

A2 Questions - Fission - The Markscheme

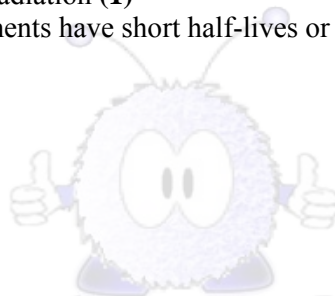
1. (a) (i) $\Delta m = Zm_p + (A - Z)m_n - M$ (1)
- (ii) binding energy per nucleon = $\frac{(\Delta m)c^2}{A}$ (1) 2
- (b) (i) A in range 54 \rightarrow 64 (1)
 stability increases as binding energy per nucleon increases (1)
 [or binding energy per nucleon is a measure of stability]
 [or large binding energy per nucleon shows nucleus is difficult to break apart] 5
- (ii) binding energy per nucleon increases from about 7.6 to 8.5 (1)
 increase of about 0.9 MeV for 235 nucleons (1)
 hence 210 MeV (\approx 200 MeV) in total (1)

[7]

2. (a) for one reaction $\Delta E (= \Delta m c^2) = 3.1 \times 10^{-28} \times (3.00 \times 10^8)^2$ (1)
 $= (2.79 \times 10^{-11} \text{ J})$
- number of nuclei required = $\frac{1}{2.79 \times 10^{-11}} = 3.5(8) \times 10^{10}$ (1)
- [or equivalent credit for any other valid method] 2
- (b) output power from reactor = $\frac{600}{0.35} = 1700$ (MW) (1)
 (1714 MW)
- energy output from fuel rods in one week
 $= 1.70 \times 10^9 \times 24 \times 7 \times 3600$ (1)
 $(= 1.03 \times 10^{15} \text{ J})$
- $\Delta m \left(= \frac{\Delta E}{c^2} \right) = \frac{1.03 \times 10^{15}}{(3.0 \times 10^8)^2}$ (1)
- $= 1.14 \times 10^{-2} \text{ kg}$ (1)
- [or equivalent credit for any other valid method] 4

[6]

3. (a) (i) amount of (fissionable) uranium (235) in fuel decreases (1)
 fission fragments absorb neutrons (1)
- (ii) fission fragments are radioactive or unstable (1)
 emitting β^- and γ radiation (1)
 some fission fragments have short half-lives or high activities (1) Max 3



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- (b) moved by remote control (1)
 placed in cooling ponds (1)
 for several months (1)
 [or to allow short $T_{1/2}$ isotopes to decay]
 transport precautions, e.g. impact resistant flasks (1)
 separation of uranium from active wastes (1)
 high level waste stored (as liquid) (1)
 [alternative for last two marks:
 rods are buried deep underground
 at geologically stable site]
 storage precautions, e.g. shielded tanks or monitoring (1)
 reference to vitrification (1)

Max 5

[8]

4. (a) (i) to reduce the average speed (or kinetic energy) of the fission neutrons (1)

- (ii) mean E_k (or $\frac{1}{2}mv^2$) = $\frac{3}{2}kT$ (1)

$$\text{gives } v \left(= \left[\frac{3kT}{m} \right]^{1/2} \right) = \left(\frac{3 \times 1.38 \times 10^{-23} \times 700}{1.67 \times 10^{-27}} \right)^{1/2} \quad (1)$$

$$= 4.1(7) \times 10^3 \text{ m s}^{-1} \quad (1)$$

4

- (b) (i) mass of carbon 12 nucleus ($= \frac{0.012}{6.02 \times 10^{23}}$) = 2.0×10^{-26} (kg) (1)

final momentum of neutron and nucleus = initial momentum of neutron (1)

$$(1.67 \times 10^{-21} \times v) + (2.0 \times 10^{-26} \times 6.0 \times 10^5) = 1.67 \times 10^{-27} \times 3.9 \times 10^6 \quad (1)$$

$$v = \frac{65 \times 10^{-21} - 12 \times 10^{-21}}{1.67 \times 10^{-27}} \quad (1) \quad (= 3.3 \times 10^6 \text{ m s}^{-1})$$

- (ii) initial E_k of neutron ($= \frac{1}{2} \times 1.67 \times 10^{-27} \times (3.9 \times 10^6)^2$) = 1.27×10^{-14} (J)

$$\text{final } E_k \text{ of neutron } (= \frac{1}{2} \times 1.67 \times 10^{-27} \times (3.3 \times 10^6)^2) = 9.1 \times 10^{-15} \text{ (J)}$$

$$E_k \text{ of carbon nucleus } (= \frac{1}{2} \times 2.0 \times 10^{-26} \times (6.0 \times 10^5)^2) = 3.6 \times 10^{-15} \text{ (J)}$$

