23.2 Fission (full E.4)

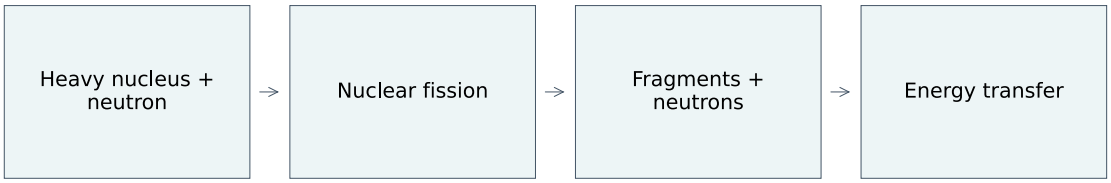
Name: _____ Class: _____ Date: _____ **Total: 21 marks**

KEY WORDS chain reaction • moderator • control rods • nuclear waste

Objective

Practise the full guide E.4 toolkit: energy release in spontaneous and neutron-induced fission with conserved equations, chain reactions, the roles of moderator, control rods, heat exchanger and shielding in a power plant, the properties and management of fission products, and energy calculations from mass difference and binding energy. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The E.4 rule set**

$$E = \Delta mc^2, \qquad 1\ u = 931.5\ \text{MeV/c}^2$$

Neutron-induced fission of U-235 gives Ba-141, Kr-92 and three neutrons – A and Z conserved exactly. The chain reaction is sustained when at least one product neutron triggers another fission.

■ Worked example: from mass defect to megajoules

A fission releases $\Delta m = 0.19\ u$: $E = 0.19 \times 931.5 = 177$ MeV $\approx 2.8 \times 10^{-11}$ J. One kilogram of U-235 holds $(1000/235) \times 6.0 \times 10^{23} = 2.6 \times 10^{24}$ nuclei, so the total is about 7×10^{13} J. Two habits: check A and Z on both sides before trusting a fission equation, and convert through u $\rightarrow$ MeV $\rightarrow$ J in one clean chain.

2 Practice

2.1 Distinguish spontaneous fission from neutron-induced fission. [2]

2.2 State the role of the moderator in a nuclear reactor. [2]

2.3 State two properties of fission products that make them hazardous. [2]

2.4 State the function of control rods. [1]

3 Exam-style questions

3.1 Complete and balance: ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + \ldots$ State how many neutrons are released, and explain how this number makes a chain reaction possible. [3]

3.2 A fission reaction has a mass difference of 0.21 u. Calculate the energy released in MeV and in joules. [3]

3.3 Explain why fission fragments are radioactive even though the parent uranium is only weakly so, and describe one long-term management option for them. [4]

3.4 A reactor runs at a thermal power of 2.0×10^9 W. Using $E = 2.8 \times 10^{-11}$ J per fission, calculate the number of fissions per second, and the mass of U-235 consumed per day if every nucleus fissions (235 $u = 3.9 \times 10^{-25}$ kg). [4]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Spontaneous: the nucleus splits by itself, no incoming particle; induced: an absorbed neutron triggers the split.

2.2 To slow fast neutrons to thermal speeds by collisions; slow neutrons are far more likely to cause further U-235 fissions.

2.3 Any two: they are radioactive; neutron-rich, undergoing further beta decay; intensely ionizing with long half-lives; generate decay heat.

2.4 Absorb neutrons to control – hold or damp – the reaction rate.

3.1 Three neutrons: $+\,3\,{}^{1}_{0}n$; A: $236 = 141 + 92 + 3$ and Z: $92 = 56 + 36$ balance; at least one of the three can trigger the next fission, so the reaction can sustain – and if more than one does, grow.

3.2 $E = 0.21 \times 931.5 = 196$ MeV ≈ 200 MeV; in joules: $196 \times 1.6 \times 10^{-13} = 3.1 \times 10^{-11}$ J.

3.3 The fragments inherit uranium's neutron-to-proton ratio while sitting at medium mass numbers, where stability demands fewer neutrons – they are neutron-rich and beta-decay repeatedly; long-term option: after years of cooled pool storage, seal the waste in corrosion-resistant containers inside deep geological repositories, stable for the tens of thousands of years the longest half-lives demand.

3.4 Fissions per second $= P/E = (2.0 \times 10^{9})/(2.8 \times 10^{-11}) = 7.1 \times 10^{19}$ s^{-1}; per day: $\times 86400 = 6.2 \times 10^{24}$ fissions; mass $= 6.2 \times 10^{24} \times 3.9 \times 10^{-25} = 2.4$ kg.