

## E.4 Fission

Practice Worksheet — name: \_\_\_\_\_ date: \_\_\_\_\_

### FORMULAS FOR THIS TOPIC

MASS-ENERGY EQUIVALENCE  $E = \Delta m c^2$ 

### SECTION A — MULTIPLE CHOICE

A1. The purpose of the moderator in a fission reactor is to:

- A Absorb excess neutrons to stop the reaction
- B Slow neutrons so they are more likely to induce fission in U-235
- C Speed up neutrons to increase collision energy
- D Cool the reactor core

A2. In one fission of U-235, about 200 MeV is released. This energy appears mainly as:

- A Gamma radiation
- B Kinetic energy of the fission fragments
- C Kinetic energy of the emitted neutrons
- D Mass of the products

A3. A chain reaction is self-sustaining when, on average:

- A Every neutron produced causes a fission
- B At least one neutron per fission goes on to cause another fission
- C Three neutrons are produced per fission
- D The moderator absorbs no neutrons

### SECTION B — SHORT ANSWER

B1. One fission reaction is  ${}_{92}^{235}\text{U} + n \rightarrow {}_{56}^{144}\text{Ba} + {}_{36}^{89}\text{Kr} + 3n$ . Show that the equation balances, and explain the origin of the released energy. [4 marks]

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**B2.** Explain why fission products are radioactive, referring to the neutron-to-proton ratio. [3 marks]

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**B3.** Outline two challenges in the management of spent nuclear fuel and one strategy used to address them. [3 marks]

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## ANSWER KEY

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### Section A

**A1:** Slow neutrons so they are more likely to induce fission in U-235 — Fast fission neutrons are inefficient at inducing further fissions in U-235; slowing them to thermal speeds (by collisions with water or graphite nuclei) raises the capture probability enormously. Absorbing neutrons is the CONTROL RODS' job — a distinct role, and a favourite MCQ confusion.

**A2:** Kinetic energy of the fission fragments — The mutual Coulomb repulsion of the two positively charged fragments converts most of the released energy ( $\sim 165$  MeV) into their kinetic energy, which becomes heat in the fuel. Neutrons and gammas carry the smaller remainder.

**A3:** At least one neutron per fission goes on to cause another fission — Criticality is bookkeeping: of the 2–3 neutrons released, losses to absorption and escape must leave exactly one (on average) to trigger the next fission. More than one  $\rightarrow$  supercritical growth; fewer  $\rightarrow$  the reaction dies away.

### Section B

**B1:** Nucleons:  $235 + 1 = 236 = 144 + 89 + 3$ . ✓ Protons:  $92 = 56 + 36$ . ✓ The products have greater binding energy per nucleon than uranium, so the total rest mass decreases; the mass defect appears as energy via  $E = \Delta mc^2$ , mostly as fragment kinetic energy.

**B2:** Heavy nuclei need a high neutron-to-proton ratio for stability ( $N/Z \approx 1.55$  for uranium); mid-mass stable nuclei need less ( $\approx 1.3$ ). Fission fragments inherit uranium's ratio and are therefore neutron-rich for their size, decaying by  $\beta^-$  emission (often in chains) towards stability.

**B3:** Challenges: some products remain hazardous for thousands of years (long half-lives), and the waste generates heat requiring active cooling initially; secure isolation from groundwater and society is needed throughout. Strategy: interim cooling ponds followed by vitrification and deep geological repositories in stable rock formations (also acceptable: reprocessing to recover usable fuel).