(1) for all correct

$$\text{initial } E_k (= 1.27 \times 10^{-14} \text{ J}) = \text{final } E_k (= 9.1 \times 10^{-15} \text{ (J)} + 3.6 \times 10^{-15} \text{ (J)}) \quad (1)$$

- (iii) % E_k transferred $\left(= \frac{3.6 \times 10^{-15}}{1.27 \times 10^{-14}} \right) \times 100 = 28(.3)\% \quad (1)$

7

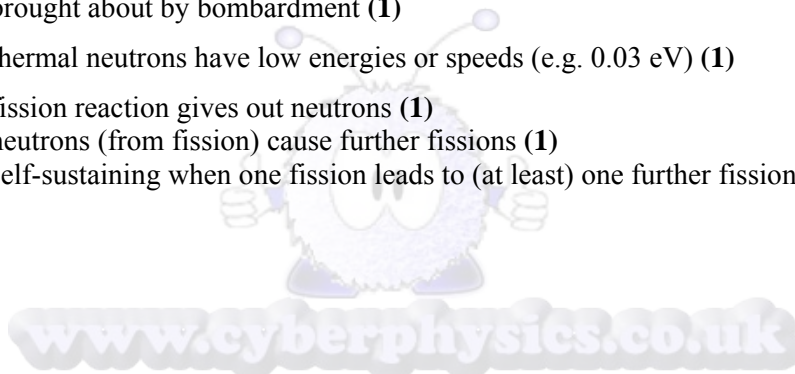
[11]

5. (a) (i) splitting of nucleus into two smaller nuclei (1)
 brought about by bombardment (1)

- (ii) thermal neutrons have low energies or speeds (e.g. 0.03 eV) (1)

- (iii) fission reaction gives out neutrons (1)
 neutrons (from fission) cause further fissions (1)
 self-sustaining when one fission leads to (at least) one further fission (1)

max 5



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- (b) (i) neutrons from fission are fast (high energy) neutrons (e.g. 2 MeV) (1)
 fission most favourable with low energy neutrons (1)
 moderation involves slowing down neutrons (1)
 by collision with moderator atoms (1)
 large number of collisions required (e.g. 50) (1)
 collisions are elastic/k.e. transferred to atoms (1)
 suitable moderator material named e.g. graphite, water (1)
 moderator must not absorb neutrons (1)
 moderator atoms should have (relatively) low mass (1)

QWC 1

- (ii) control involves limiting number of neutrons (1)
 excess neutrons absorbed by control rods (1)
 suitable control rod material named e.g. boron, cadmium (1)
 control rods inserted into reactor to slow reaction rate (or vice-versa) (1) max 7

[12]

6. (a) (i) a neutron strikes the nucleus (1)
 nucleus splits into two fragments (1)
- (ii) some electrostatic E_p converted to E_k of fragments (1)
 some electrostatic E_p used to overcome strong interaction (1)
 some electrostatic E_p used to increase surface energy (1)
- (iii) fission fragments repel and collide with other atoms in fuel rod (1)
 high energy fission neutrons enter moderator
 [or collide with moderator atoms] (1)
 atoms gain E_k due to collisions (and vibrate more) (1)
 temperature depends on the average E_k of (vibrating) atoms (1)
 a chain reaction occurs (1)

max 8

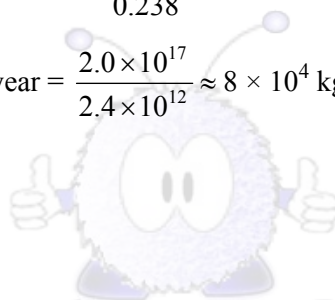
- (b) energy from fuel per year at 100% efficiency
 $= 1600(\text{MW}) \times 3.2 \times 10^7 \text{ s} \approx 5.0 \times 10^{16} \text{ (J) (1)}$
 energy supplied from fuel per year at 25% efficiency
 $\approx 4 \times 5.0 \times 10^{16} \approx 2.0 \times 10^{17} \text{ (J) (1)}$
 energy released per kilogram of fuel

$$= 200 \times 1.6 \times 10^{-13} \times 6.0 \times 10^{23} \times \frac{1}{0.238} \text{ (1)} \times 0.03 \approx 2.4 \times 10^{12} \text{ (J) (1)}$$

$$\text{mass of fuel needed per year} = \frac{2.0 \times 10^{17}}{2.4 \times 10^{12}} \approx 8 \times 10^4 \text{ kg (1)}$$

5

[13]



