

Radioactive decay and nuclear binding energy

Physics grades 11-12 (A Level · IB · Class 11-12) · Test answers (mark scheme)

The marking notes show where each mark is earned. Give credit for correct method even when an arithmetic slip changes the result, and accept answers to two or three significant figures unless the question demands otherwise.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB E.3-E.5

Question 1 A plutonium decay (3 marks)

- a. $A = 239 - 4 = \mathbf{235}$; $Z = 94 - 2 = \mathbf{92}$.
- b. The daughter has $Z = 92$, so it is **uranium-235**.

Marking: 1 mark for each correct number; 1 mark for uranium.

Question 2 Reading a decay graph (3 marks)

- a. The activity falls from 800 kBq to 400 kBq in **4.0 days**.
- b. $10 / 4.0 = 2.5$ half-lives, so $A = 800 \times (\frac{1}{2})^{2.5} = 800 \times 0.1768 = \mathbf{141 \text{ kBq}}$.

Marking: 1 mark for the half-life; 1 mark for 2.5 half-lives; 1 mark for the answer (accept 140 to 142 kBq).

Question 3 Polonium-210 source (3 marks)

- a. $T_{1/2} = 138 \times 86\,400 = 1.19 \times 10^7 \text{ s}$; $\lambda = 0.693 / 1.19 \times 10^7 = \mathbf{5.81 \times 10^{-8} \text{ s}^{-1}}$.
- b. $A = \lambda N = 5.81 \times 10^{-8} \times 4.0 \times 10^{16} = \mathbf{2.3 \times 10^9 \text{ Bq}}$.

Marking: 1 mark for converting days to seconds; 1 mark for λ ; 1 mark for A.

Question 4 Binding energy of lithium-7 (3 marks)

- a. Mass of parts = $3 \times 1.007825 + 4 \times 1.008665 = 7.058135 \text{ u}$; $\Delta m = 7.058135 - 7.016004 = \mathbf{0.042131 \text{ u}}$.
- b. $E = 0.042131 \times 931.5 = \mathbf{39.25 \text{ MeV}}$.
- c. $39.25 / 7 = \mathbf{5.61 \text{ MeV per nucleon}}$.

Marking: 1 mark for each part, with units.

Question 5 Why fusion and fission release energy (2 marks)

The curve rises to a maximum near iron-56. When light nuclei fuse, the product has a higher binding energy per nucleon than the reactants. When a heavy nucleus splits, the fragments also have a higher binding energy per nucleon. In both cases the products are more tightly bound, and the difference is released as energy.

Marking: 1 mark for the maximum near iron-56 (or the shape of the curve); 1 mark for products with higher binding energy per nucleon in both processes.

Question 6 A chain reaction (3 marks)

A neutron splits a uranium-235 nucleus and releases two or three more neutrons. Each of these can split another nucleus, so the number of fissions grows rapidly, which is a chain reaction. Control rods absorb neutrons, so that on average exactly one neutron from each fission goes on to cause another fission, and the rate stays constant.

Marking: 1 mark for neutrons released by fission causing further fission; 1 mark for the growing chain; 1 mark for control rods absorbing neutrons so the average stays at one.

Question 7 Fusion conditions (2 marks)

The nuclei are positively charged and repel each other. They must approach to within about 10^{-15} m, where the strong nuclear force acts, so they need very high kinetic energy. Such energy corresponds to temperatures of millions of kelvin.

Marking: 1 mark for electrostatic repulsion; 1 mark for the need for high kinetic energy (temperature) to get close enough.

Question 8 Activity (1 mark)

Activity is the number of nuclei that decay per second, measured in becquerel (Bq), where 1 Bq is one decay per second.

Marking: 1 mark for decays per second with the unit becquerel.