



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

**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]  
 $E = 9.0 \times 10^{-12} \text{ J}$  (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);  $1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$  (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 =  $2 \times 1.00728 + 2 \times 1.00867 = 4.03190 \text{ u}$  (1) [4]  
 Mass defect =  $4.03190 - 4.00150 = 0.03040 \text{ u}$  (1)  
 Binding energy =  $0.03040 \times 931.5$  (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]  
 $E = 4.53 \times 10^{-12} \text{ J}$  (1)
- B4**  $m = E/c^2 = (2.0 \times 10^{-11})/(3.0 \times 10^8)^2$  (1) [2]  
 $m = 2.22 \times 10^{-28} \text{ kg}$  (1)
- B5** Total binding energy =  $7.98 \times 16 = 127.7 \text{ MeV}$  (1) [3]  
 $\Delta m = \text{BE}/931.5$  (1)  
 $\Delta m = 0.137 \text{ u}$  (1)
- B6** Mass after =  $222.01757 + 4.00260 = 226.02017 \text{ u}$  (1) [3]  
 $\Delta m = 226.02540 - 226.02017 = 0.00523 \text{ u}$  (1)  
 $E = 0.00523 \times 931.5 = 4.9 \text{ MeV}$  (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 =  $0.099 \times 931.5$  (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  $\approx$  930 MeV (1)
- C5** Each nucleon becomes more tightly bound by  $8.5 - 7.6 = 0.9$  MeV (1) [3]  
 Energy released  $\approx 0.9 \times 240$  (1)  
 $E \approx 216$  MeV (1)
- C6** Mass after separation =  $11.99671 + 1.00867 = 13.00538$  u (1) [4]  
 The products are more massive than carbon-13 by  $\Delta m = 13.00538 - 13.00006 = 0.00532$  u (1)  
 This extra mass must be supplied as energy:  $E = 0.00532 \times 931.5$  (1)  
 $E = 5.0$  MeV (1)