

Chapter 13 · Nuclei

CBSE Class 12 Physics (042) · Unit VIII · Unit VII + VIII = 12 marks · Ultimate Revision Sheet

SCOPE ALERT — OFFICIAL 2026-27 SYLLABUS The chapter is now: **composition and size of the nucleus, nuclear force, mass-energy relation, mass defect, binding energy per nucleon and its variation with mass number, nuclear fission and fusion.**

Radioactivity and the decay law are **NOT** in the list — confirm with your teacher before skipping, since schools often still test them internally.

60-SECOND RECALL

Nuclear radius	$R = R_0 A^{1/3}$, $R_0 = 1.2 \times 10^{-15} \text{ m}$
Density	Independent of A $\approx 2.3 \times 10^{17} \text{ kg m}^{-3}$
Mass defect	$\Delta m = [Zm_p + (A-Z)m_n] - M_{\text{nucleus}}$
Einstein	$E = \Delta mc^2 \cdot 1 \text{ u} = 931.5 \text{ MeV}$
BE per nucleon	Peak $\approx 8.8 \text{ MeV}$ near A = 56 (iron) — the most stable
Fission	Heavy nucleus splits $\rightarrow \sim 200 \text{ MeV}$ per event
Fusion	Light nuclei join $\rightarrow$ more energy per nucleon ; powers the Sun

1. Composition and Size

THE BASICS A nucleus contains **Z protons** and **(A - Z) neutrons**, together called **nucleons**.

Isotopes: same Z, different A (^1H , ^2H , ^3H). **Isobars:** same A, different Z. **Isotones:** same number of neutrons.

$$R = R_0 A^{1/3} \rightarrow \text{volume} \propto A$$

Since mass $\propto A$ and volume $\propto A$, the **nuclear density is the same for every nucleus** — a standard 1-marker.

NUCLEAR FORCE — the four properties 1. **Strongest force** in nature, about 100 times the electrostatic force.

2. **Extremely short range** — effective only within about 10^{-15} m ; beyond a few fermi it is negligible.

3. **Charge independent** — the same between n-n, p-p and n-p.

4. **Saturated** — each nucleon interacts only with its **immediate neighbours**, which is why BE per nucleon stays roughly constant.

2. Mass Defect and Binding Energy

DEFINITIONS Mass defect: the difference between the sum of the masses of the free nucleons and the actual mass of the nucleus.

Binding energy: the energy equivalent of the mass defect — equally, the energy needed to break the nucleus into its free nucleons.

FORMULAS

$$\Delta m = [Zm_p + (A - Z)m_n] - M$$

$$BE = \Delta m \times c^2 \rightarrow BE \text{ (MeV)} = \Delta m \text{ (u)} \times 931.5$$

$$BE \text{ per nucleon} = BE / A \text{ — this, not total BE, measures stability}$$

THE BE-PER-NUCLEON CURVE — read all three regions Rises steeply for light nuclei → peaks at about 8.8 MeV near $A = 56$ (iron region) → falls slowly for heavy nuclei (about 7.6 MeV at uranium). Light nuclei can **FUSE** to climb the curve; heavy nuclei can **FISSION** to climb it from the other side. Both move towards the peak, and both therefore **release energy**. This single sentence explains the whole chapter.

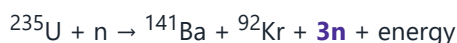


Energy is released when the products sit **HIGHER** on this curve.
Nearly flat from $A \approx 30$ to 170 — the nuclear force is short-range and saturated.

Both processes move nuclei **towards Fe-56**. That single sentence answers "why does fission of heavy nuclei and fusion of light nuclei both release energy?"

3. Fission and Fusion

NUCLEAR FISSION A heavy nucleus splits into two lighter nuclei of comparable mass, releasing neutrons and about **200 MeV** per fission.



The released neutrons can trigger further fissions — a **chain reaction**. Controlled in a **nuclear reactor** using **cadmium or boron control rods** (to absorb neutrons) and a **moderator** such as heavy water or graphite (to slow the fast neutrons).

NUCLEAR FUSION Light nuclei combine to form a heavier nucleus, releasing energy.



Requires **extremely high temperature** ($\approx 10^7\ \text{K}$) to overcome the **Coulomb repulsion** between nuclei, which is why it is called a **thermonuclear** reaction.

TRAP — the comparison examiners want **Fission releases more energy per EVENT** ($\sim 200\ \text{MeV}$); **fusion releases more energy per NUCLEON** ($\sim 6\ \text{MeV}$ vs $\sim 0.85\ \text{MeV}$). A question asking "which releases more energy" is almost always testing which of the two you compare. Fusion is **cleaner** (no long-lived radioactive waste) and its fuel is abundant, but it is **hard to control** at the required temperatures.

WORKED EXAMPLE Find the binding energy per nucleon of ^4He . Given $m_p = 1.00728\ \text{u}$, $m_n = 1.00867\ \text{u}$, $M(^4\text{He nucleus}) = 4.00151\ \text{u}$.

$$\text{Free nucleons} = 2(1.00728) + 2(1.00867) = 2.01456 + 2.01734 = \mathbf{4.03190\ u}$$

$$\Delta m = 4.03190 - 4.00151 = \mathbf{0.03039\ u}$$

$$\text{BE} = 0.03039 \times 931.5 = \mathbf{28.3\ MeV}$$

BE per nucleon = $28.3 / 4 = \mathbf{7.1\ MeV}$ — high for such a light nucleus, which is why the α -particle is exceptionally stable.

4. Question Triggers what the wording is really asking

If the question says...	The answer is...
"density of the nucleus of different elements"	Same for all — $R \propto A^{1/3}$
"most stable nucleus"	Highest BE per nucleon → near iron, A = 56
"why energy is released in fission AND fusion"	Both move towards the peak of the BE curve
"role of the moderator"	Slows fast neutrons (heavy water, graphite)
"role of control rods"	Absorb neutrons (cadmium, boron)
"why fusion needs high temperature"	To overcome Coulomb repulsion
"energy equivalent of 1 u"	931.5 MeV

MOST-ASKED BOARD QUESTIONS

- [3M]** Draw the **binding energy per nucleon vs mass number** curve and use it to explain fission and fusion.
- [3M]** Define **mass defect** and **binding energy**; calculate BE per nucleon for a given nucleus.
- [2M]** State four properties of the **nuclear force**.
- [2M]** Show that **nuclear density is independent of mass number**.
- [2M]** Distinguish between **nuclear fission and fusion**.
- [1M]** What is the energy equivalent of **1 atomic mass unit**? → **931.5 MeV**

THE HABIT THAT SCORES — Draw the BE-per-nucleon curve from memory at the start of any long answer here, and label the peak at $A = 56$. Half the marks in this chapter are explanations that become obvious the moment that curve is on the page.