A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 23 · ~5 MIN READ

Nuclear physics

Mass–energy equivalence, mass defect and binding energy, the binding energy per nucleon curve and why fission and fusion release energy, and the random, spontaneous nature of radioactive decay with activity, decay constant and half-life.

E = mc² | Mass defect | Binding energy | Binding energy per nucleon | Fission & fusion | Random & spontaneous decay | Activity A = λN | Exponential decay

RS by Riyaz Sir
mentorriyaz.in

Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Mass and energy are equivalent:** E = mc². A nucleus has less mass than its separate nucleons; the difference is the mass defect.
- **Binding energy** is the energy needed to separate a nucleus into its nucleons. Higher binding energy per nucleon means a more stable nucleus.
- **Fission and fusion both release energy** because the products have a higher binding energy per nucleon than the starting nuclei (iron-56 is near the peak).
- **Decay is random and spontaneous.** Activity A = λN, and N = $N_0e^{-\lambda t}$, with half-life $t_{½} = \ln 2/\lambda$.

BY THE END YOU CAN

- Understand mass defect and binding energy, and use E = mc².
- Sketch and interpret the binding energy per nucleon curve, explaining fission and fusion.
- Explain that radioactive decay is random and spontaneous.
- Define and use activity, decay constant and half-life; use A = λN and $x = x_0e^{-\lambda t}$.

1 Mass and energy

Binding energy

Mass defect — the difference between the total mass of the separate nucleons and the mass of the nucleus.

Binding energy — the minimum energy required to separate a nucleus into its constituent protons and neutrons.

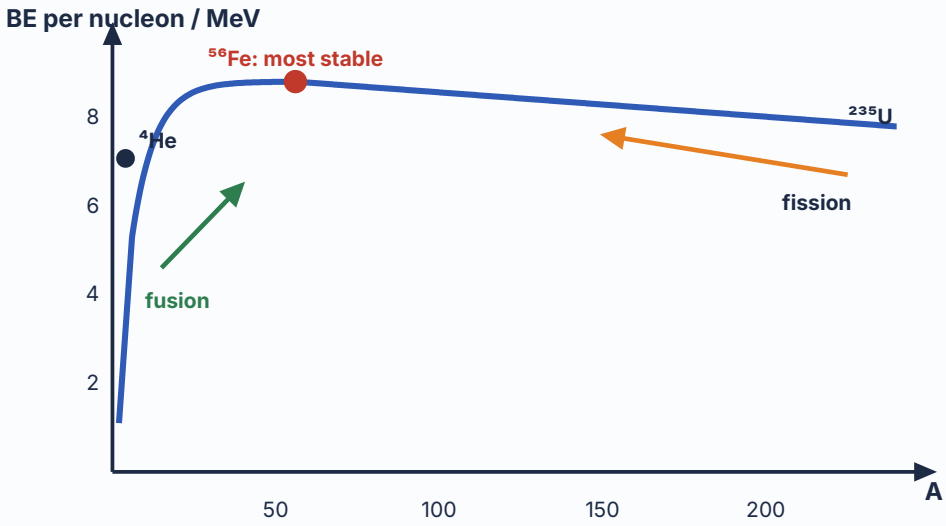
$$E = mc^2 \; ; \; 1 \text{ u} \equiv 931.5 \text{ MeV}$$

$$\Delta E = \Delta m \, c^2$$

WORKED EXAMPLE

Find the binding energy per nucleon of helium-4. Masses: proton 1.007276 u, neutron 1.008665 u, He-4 nucleus 4.001506 u.

1. $\Delta m = 2(1.007276) + 2(1.008665) - 4.001506 = 0.030376$ u C1
2. $E = 0.030376 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 = 4.5 \times 10^{-12}$ J (28.3 MeV) C1 A1
3. **per nucleon: 1.1×10^{-12} J ≈ 7.1 MeV** A1



Binding energy per nucleon peaks near iron-56; moving towards the peak releases energy.

- **Fission:** a heavy nucleus (e.g. uranium-235) splits into two medium nuclei, which have greater binding energy per nucleon. **Fusion:** light nuclei (hydrogen isotopes) join, also moving up the curve.

COMMON MISTAKE

"Binding energy is the energy stored in the nucleus that is released". It's the energy needed to pull it apart. Energy is released when binding energy per nucleon increases.

2 Radioactive decay

Random and spontaneous

- **Random:** you can't predict which nucleus will decay next or when; each nucleus has a constant probability of decay per unit time. Evidence: fluctuations in count rate.
- **Spontaneous:** decay isn't affected by external conditions (temperature, pressure, chemical state).

