Atoms

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How we found the nucleus (gold foil), how Bohr quantised the atom to explain hydrogen's line spectrum, and how de Broglie's standing waves justify it all.

1. Rutherford Model & Alpha Scattering

Gold-foil experiment reveals a tiny, massive, positive nucleus in a mostly empty atom.

$N(\theta) \propto 1/\sin^4(\theta/2)$
scattering count vs angle

$r_0 = (1/4\pi\varepsilon_0)(2Ze^2/K)$
distance of closest approach (head-on)

$b = (Ze^2/4\pi\varepsilon_0 K)\cot(\theta/2)$
impact parameter b vs angle θ

MUST KNOW Most alphas pass straight through (atom is empty); ~1 in 8000 rebound >90° (nucleus is tiny and dense). Nucleus ~10^{-15} m, atom ~10^{-10} m.

MUST KNOW $r_0 \propto 1/K$ and $\propto 1/m$ — faster (higher-K) alphas approach closer; r_0 is only an UPPER estimate of nuclear size.

- Small b → large angle; head-on (b = 0) → θ = 180°. Drawback: orbiting electron should radiate, spiral in → atom unstable + continuous spectrum.

2. Bohr's Postulates

Quantum rules patched onto Rutherford's atom: stable orbits, quantised L, and a frequency condition for radiation.

$mvr = nh/2\pi$ (Bohr quantization)
L quantised, n = 1,2,3...

$E = E_2 - E_1 = h\nu$
frequency / transition condition

MUST KNOW Electrons revolve in stationary orbits WITHOUT radiating, even though they accelerate (centripetal) — this defies classical EM, it is postulated.

MUST KNOW Jump to lower orbit → photon EMITTED; jump to higher orbit → photon ABSORBED. No radiation while resting in an orbit.

- Works only for hydrogen and hydrogen-like one-electron ions (He^+, Li^{2+}); fails for multi-electron atoms (even neutral He).

3. Radius, Velocity & Energy of Orbits

Coulomb force = centripetal force, plus the L rule, give clean formulas for each orbit of a hydrogen-like atom.

$r_n = 0.53\, n^2/Z$ Å
$r \propto n^2/Z$; 0.53 Å = Bohr radius

$v_n = 2.18\times10^6\, Z/n$ m/s
$v \propto Z/n$; ground state ≈ c/137

$E_n = -13.6\, Z^2/n^2$ eV
$E \propto Z^2/n^2$; negative = bound

$K = -E,\ U = 2E = -2K$
virial relations

MUST KNOW Z is in the DENOMINATOR for radius but the NUMERATOR for speed (Z) and energy (Z^2). Don't misplace it.

MUST KNOW H ground-state energy = −13.6 eV → ionisation energy = 13.6 eV; for ion, ionisation energy = 13.6 Z^2 eV.

- Ground state n = 1, first excited n = 2, second excited n = 3 — count excited states carefully.

4. Hydrogen Spectrum & Spectral Series

Electron jumps to a lower level n_f emit photons whose wavelength obeys the Rydberg formula; series are named by landing level.

$1/\lambda = R(1/n_1^2 - 1/n_2^2)$
Rydberg, R = 1.097×10^7 m^{-1}, $n_1 < n_2$

Number of lines = $n(n-1)/2$
cascade from level n

MUST KNOW Lyman (n_f = 1) UV; Balmer (n_f = 2) VISIBLE (only series fully visible); Paschen/Brackett/Pfund (n_f = 3/4/5) infrared.

MUST KNOW First line of a series = smallest jump = LONGEST wavelength = least energy; series limit (n_i = ∞) = SHORTEST wavelength.

- Lyman series limit = ionisation from ground state (13.6 eV). Keep Z^2 factor for hydrogen-like ions.

5. Limitations & de Broglie Justification

Bohr's quantisation looked arbitrary until de Broglie's standing electron waves explained it.

$\lambda = h/mv$
de Broglie wavelength

$2\pi r = n\lambda \Rightarrow mvr = nh/2\pi$
standing wave → Bohr's L rule

MUST KNOW A stable orbit holds a WHOLE number of electron wavelengths (standing wave); the nth orbit contains exactly n wavelengths.

- de Broglie justifies ONLY the angular-momentum quantisation — not the nucleus, photon emission, or scattering law.
- Bohr's limits: works only for one-electron systems; can't explain fine structure, line intensities, or Zeeman splitting.

Hydrogen Spectral Series

Series	n_f (final)	Transitions	Region
Lyman	1	$n \geq 2 \rightarrow 1$	Ultraviolet
Balmer	2	$n \geq 3 \rightarrow 2$	Visible
Paschen	3	$n \geq 4 \rightarrow 3$	Infrared
Brackett	4	$n \geq 5 \rightarrow 4$	Infrared
Pfund	5	$n \geq 6 \rightarrow 5$	Infrared

n-Dependence (Hydrogen-like)

Quantity	Formula	Varies as
Radius	$0.53\ n^2/Z$ Å	n^2/Z
Speed	$2.18\times10^6\ Z/n$ m/s	Z/n
Energy	$-13.6\ Z^2/n^2$ eV	Z^2/n^2

Mnemonic - Series order Lyman-Balmer-Paschen-Brackett-Pfund and Lyman=UV, Balmer=Visible, rest=IR
Lyman Born As Baby Pfund — UltraViolet, VISible, then InfraRed

Common traps

- Scattering law is $1/\sin^4(\theta/2)$. A bare $\sin^4(\theta/2)$ option is a deliberate trap.
- $L = nh/2\pi$, NOT nh. Forgetting the 2π is the classic blunder.
- An electron in a stationary orbit IS accelerating (centripetal); Bohr postulates it does not radiate anyway — 'not accelerating' is false.
- Longest wavelength means LEAST energy (smallest jump), not most energetic. Don't swap.
- r_0 is only an upper estimate of nuclear size and only for a head-on hit — not the actual nuclear radius.

Most asked in NEET » Closest approach $r_0 \propto 1/K$, $1/m$ | Impact parameter $b = 0 \rightarrow \theta = 180°$ | Energy $E_n = -13.6/n^2$ eV | Bohr validity (one-electron only) | Balmer = visible / longest-shortest λ | de Broglie: n wavelengths in nth orbit

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