Solutions

Each answer shows the steps, then the **result**.

2.1

- the mass defect is the **difference** between the total mass of the separate nucleons and the mass of the nucleus they form
- the **total mass of the separate nucleons is larger**; the nucleus is always lighter

2.2

- the **energy needed to separate a nucleus into its individual nucleons**
- equivalently, the energy released when those separate nucleons come together to form the nucleus

2.3

- use $E = mc^2$ in SI units

$$E = 1.66 \times 10^{-27}\ \text{kg} \times (3.00 \times 10^8\ \text{m s}^{-1})^2 = 1.49 \times 10^{-10}\ \text{J}$$

- convert to MeV

$$E = \frac{1.49 \times 10^{-10}\ \text{J}}{1.60 \times 10^{-13}\ \text{J MeV}^{-1}} = \mathbf{934}\ \text{MeV}$$

- this is the tabulated 931.5 MeV, to the precision of the data given

2.4

- divide the total binding energy by the number of nucleons

$$\frac{492\ \text{MeV}}{56} = \mathbf{8.8}\ \text{MeV per nucleon}$$

2.5

- the maximum is at about **iron-56**, and it marks the **most stable** nuclide
- a higher binding energy per nucleon means more energy is needed to pull the nucleus apart; nothing beyond iron can be made with a release of energy

3.1 C

- binding energy is the energy that must be **put in** to separate the nucleons
- **A** reverses the direction; **B** is the energy released in a particular decay, not the binding energy; **D** would be about 10^5 times too large

3.2

(a)

- a **steep rise** from hydrogen through the light nuclei
- a **maximum** at about nucleon number **56**, at roughly 8.8 MeV per nucleon
- a **gentle fall** from there to about 7.6 MeV per nucleon at uranium

(b)

- energy is released whenever the products have a **higher binding energy per nucleon** than the reactants, that is, whenever the nucleons move **up** the curve
- **fusion** of two light nuclei moves far up the steep left-hand side, towards the maximum
- **fission** of a heavy nucleus produces two nuclei nearer the maximum, moving back up the gentle right-hand side

3.3

(a)

- nucleon number: $3 + 3 = 6$ on the left, and $4 + 2 \times 1 = 6$ on the right
- proton number: $2 + 2 = 4$ on the left, and $2 + 2 \times 1 = 4$ on the right

(b)

- total masses before and after, keeping all the decimal places

$$\text{before} = 2 \times 3.01603\ \text{u} = 6.03206\ \text{u}, \qquad \text{after} = 4.00260 + 2 \times 1.00783 = 6.01826\ \text{u}$$

$$\Delta m = 6.03206\ \text{u} - 6.01826\ \text{u} = \mathbf{1.380 \times 10^{-2}}\ \text{u}$$

(c)

- multiply by the conversion factor

$$E = 931.5\ \text{MeV u}^{-1} \times 1.380 \times 10^{-2}\ \text{u} = \mathbf{12.9}\ \text{MeV}$$

(d)

- both nuclei carry a **positive charge**, so they **repel** each other electrostatically
- to fuse they must come close enough for the short-range **strong nuclear force** to act, which needs a very large kinetic energy to overcome that repulsion
- a very high temperature is what gives the nuclei kinetic energy of that size, since the mean kinetic energy of a particle is proportional to the thermodynamic temperature

(e)

- the reaction **absorbs** energy; it cannot happen spontaneously
- mass has increased, so by $E = \Delta mc^2$ energy of at least $|\Delta m|c^2$ must have been **supplied** from outside to create it

(f)

- the binding-energy-per-nucleon curve **rises very steeply** on the light side but **falls only gently** beyond the maximum
- so fusing two light nuclei moves each nucleon much further up the curve than splitting a heavy nucleus does, and the energy released per nucleon is correspondingly larger