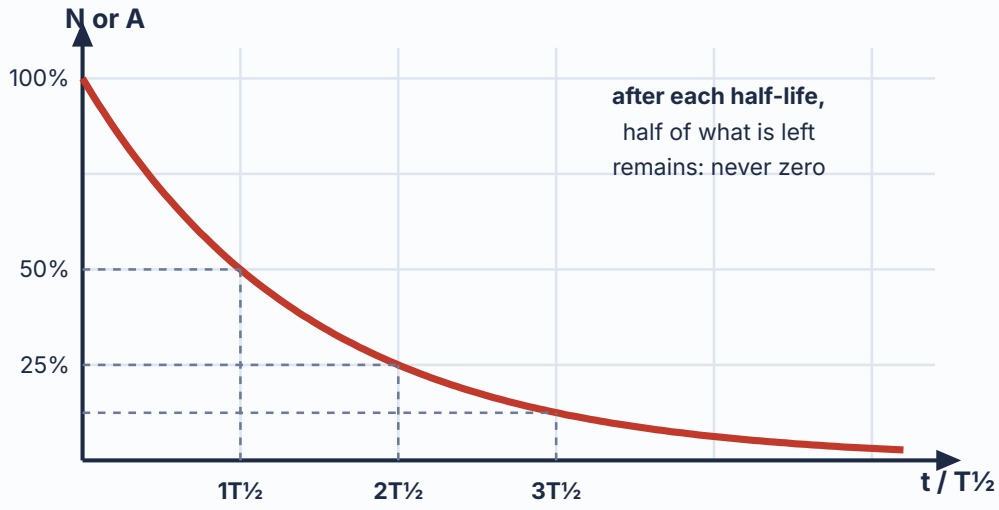
Activity — the number of nuclei decaying per unit time: $A = \lambda N$ (unit: becquerel, Bq = s^{-1}).

Decay constant λ — the probability that an individual nucleus will decay per unit time.

Half-life — the time taken for the number of undecayed nuclei (or the activity) to halve.

$$A = \lambda N \; ; \; x = x_0 e^{-\lambda t} \; ; \; \lambda = 0.693/t_{½}$$ DATA & FORMULAE

x can be N, A or the count rate (corrected)



Exponential decay: equal times give equal fractional decreases.

WORKED EXAMPLE

Iodine-131 has a half-life of 8.0 days. A sample has activity 4.0×10^6 Bq. Find (a) λ, (b) the number of nuclei, (c) the activity after 20 days, (d) the time for the activity to fall to 10%.

1. (a) $\lambda = 0.693/(8.0 \times 86\,400) =$ **1.0×10^{-6} s^{-1}** A1
2. (b) $N = A/\lambda =$ **4.0×10^{12} nuclei** A1
3. (c) $A = 4.0 \times 10^6 \times 0.5^{2.5} =$ **7.1×10^5 Bq** C1 A1
4. **(d) $t = \ln 10/\lambda = 27$ days** A1

COMMON MISTAKE

Mixing units of λ and t, e.g. λ in day^{-1} with t in seconds. Also forgetting to subtract background count before analysing.

LINKING QUESTION

Nuclear notation and decay types are in Particle physics; exponential decay also governs capacitor discharge; and annihilation ($E = mc^2$) is used in PET in Medical physics.

Test yourself — cover the answers first

QUICK CHECK

1. Define binding energy.
2. Which nucleus is near the peak of the binding energy per nucleon curve?
3. What does "spontaneous" mean for radioactive decay?
4. Find λ for a half-life of 10 s.
5. What fraction remains after 3 half-lives?

EXAM-STYLE

6. Find the energy equivalent of 1.0 u in MeV.
7. A source has 3.0×10^{15} nuclei and $\lambda = 2.0 \times 10^{-9}$ s^{-1}. Find its activity.
8. The count rate (corrected) falls from 800 to 200 in 6.0 h. Find the half-life.

Show answers

1. the minimum energy needed to separate a nucleus into its nucleons
2. iron-56
3. not affected by external factors
4. 0.0693 s^{-1}
5. 1/8
6. $1.66 \times 10^{-27} \times 9.0 \times 10^{16} = 1.49 \times 10^{-10}$ J = 934 MeV (931.5 with precise constants)
7. $A = 6.0 \times 10^{6}$ Bq
8. two half-lives in 6.0 h ⇒ t½ = 3.0 h

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Want regular help? Send this to your parent →

Share with a friend

Ask Riyaz Sir