InkPhysics

ANSWER BOOK

Mass-energy and binding energy

Nuclear physics · Year 13

AQA 3.8.1.6 · CIE 11.1.12, 23.1.1, 23.1.3, 23.1.4, 23.1.6, 23.1.7
OCR A 6.4.4(a), 6.4.4(b), 6.4.4(d), 6.4.4(e), 6.4.4(f)

18 questions · 48 marks

NAVY EDITION

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SECTION A · Warm-up

A1 $E = mc^2$ (1). Binding energy is the energy required to separate a nucleus completely into its individual nucleons (or the energy released when the nucleus forms from separate nucleons) (1). [2]

A2 $E = mc^2 = 1.0 \times 10^{-28} \times (3.0 \times 10^8)^2$ (1) [2]
$E = 9.0 \times 10^{-12}$ J (1)

A3 1 u is equivalent to 931.5 MeV (1). [1]

A4 One twelfth of the mass of an atom of carbon-12 (1); 1 u = 1.661×10^{-27} kg (1). [2]

A5 The mass increases (1). $\Delta m = E/c^2$, and because c^2 is so large the mass gained in any everyday energy transfer is far too small to measure (1). [2]

SECTION B · Standard

B1 Total nucleon mass = $2 \times 1.00728 + 2 \times 1.00867 = 4.03190$ u (1) [4]
Mass defect = $4.03190 - 4.00150 = 0.03040$ u (1)
Binding energy = 0.03040×931.5 (1)
BE = 28.3 MeV (1)

B2 BE per nucleon = $28.3/4$ (1) [2]
= 7.08 MeV per nucleon (1)

B3 $E = 28.3 \times 1.60 \times 10^{-13}$ (1) [2]
$E = 4.53 \times 10^{-12}$ J (1)

B4 $m = E/c^2 = (2.0 \times 10^{-11})/(3.0 \times 10^8)^2$ (1) [2]
$m = 2.22 \times 10^{-28}$ kg (1)

B5 Total binding energy = $7.98 \times 16 = 127.7$ MeV (1) [3]
$\Delta m = BE/931.5$ (1)
$\Delta m = 0.137$ u (1)

B6 Mass after = $222.01757 + 4.00260 = 226.02017$ u (1) [3]
$\Delta m = 226.02540 - 226.02017 = 0.00523$ u (1)
$E = 0.00523 \times 931.5 = 4.9$ MeV (1)

B7 Stability is compared using binding energy per nucleon, not total binding energy (1) [3]
X: 1638/210 = 7.8 MeV per nucleon; Y: 492/56 = 8.8 MeV per nucleon (1)
Y is the more tightly bound per nucleon, so the student is not correct (1)

SECTION C · Stretch

C1 Binding energy = 0.099 × 931.5 (1) [3]
BE = 92.2 MeV (1)
BE per nucleon = 92.2/12 = 7.68 MeV per nucleon (1)

C2 The curve rises steeply for light nuclei to a broad maximum near iron-56 at about 8.8 MeV per nucleon (1); it falls gently for heavier nuclei (1). Any change that moves nuclei towards the peak increases the binding energy per nucleon, releasing energy (1); fusion moves light nuclei up the rising part, and fission moves heavy nuclei back towards the peak, so both release energy (1). [4]

C3 The peak, near iron-56, corresponds to the most tightly bound and most stable nuclei (1). Nuclei on either side can release energy by changing towards the peak (1); iron itself cannot release energy by fusion or fission, so it is the endpoint of energy-releasing nuclear processes in stars (1). [3]

C4 $E = mc^2 = 1.661 \times 10^{-27} \times (3.0 \times 10^8)^2$ (1) [3]
$E = 1.495 \times 10^{-10}$ J (1)
$E = 1.495 \times 10^{-10}/(1.60 \times 10^{-13}) = 934$ MeV ≈ 930 MeV (1)

C5 Each nucleon becomes more tightly bound by 8.5 - 7.6 = 0.9 MeV (1) [3]
Energy released ≈ 0.9 × 240 (1)
E ≈ 216 MeV (1)

C6 Mass after separation = 11.99671 + 1.00867 = 13.00538 u (1) [4]
The products are more massive than carbon-13 by Δm = 13.00538 - 13.00006 = 0.00532 u (1)
This extra mass must be supplied as energy: E = 0.00532 × 931.5 (1)
E = 5.0 MeV (1)