

Electron configurations

Structure 1.3 · SL

What coloured light tells us about atoms

The light an element gives out is a record of how its electrons are arranged.

- Sodium turns a flame orange-yellow; hydrogen in a discharge tube glows pink.
- Each element gives its own colours, because its electrons sit in fixed energy levels.
- This unit: spectra → energy levels → orbitals → configurations.

Light carries energy in packets

- All electromagnetic radiation travels at $c = 3.00 \times 10^8 \text{ m s}^{-1}$.
- Light comes in packets called **photons**; the energy of one **photon** depends only on its frequency.
- Higher frequency means higher energy and shorter wavelength.

$$c = f\lambda \quad E = hf$$
$$h = 6.63 \times 10^{-34} \text{ J s (Planck constant)}$$

Visible light: red (about 700 nm, lowest energy) to violet (about 400 nm, highest energy).

Continuous spectrum or line spectrum?

Continuous spectrum

White light from a lamp filament.

A smooth band of colour with no gaps.

Line emission spectrum

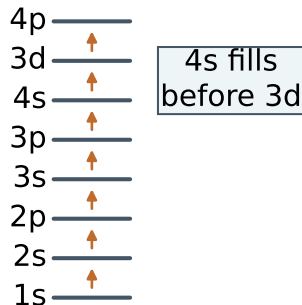
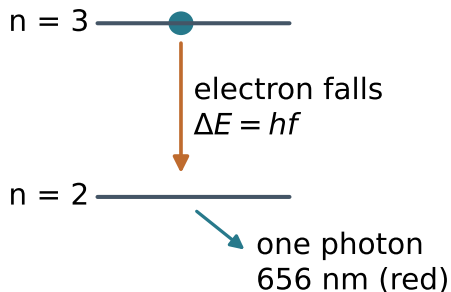
Light from excited gas atoms.

A few sharp coloured lines on a dark background, different for each element.

Where each line comes from

one gap $\rightarrow$ one exact line

fill lowest energy first



One fixed gap gives one **photon** energy, so one exact line: $\Delta E = hf$.

Hydrogen's spectrum is evidence for energy levels

If the electron could have any energy, hydrogen would give a **continuous spectrum**. It does not.

- Separate lines $\rightarrow$ the electron's energy is **quantized** (only fixed values).
- Lines crowd together at higher frequency $\rightarrow$ the levels get closer together.
- Falls to $n = 1$ are ultraviolet, to $n = 2$ visible, to $n = 3$ infrared.

Worked example: the red line at 656 nm

1 **Convert.** $\lambda = 656 \times 10^{-9} \text{ m}$

2 **Frequency.** $f = c/\lambda = 3.00 \times 10^8 / 656 \times 10^{-9} = 4.57 \times 10^{14} \text{ Hz}$

3 **Energy.** $E = hf = 6.63 \times 10^{-34} \times 4.57 \times 10^{14} = 3.03 \times 10^{-19} \text{ J}$

Decision

This is the gap between $n = 3$ and $n = 2$ for one hydrogen atom.

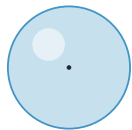
Main levels hold $2n^2$ electrons

n	Maximum electrons	Sublevels
1	2	1s
2	8	2s, 2p
3	18	3s, 3p, 3d
4	32	4s, 4p, 4d, 4f

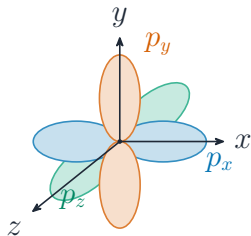
Use the evidence

Check $n = 3$: $2 + 6 + 10 = 18 = 2n^2$.

Shapes of s and p orbitals



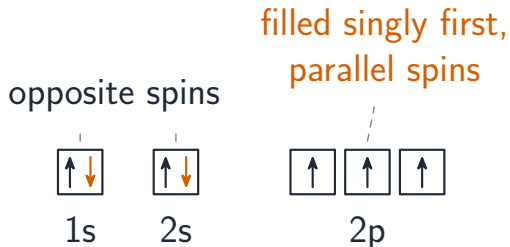
s orbital
(sphere)



p orbitals
(two lobes each)

- An s orbital is a sphere centred on the nucleus.
- Each p orbital is a dumbbell; the three point along x, y and z.
- The three p orbitals have equal energy (they are **degenerate**).

Three rules for filling orbitals



- **Aufbau:** fill the lowest-energy orbital first.
- **Pauli:** at most two electrons per orbital, with **opposite spins**.
- **Hund:** in equal-energy orbitals, go in singly with parallel spins first.

Order to $Z = 36$: 1s 2s 2p 3s 3p 4s 3d 4p.

Full and condensed configurations

Atom	Full	Condensed
S	$1s^2 2s^2 2p^6 3s^2 3p^4$	$[\text{Ne}] 3s^2 3p^4$
Fe	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$	$[\text{Ar}] 4s^2 3d^6$
Cr	exception	$[\text{Ar}] 4s^1 3d^5$
Cu	exception	$[\text{Ar}] 4s^1 3d^{10}$

Use the evidence

Always check that the superscripts add up to the number of electrons.

Ions: 4s fills first and empties first

Species	Configuration
O^{2-}	$1s^2 2s^2 2p^6$ (like neon)
Fe	$[\text{Ar}] 4s^2 3d^6$
Fe^{2+}	$[\text{Ar}] 3d^6$
Fe^{3+}	$[\text{Ar}] 3d^5$

Use the evidence

Fe^{2+} is not $[\text{Ar}] 4s^2 3d^4$.

Check: the configuration of Cr^{3+}

Your turn

Which is the configuration of Cr^{3+} ?

Ar $4s^2 3d^1$

Ar $4s^1 3d^2$

Ar $3d^3$

Ar $3d^5$

Exam tips

Most lost marks come from half-explanations. Give both the level idea and the **photon** idea.

- Line spectrum: fixed energy levels **and** a photon given out when an electron falls.
- Lines **converge** because the levels get closer together.
- 4s fills before 3d, but 4s empties first; learn Cr and Cu.

Check yourself

Try these

A line has $\lambda = 589 \text{ nm}$. Find the energy of one photon.

Write the full configuration of Cl and the condensed configuration of Cr^{3+} .

How many unpaired electrons does phosphorus have?