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7. (a) neutron speed [or kinetic energy] reduced (1)
to thermal energies [or speeds] (1)
by collisions (1)
absorbed to produce fission of uranium-235 (1)
(power constant when) one net fission per absorbed neutron (1)
others neutrons absorbed [or escape] (1) max 5
- (b) (i) (control rods) absorb neutrons (1)
neutron flux [or power or reaction rate] kept constant (1)
by raising or lowering control rods (1)
rapidly dropped in emergency (1)
to stop reaction (1)
- (ii) neutrons and gamma radiation must be contained
by concrete shielding (1)
- (iii) keep underwater (in ponds) (1)
then store safely for long period (1)
reference to long and short half-life products max 8
- (c) element bombarded with neutrons (1)
absorption by nucleus (1) 2
- [15]**
8. (a) (i) ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U}$
- (ii) ${}_{92}^{236}\text{U} \rightarrow {}_{56}^{145}\text{Ba} + {}_{36}^{87}\text{Kr} + 4 {}_0^1\text{n}$ (1) 2
- (b) ($\Delta m = m_{\text{u}} - m_{\text{Ba}} - m_{\text{Kr}} - 4m_{\text{n}}$, electron masses balance)
 $\Delta m = 236.04573 - 144.92694 - 86.91340 - 4 \times 1.00867$ (1)
 $= 0.17071\text{u}$ (1)
 $Q = (0.17071 \times 931.3\text{MeV}) = 159(\text{MeV})$ (1) 3
- [5]**
9. (a) (i) proportion of U-235 is greater than in natural uranium (1)
(ii) induced fission more probable with U-235 than with U-238 (1) 2
- (b) (i) for steady rate of fission, one neutron per fission required to go on to produce further fission (1)
each fission produces two or three neutrons on average (1)
some neutrons escape [or some absorbed by U-238 without fission] (1)
control rods absorb sufficient neutrons (to maintain steady rate of fission) (1)
- (ii) neutrons need to pass through a moderator (1)
to slow them (in order to cause further fissions or prevent U-238 absorbing them) (1)
neutrons that leave the fuel rod (and pass through the moderator)
are unlikely to re-enter the same fuel rod (1)
makes it easier to replace the fuel in stages (1) max 5
- [7]**
10. (a) (i) proton number = 36 (1)
neutron number = 56 (1)
- (ii) krypton (1) 3
- (b) one-fifth efficiency so total output ($= 10 \times \frac{100}{20} = 50(\text{MW})$) (1)

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energy in one day = $50 \times 10^6 \times 24 \times 3600$ (J) **(1)** (4.32×10^{12} J)

fission atoms per day = $\frac{4.32 \times 10^{12}}{3.2 \times 10^{-11}} = 1.35 \times 10^{23}$ **(1)** 3

[6]

- 11.** (a) (i) ${}_{92}^{235}\text{U} + {}_0^1n \rightarrow {}_{38}^{98}\text{Sr} + {}_{54}^{135}\text{Xe} + 3{}_0^1n(+Q)$ **(1)**
- (ii) three correct positions to within ± 2 on x-axis **(1)** **(1)** (one mark if two correct)
- (iii) *estimate of energy released:*
 binding energy of U-235 nucleus = $(235 \times 7.5) = 1763(\pm 15)$ (MeV) **(1)**
 binding energy of Sr-98 = $(98 \times 8.6) = 843(\pm 15)$ (MeV) **(1)**
 binding energy of Xe-135 = $(135 \times 8.4) = 1134(\pm 15)$ (MeV) **(1)**
 binding energy released = $1134 + 843 - 1763 = 214$ MeV **(1)**
 (± 40 MeV) max 6
- (b) (i) 235g of U-235 releases $6 \times 10^{23} \times 214 \times 1.6 \times 10^{-13}\text{J} = 2.1 \times 10^{13}$ (J) **(1)**
 1.0 kg of uranium containing 3% U-235 contains 30g of U-235 **(1)**
 energy from 1.0kg of uranium = $\frac{2.1 \times 10^{13} \times 30}{235} = 2.6 \times 10^{12}\text{J}$ [[1.6×10^{25} MeV]] **(1)**
- (ii) *advantage:*
 less mass of fuel used **(1)** because more energy per kilogram **(1)**
 [alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
 or any statement **(1)** argued **(1)**]
disadvantage:
 hazardous waste **(1)** because fission products are radioactive **(1)**
 [alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
 or any statement **(1)** argued **(1)**] max 6

[12]

- 12.** (a) $100\text{y} = 100 \times 365 \times 24 \times 3600 (= 3.15 \times 10^9 \text{ s})$ **(1)**
 energy needed = $3.15 \times 10^9 \times 300$ **(1)** $\times 10$ **(1)** ($= 9.46 \times 10^{12}$ J)
 number of disintegrations = $\frac{9.46 \times 10^{12}}{3.2 \times 10^{-11}}$ ($= 2.96 \times 10^{23}$) **(1)**
 number of moles needed = $\frac{2.96 \times 10^{23}}{6.02 \times 10^{23}}$ ($= 0.49$) **(1)**
 molar mass = 0.239kg **(1)**
 mass needed = $0.49 \times 0.239 = 0.117$ kg **(1)**

[7]



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