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WORKSHEETS
ATTEMPT | CHECK | CORRECT | IMPROVE

Binding energy per nucleon

From the binding-energy curve to reaction energy

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 38 marks

Specification points covered

6.4.4(e): binding energy per nucleon, its variation with nucleon number, and interpretation for fusion and fission.

Supporting 6.4.4(a), (b), (d): mass–energy, total binding energy and nuclear-energy calculations.

Prerequisites: nucleon/proton numbers and balanced nuclear equations. Numerical calculations use the supplied tables, not a scale read from the qualitative graph.

Write $b = E_B/A$ for binding energy per nucleon. Use 1 MeV = 1.602×10^{-13} J. A free proton or neutron has zero nuclear binding energy. Use the supplied rounded illustrative values throughout.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Compare like with like

A spacecraft-power research team compares nuclear reaction proposals. It must distinguish energy per nucleus, energy per nucleon and energy per complete reaction.

Figure 1 shows the broad trend. Fine structure and individual isotopes are not represented; use the data supplied for every numerical calculation.

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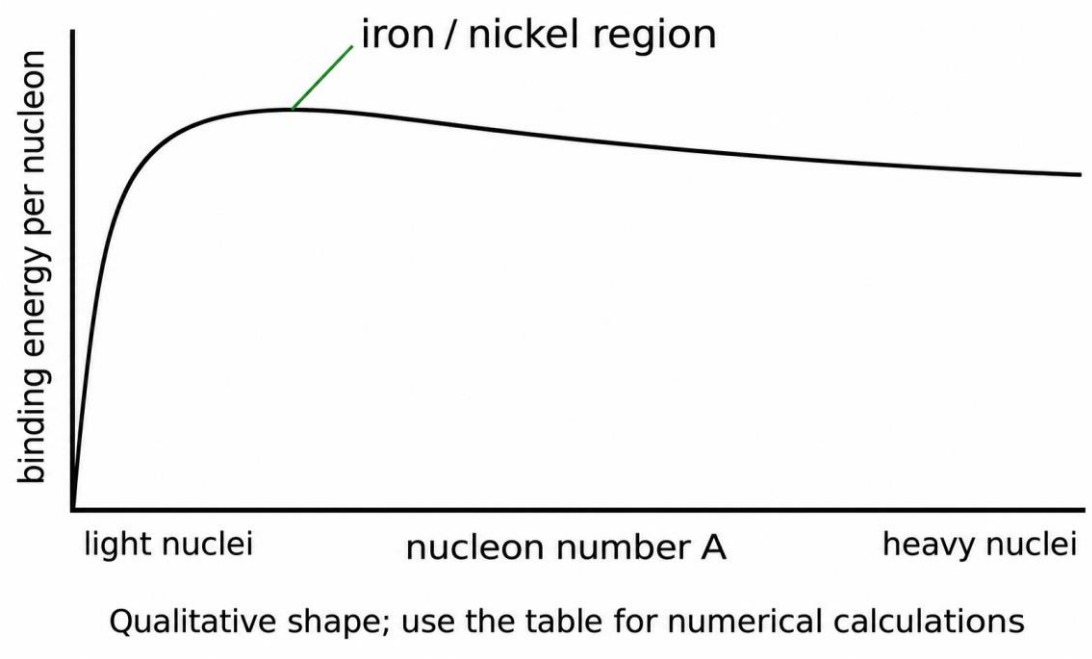


Figure 1 Qualitative variation of binding energy per nucleon

1(a) A model nucleus has total binding energy 522 MeV and A = 60. Calculate its binding energy per nucleon, giving an appropriate unit. **[1 mark]**

1(b) A second model nucleus has A = 200 and b = 7.90 MeV nucleon^{-1}. Calculate its total binding energy and decide which of the two nuclei has the greater average binding per nucleon. **[2 marks]**

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2 Read the physical meaning of the curve

2(a) Describe the broad change in binding energy per nucleon as A increases from very light nuclei through the iron/nickel region to very heavy nuclei. **[2 marks]**

2(b) Explain why some fusion reactions between light nuclei release energy. Refer to total binding energy as well as the curve. **[2 marks]**

2(c) Explain why splitting a very heavy nucleus into suitable medium-mass products can release energy. **[2 marks]**

2(d) Why is it incorrect to read a height from this qualitative figure and quote it as a three-significant-figure reaction energy? **[1 mark]**

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3 Calculate a complete fusion energy

Table 1 Rounded binding data for the fusion model

Nuclide	A	b / MeV nucleon^{-1}
Deuterium	2	1.112
Tritium	3	2.827
Helium-4	4	7.074
Free neutron	1	0

3(a) For deuterium (A = 2), tritium (A = 3) and helium-4, calculate the total binding energies from Table 1. **[2 marks]**

3(b) The proposed reaction is deuterium plus tritium forming helium-4 and a neutron. Write the balanced nuclear equation. **[1 mark]**

3(c) Calculate the rest-energy release Q per reaction from the binding energies, showing the separate reactant and product sums. **[3 marks]**

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3(d) Convert the fusion energy release to joules and calculate the energy release per reacting nucleon, counting all five initial nucleons. **[2 marks]**

4 Apply the same method to a fission model

Table 2 Illustrative fission-model binding values

Species	A	b / MeV nucleon^{-1}
Compound uranium	236	7.60
Strontium product	94	8.60
Xenon product	140	8.40

4(a) A compound uranium-236 nucleus (Z = 92) splits into strontium-94 (Z = 38), xenon-140 (Z = 54) and free neutrons. Determine the number of free neutrons and write the balanced nuclear equation. **[2 marks]**

4(b) Use Table 2 to calculate the initial total binding energy and the final combined total binding energy. **[2 marks]**

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4(c) Calculate Q per fission in MeV and the energy release per initial nucleon. Compare the latter with the fusion value from 3(d). **[2 marks]**

4(d) A colleague instead averages 8.60 and 8.40, subtracts 7.60, then multiplies by 236 to obtain 212.4 MeV. Identify two mistakes in that method. **[2 marks]**

5 Check the limits of a quick conclusion

5(a) For a supplied model, two helium-4 nuclei form a beryllium-8 nucleus. Use b(He-4) = 7.074 and b(Be-8) = 7.062 MeV nucleon^{-1} to calculate Q. Does this fusion model release energy? **[2 marks]**

5(b) Two candidate nuclei have A = 56, b = 8.790 and A = 62, b = 8.795 MeV nucleon^{-1}. Calculate each total binding energy, then explain which quantity answers “which has the greater mean binding per nucleon?”. **[2 marks]**

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5(c) For the fusion and fission reactions above, the total numbers of protons and neutrons are separately unchanged. Explain why this lets us obtain Q from the increase in total binding energy. Why should that shortcut not be used uncritically for beta decay? **[2 marks]**

5(d) The fission-model team quotes Q = 190.800000 MeV from Table 2. Explain why the displayed precision is misleading. **[1 mark]**

6 Give a defensible recommendation

6(a) A proposal claims “fission is always the better energy source because 190.8 is larger than 17.6”. Evaluate that numerical argument using the models here, then identify one further piece of information needed for an actual spacecraft design choice. **[2 marks]**

6(b) A researcher says the nucleus with the larger b must always have the longer radioactive half-life. Explain why that conclusion does not follow from this worksheet’s data. **[1 mark]**

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6(c) Write a short checking sequence that would prevent a student from confusing per-nucleon binding values with a reaction energy. Include the sign of the final result. **[2 marks]**

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