine isotopes: same protons, different neutrons

What isotopes change, and what they do not

the atomic number 原子序数	the proton count – identical between isotopes, so the element is the same
the mass number 质量数	protons plus neutrons – this is what differs
chemical properties 化学性质	identical, because they depend on the electron arrangement, which is unchanged
physical properties 物理性质	some depend on mass, so they differ: a heavier isotope diffuses more slowly and has a higher density and boiling point
neutral 中性 atoms	protons equal electrons; an ion has gained or lost electrons, never protons
the atomic radius 原子半径	unchanged between isotopes, since it is set by the electron shells

> Chemistry is electrons; mass effects are physics. That single split answers every isotope question on the paper.

Exam tips

- Define **isotopes** in full: atoms of the same element with the same number of protons but a different number of neutrons – the mark scheme wants both halves.
- 4s fills **before** 3d, but electrons are **removed from 4s first** when forming ions, so Fe^{3+} is $[Ar]3d^5$ (not $[Ar]3d^3 4s^2$).
- In successive ionisation energies, a **big jump** marks the start of a new (inner) shell – use the jumps to place the element in its group.
- Explain every ionisation-energy trend with the same three factors: **nuclear charge, distance and shielding**, plus sub-shell effects for the small dips.
- Learn the exact reason first ionisation energy of oxygen is **below** nitrogen: oxygen's **paired 2p electrons repel**, so one is easier to remove.

4 Recap

Topic 1 – key takeaways

1 **The atom**

nucleus (p,n) + electrons in shells

2 **Isotopes**

same protons, different neutrons

3 **Configuration**

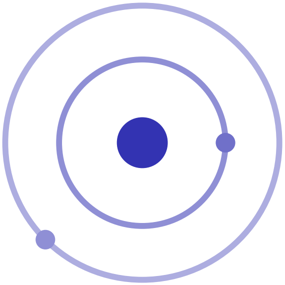
s, p, d sub-shells; 4s fills before 3d

4 **Ionisation energy**

dips show sub-shells; jumps show shells

Check yourself

1. How many neutrons in ${}^{37}_{17}$Cl?
2. Which fills first, 4s or 3d?
3. Why does first IE dip from Mg to Al?
4. What do big jumps in successive IE reveal?



Answers **1.** 20 **2.** 4s **3.** Al's electron leaves a higher-energy 3p sub-shell **4.** the shells