Unit 24 · Nuclear Physics

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 28

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

She subtracted the **atomic** mass, which includes 7 electrons, from bare protons and neutrons. The nucleus is $14.003\,074 - 7 \times 0.000\,549 = 13.999\,231$ u. Mass defect $= 14.111\,587 - 13.999\,231 = 0.112\,356$ u, so the binding energy is **104.7 MeV** (7.48 MeV per nucleon).

MARKING SCHEME

- ✓ The error: the atomic mass includes 7 electrons.
- ✓ Nuclear mass 13.999 231 u; mass defect 0.112 356 u.
- ✓ Binding energy 104.7 MeV.

2 Work backwards

ANSWER A · 2

A^(1/3) = $R/r_0 = 6.0 \div 1.2 = 5.0$, so **A = 125**.

MARKING SCHEME

- ✓ A^(1/3) = $R/r_0 = 5.0$.
- ✓ A = 125.

3 Check the readings

ANSWER HA · 3

A^(1/3) is 2, 3, 4, 5, 6, so R/A^(1/3) is 1.2, 1.2, 1.45, 1.2, 1.2 fm. The reading for **A = 64** is wrong: it should be $1.2 \times 4 =$ **4.8 fm**. (It can't be right: it is nearly as large as the 125-nucleon nucleus.)

MARKING SCHEME

- ✓ R/A^(1/3) worked out for each: 1.2 fm.
- ✓ A = 64 doesn't fit.
- ✓ It should be 4.8 fm.

4 Show that

MARKING SCHEME A · 3

- ✓ 2.56×10^{24} nuclei in 1 kg.
- ✓ 8.2×10^{13} J.
- ✓ About 2,600 years, over two thousand.

5 Estimate it

ANSWER A · 2

$V = m/\rho = 6.0 \times 10^{24} \div 2.3 \times 10^{17} = 2.6 \times 10^{7}$ m^3; r = (3V/4π)^(1/3) ≈ **180 m**, a ball about 370 m across, smaller than the hill a village stands on. Ordinary matter is almost all empty space.

MARKING SCHEME

- ✓ $V = 2.6 \times 10^{7}$ m^3.
- ✓ r ≈ 180 m.

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6 A real setting

ANSWER A · 3

i. $\Delta m = P/c^2 = 4 \times 10^{26} \div 9.0 \times 10^{16} =$ **4.4×10^9 kg each second**, over four million tonnes.

ii. $4.4 \times 10^9 \times 4.6 \times 10^9 \times 3.15 \times 10^7 = 6.4 \times 10^{26}$ kg; $\div 1.99 \times 10^{30} \approx$ **3×10^{-4}**, about 0.03 %.

MARKING SCHEME

✓ $\Delta m = E/c^2$ per second.

✓ 4.4×10^9 kg/s.

✓ About 0.03 % of its mass.

7 Predict, then explain

ANSWER HA · 3

Neither. Iron-56 is at the peak of the curve. Fusing two irons makes a nucleus of A = 112, lower down the falling side; splitting one makes two nuclei of A ≈ 28, lower down the rising side. Either way the products have **less** binding energy per nucleon, so energy would have to be **put in**. Iron is the ash of the nuclear fire.

MARKING SCHEME

✓ Neither gives out energy.

✓ Iron-56 is at the peak; both kinds of products lie lower on the curve.

✓ Lower binding energy per nucleon means energy must be put in.

8 Which explanation?

ANSWER HA · 2

Bishal. The pair meets nearly at rest, with almost zero momentum, so the two photons must carry equal and opposite momentum: they fly apart back to back. Photons carry no charge and don't repel. The scanner uses this: the line joining the two detectors that fire together passes through the place of the annihilation.

MARKING SCHEME

✓ Bishal: total momentum about zero, so equal and opposite photons.

✓ Photons have no charge to repel; the scanner traces the line between them.

9 Correct the misconceptions

ANSWER U · 3

1. A large binding energy means the nucleus has **less** energy and less mass than its separate nucleons: that energy has **already been given out**.
2. No protons are destroyed: the numbers of protons and nucleons are the same before and after; the energy comes from the small **mass defect** difference.
3. Binding energy per nucleon rises only to A ≈ 56–62, then **falls**: uranium (7.6 MeV) is less tightly bound than iron (8.8 MeV).

MARKING SCHEME

✓ Binding energy is energy already given out, not stored.

✓ Nucleons are conserved; the energy comes from the change in mass.

✓ Heavier than about A = 60, nuclei are less tightly bound per nucleon.

10 Think

ANSWER HA · 2

The strong force reaches only about 1 fm, so each nucleon is held only by its **immediate neighbors**, not by every nucleon in the nucleus. Once a nucleus is big enough for a nucleon to be surrounded by neighbors, adding more doesn't hold it more tightly. (And the electric repulsion, which reaches across the whole nucleus, does grow, so large nuclei are less tightly bound.)

MARKING SCHEME

✓ The strong force's short range: a nucleon is held only by its neighbors.

✓ So the binding per nucleon levels off (and the long-range repulsion lowers it in big nuclei).

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11 Make your own

ANSWER HA · 2

For example ${}^{1}_{0}\mathrm{n} + {}^{10}_{5}\mathrm{B} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$: upper numbers $1 + 10 = 7 + 4 = 11$; lower numbers $0 + 5 = 3 + 2 = 5$. Any reaction whose upper and lower numbers both balance is right.

MARKING SCHEME

- ✓ A reaction with a neutron, a target and two products.
- ✓ Upper (nucleon) and lower (charge) numbers both shown to balance.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	10	12	**28**

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