23.1 Mass defect and nuclear binding energy

Name: ____________ Class: ________ Date: __________ **Total: 18 marks**

Objective

Build the skills to answer exam questions on **mass defect and binding energy**.

You must be able to:

- use $E = mc^2$ and balance **nuclear equations**
- define **mass defect** and **binding energy**
- use the **binding energy per nucleon** curve for fusion and fission

1 Worked examples

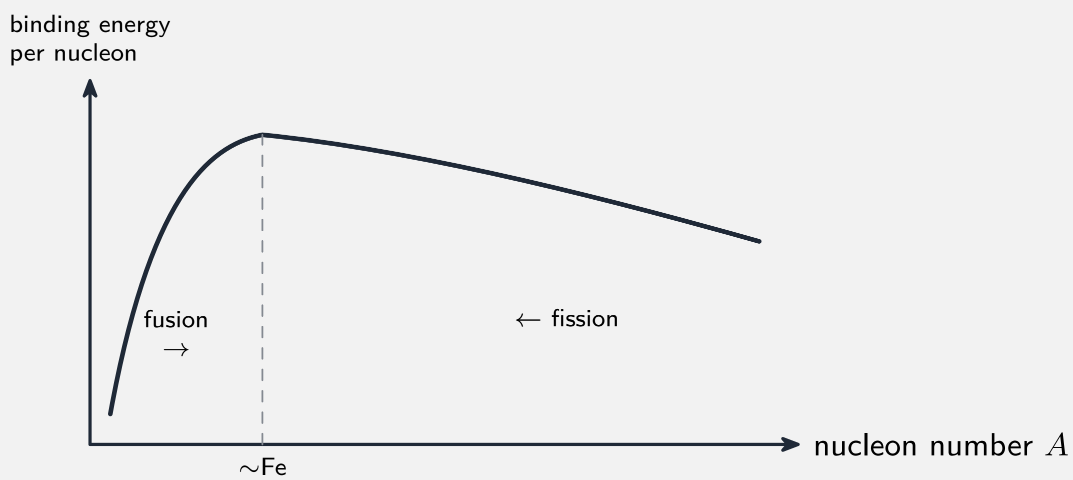
Study these first. Each one shows the method for a question type used later —follow the steps and you can do the Practice and Exam-style questions yourself.

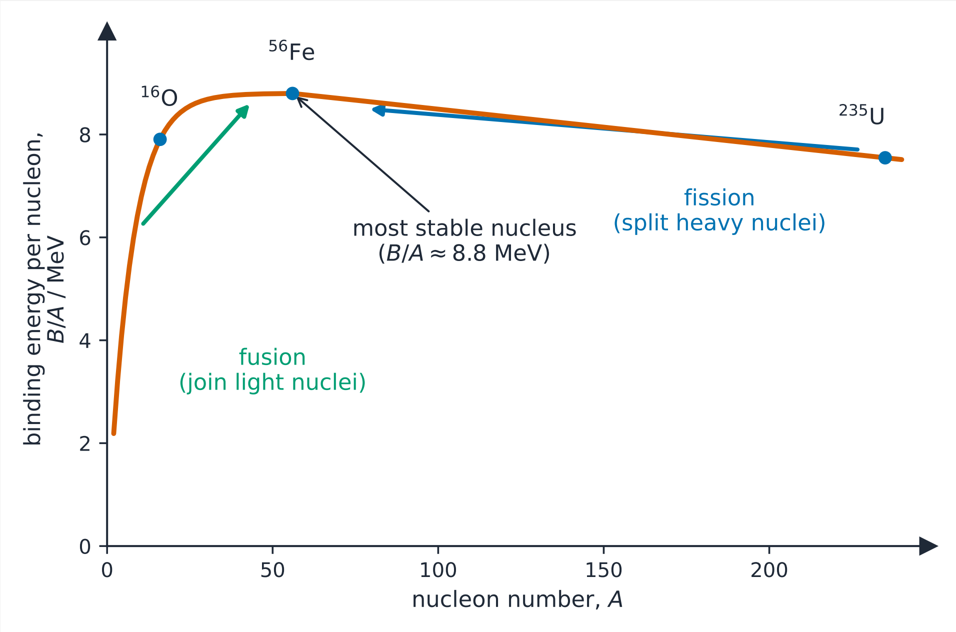
■ Mass-energy and binding energy

$$E = mc^2, \qquad \Delta E = c^2 \Delta m, \qquad 1\ \text{u} \approx 931\ \text{MeV}.$$

