Nuclei

Class 12 · Physics · Quick Revision · **chapternotes.in**

NEET: 1-2 Qs (~4-8 marks) | Boards: 4-6 marks

Scan: practise free

The tiny, ultra-dense core of the atom: what holds it together (binding energy), how it breaks apart (radioactivity), and how splitting or fusing it unleashes energy.

1. Nuclear Size, Density & Composition

Nucleus = protons (Z) + neutrons (A-Z); radius depends only on A, density is constant.

Nucleons: Z protons + (A−Z) neutrons
$^{A}_{Z}X$, A = mass number

$R = R_0 A^{1/3}$, $R_0 = 1.2$ fm
1 fm = 10^{-15} m

$V \propto R^3 \propto A$
volume ∝ mass number

$\rho \approx 2.3 \times 10^{17}$ kg/m³
same for ALL nuclei

1u = 1.66×10^{-27} kg = 931.5 MeV
atomic mass unit

MUST KNOW Nuclear density is constant (independent of A and Z) - mass ∝ A and volume ∝ A cancel.

MUST KNOW Radius ratio = cube root of A ratio; volume ratio = A ratio itself. Don't mix them.

- Nuclear matter is ~10^{14} times denser than water - almost all atomic mass sits in the nucleus.

2. Mass Defect & Binding Energy

A bound nucleus is lighter than its free nucleons; the missing mass is its binding energy.

$\Delta m = [Z m_p + (A-Z) m_n] - M_{nucleus}$
mass defect (always > 0)

$BE = \Delta m c^2$
Einstein mass-energy

$BE = \Delta m \times 931.5$ MeV
when Δm is in u

MUST KNOW Mass of nucleus < sum of free nucleon masses; the deficit becomes binding energy.

MUST KNOW BE = energy released on formation = energy needed to break it apart (same number).

- Deuteron BE ≈ 2.2 MeV (Δm ≈ 0.0024 u) - a classic worked value.

3. BE per Nucleon Curve & Stability

BE per nucleon, not total BE, measures stability; the curve peaks at iron.

$\bar{E} = BE / A$
binding energy per nucleon

Peak: A ≈ 56 (Fe), $\bar{E} \approx 8.8$ MeV
most stable region

Energy released = (Σ BE products) − (Σ BE reactants)
each BE = $\bar{E} \times A$

MUST KNOW Higher $\bar{E}$ = more tightly bound = more stable. Everything drifts toward the iron peak.

MUST KNOW Heavy nuclei fission, light nuclei fuse - both move products to higher $\bar{E}$, releasing energy.

- Flat middle of the curve proves the nuclear force is short-range and saturates.

4. Radioactivity: α, β, γ & Decay Law

Unstable nuclei spontaneously emit radiation; decay rate ∝ number present.

α: Z → Z−2, A → A−4
emits $^{4}_{2}He$ nucleus

β^-: Z → Z+1, A unchanged
$n \to p + e^- +$ antineutrino

γ: Z, A unchanged
de-excitation photon

$dN/dt = -\lambda N \rightarrow N = N_0 e^{-\lambda t}$
λ = decay constant

MUST KNOW Balance every decay by conserving BOTH charge (Z) and mass number (A).

MUST KNOW Decay rate is independent of temperature, pressure or chemical state - a pure nuclear property.

- Penetration: γ > β > α. Ionising power is the exact reverse: α > β > γ.

5. Half-Life, Activity, Fission & Fusion

Decay timescales, then the two energy-releasing nuclear reactions.

half-life $T = 0.693/\lambda$
$T = \ln 2 / \lambda$

mean life $\tau = 1/\lambda \approx 1.44\ T$
$\tau > T$

$N/N_0 = (1/2)^n$, $n = t/T$
fraction remaining

activity $A = \lambda N = A_0 e^{-\lambda t}$
Bq = 1 decay/s; 1 Ci = 3.7×10^{10} Bq

Fission ≈ 200 MeV; D+T fusion ≈ 17.6 MeV
per nucleon, fusion wins

MUST KNOW Fraction remaining = $(1/2)^n$; fraction decayed = $1 - (1/2)^n$. Read what's asked.

- Activity and number of nuclei both halve every half-life - same exponential law.

MUST KNOW Fusion needs ~10^7 K to beat Coulomb repulsion; a moderator SLOWS neutrons in fission.

α vs β⁻ vs γ Radiation

	Alpha (α)	Beta-minus (β^-)	Gamma (γ)
Nature	$_2^4$He nucleus	Electron (e^-)	EM photon
Charge	+2e	−e	0
Change in Z	−2	+1	0
Change in A	−4	0	0
Penetration	Lowest (paper)	Medium (Al)	Highest (lead)
Ionising power	Highest	Medium	Lowest

Fission vs Fusion

	Fission	Fusion
Process	Heavy nucleus splits	Light nuclei combine
Trigger	Neutron capture	Very high temp (~10^7 K)
Energy	~200 MeV / nucleus	~17.6 MeV (D+T)
Per nucleon	Less	More
Example	U-235 chain reaction	Powers the Sun

Mnemonic - Decay bookkeeping: α removes Z−2/A−4, β^- raises Z by 1, γ changes nothing
Alpha Adds 2&4, Beta Bumps Z up, Gamma Glides (no change)

Common traps

- Radius ratio uses the CUBE ROOT of the A ratio; volume ratio uses the A ratio directly. Mixing them is the classic blunder.
- Nuclear density is the SAME for every nucleus - it does not depend on A or Z. Free mark.
- β^- RAISES Z by 1 (neutron → proton); lowering it is a common slip. Also β-electrons are created in decay, not pre-existing.
- Decay rate cannot be changed by heat, pressure or chemistry. 931.5 MeV is per u; don't confuse with 511 keV (electron) or ~200 MeV (per fission).
- Moderator SLOWS neutrons to sustain fission; control rods ABSORB them. Fusion needs high temperature, not moderators.

Most asked in NEET » R ∝ A^(1/3) radius/nucleon ratios · Mass defect → BE (×931.5) · α/β/γ decay balancing & isotope identity · Half-life: $(1/2)^n$ & parent:daughter ratios · Activity A = λN · Fission ~200 MeV / fusion powers Sun