The **mass defect** is the difference between the mass of the separate nucleons and the mass of the nucleus; the **binding energy** is the energy equivalent of this ($\Delta E = c^2 \Delta m$) —the energy to split the nucleus apart.

■ Binding energy per nucleon





Binding energy per nucleon across the nuclides

The peak (near iron) is the **most stable**. **Fusion** of light nuclei and **fission** of heavy nuclei both move **towards the peak** —increasing binding energy per nucleon and **releasing energy**.

In nuclear equations, **nucleon number** and **charge** are conserved.

■ Energy released in a decay (from masses)

The energy released is the **mass lost** (parent mass − total product mass), converted with 1 u ≈ 931 MeV:

$$Q = \left(m_{\text{before}} - m_{\text{after}}\right) \times 931\ \text{MeV/u}.$$

Worked example. $^{238}_{92}\text{U} \to {}^{234}_{90}\text{Th} + {}^{4}_{2}\alpha$, with masses (u): U = 238.05079, Th = 234.04360, α = 4.00260. Mass lost Δm = 238.05079 − (234.04360 + 4.00260) = 0.00459 u; energy released Q = 0.00459 × 931 = 4.3 MeV.

Working **backwards**: if the released energy is known, $\Delta m = Q/931$ u, which fixes a missing mass.

2 Practice

Now apply the methods above.

2.1 State **Einstein's** mass–energy equation. [1]

2.2 Define **mass defect**. [1]

2.3 Define **binding energy**. [1]

2.4 In ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{A}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$, find the nucleon number A. [1]

3 Exam-style questions

3.1 The **most stable** nuclei have: [1]

- **A** the highest mass
- **B** the highest binding energy per nucleon
- **C** the lowest binding energy per nucleon
- **D** zero binding energy

3.2 A reaction has a mass defect of 0.030 u. Calculate the energy released. (1 u = 931 MeV.) [2]

3.3 Explain how the binding-energy-per-nucleon curve shows that **both** fusion of light nuclei **and** fission of heavy nuclei can release energy. [3]

3.4 Calculate the energy equivalent of a mass change of 1.0×10^{-29} kg. [2]

3.5 In the decay ${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\alpha$, the masses (u) are: Po = 209.98286, Pb = 205.97444, $\alpha = 4.00260$. Calculate the energy released, in MeV. (1 u = 931 MeV.) [3]

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **23.1 Mass defect and nuclear binding energy** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/41 N25 —Q8 (mass defect; energy from masses)
- 9702/42 N25 —Q9 (binding energy, structured)
- 9702/44 J25 —Q11 ($E = mc^2$ in a decay)
- 9702/42 M25 —Q9 (binding energy per nucleon)

Solutions

2.1 $E = mc^2$.

2.2 The difference between the **total mass of the separate nucleons** and the **mass of the nucleus**.

2.3 The energy needed to **separate a nucleus** into its individual nucleons (equivalent to the mass defect).

2.4 $14 + 4 = A + 1 \Rightarrow A = 17$.

3.1 **B** —the highest binding energy per nucleon.

3.2 $E = 0.030 \times 931 = 28$ MeV.

3.3 Both light nuclei (fusing) and heavy nuclei (splitting) move **towards the peak** of the curve; this **increases** the binding energy per nucleon; the products are more tightly bound, so energy is **released**.

3.4 $E = mc^2 = (1.0 \times 10^{-29})(3.0 \times 10^8)^2 = 9.0 \times 10^{-13}$ J.

3.5 Mass lost $\Delta m = 209.98286 - (205.97444 + 4.00260) = 0.00582$ u; energy released $Q = 0.00582 \times 931 = 5.4$ MeV.