Mark Scheme

Q1.

Question Number	Answer	Mark
	C	1

Q2.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: the binding energy per nucleon curve shows an increase for both processes A is not correct because both processes show decreases B is not correct because fission shows a decrease C is not correct because fusion shows a decrease	1

Q3.

Question Number	Answer	Mark
	B	1

Q4.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C because X is a smaller nucleus for which the binding energy per nucleon could increase through a process of fusion and Y is a larger nucleus for which the binding energy per nucleon could increase through a process of fission A I not correct because it states fission for both X and Y B is not correct because the processes are reversed D is not correct because it states fusion for both X and Y	1

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• High temperature so sufficient (kinetic) energy to overcome the repulsion between (positively charged) ions/nuclei **(1)** • High density to ensure ions close enough to each other to maintain collision rate to maintain fusion **(1)**		2

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• The energy equivalent to the mass deficit **(1)** • When nucleons bind together to form an atomic nucleus **(1)**		2

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to: • Identifies (very) high temperature **and** (very) high density **(1)** • (Very) high temperature to provide enough energy to overcome the (electrostatic) repulsive force between nuclei **(1)** • (Very) high density to give big enough collision rate to maintain reaction **(1)**	Accept pressure for density in MP1 Accept correct reference to strong force	3

Question Number	Acceptable answers	Additional guidance	Mark
	• Fusion involves an increase in binding energy (per nucleon) as the number of nucleons increases **(1)** • Fission involves an increase in binding energy (per nucleon) as the number of nucleons decreases **(1)** • If binding energy per nucleon increases energy is released in the process **(1)**	Accept reference to larger/smaller nuclei for number of nucleons increases/decreases	**3**

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• Calculation of mass difference in kg **(1)** • Use of $E = c^2 \Delta m$ **(1)** • $E = 2.77 \times 10^{-11}$ J **(1)**	Example of calculation: (235.0439 + 1.008665) u – (140.9144 + 91.9262+ (3×1.008665)) u = 0.186u (0.1860 u × 1.66 × 10^{-27} kg) × (3 × 10^{8} m s^{-1})^2 = 2.77 × 10^{-11} J	**3**

Q10.

Question number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Resonance is occurring… **(1)** • …when the driving frequency/forced vibration (at walking frequency) matches the natural frequency … **(1)** • …energy transfer is maximum **(1)** • Supporting the observation that the amplitude rapidly increases **(1)**		**4**

Q11.

Question Number	Acceptable answers		Additional guidance	Mark
	• attempt to determine mass difference between radium and radon-plus-alpha • conversion to kg • Use of $\Delta E = c^2\Delta m$ • Use of 1.6×10^{-19} factor • Answer = 4.87 (MeV)	(1) (1) (1) (1) (1)	$\Delta m = 225.97713\text{u} - (221.97040\text{u} + 4.00151\text{ u})$ $= 5.22 \times 10^{-3}\text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27}\text{ kg} = 8.67 \times 10^{-30}\text{ kg}$ $\Delta E = c^2\Delta m = (3 \times 10^8\text{ m s}^{-1})^2 \times 8.67 \times 10^{-30}\text{ kg} = 7.80 \times 10^{-13}\text{ J}$ ΔE in MeV $= 7.80 \times 10^{-13}\text{ J} \div 1.6 \times 10^{-19}\text{ C}$ $= 4.87\text{ MeV}$	5

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
	• Calculates change in mass • Converts from u to kg • Use of $\Delta E = c^2\Delta m$ • Use of $E_k = ½\, mv^2$ • $v = 1.4 \times 10^7\text{ m s}^{-1}$	(1) (1) (1) (1) (1)	Example of calculation $\Delta m = 238.0003u - (233.9942 + 4.0015)u$ $= 0.00463 \times 1.66 \times 10^{-27}\text{ kg}$ $= 7.636 \times 10^{-30}\text{ kg}$ $\Delta E = (3.00 \times 10^8\text{ m s}^{-1})^2 \times 7.636 \times 10^{-30}\text{ kg}$ $= 6.872 \times 10^{-13}\text{ J}$ $6.872 \times 10^{-13}\text{ J} = ½\,(4.0015\,u)\,v^2$ $v = 1.4 \times 10^7\text{ m s}^{-1}$	5

Q13.

Question Number	Acceptable answers		Additional guidance	Mark
	• Calculates change in mass • Converts from u to kg • Use of $\Delta E = c^2\Delta m$ • $2.8 \times 10^{-12}\text{ J}$	(1) (1) (1) (1)	Example of calculation $\Delta m = ((2.013553 + 3.015501) - (4.001506 + 1.008665))u$ $= 0.01883 \times 1.66 \times 10^{-27}\text{ kg}$ $= 3.13 \times 10^{-29}\text{ kg}$ $\Delta E = (3.00 \times 10^8\text{ m s}^{-1})^2 \times 3.13 \times 10^{-29}\text{ kg}$ $= 2.8 \times 10^{-12}\text{ J}$	4

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.	The following table shows how the marks should be awarded for structure and lines of reasoning.	6

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

	No. of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

Indicative content:

- Requires a (very) high temperature
- Nuclei all have positive charge leading to a large repulsive force between nuclei
- At high temperature nuclei have high kinetic energy, sufficient to overcome repulsion
- Nuclei must get close enough to fuse (accept reference to close enough for strong force)
- Requires (very) high density
- Collision rate must be high enough to sustain fusion

Q15.

Question Number	Answer		Mark
(a)(i)	(Small mass) nuclei come very close together **Or** strong (nuclear) force acts on nuclei Nuclei join to form a more massive nucleus	(1) (1)	2
(a)(ii)	A very/extremely high temperature (plasma) is required Plasma must not touch reactor walls, so strong magnetic fields are required **Or** If plasma touches the walls of the reactor its temperature falls (and fusion stops)	(1) (1)	2
(b)	Mass of fused nucleus is less than sum of masses of fusing nuclei Mass difference/deficit releases energy according to $\Delta E = c^2 \Delta m$ **Or** Binding energy per nucleon is greater in the fused nucleus; **Or** Strong (nuclear) force binds the nucleons, lowering total energy of system.	(1) (1)	2
	Total for question		**6**

Q16.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	(see below)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning.	

IC points	IC mark	Max linkage mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5–4	3
3–2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content:

IC1 The rate of decay depends upon the number of unstable nuclei in the sample $(A = -\lambda N)$	
IC2 Radium has a large half-life, so unstable nuclei are present in the sample for a long time	IC2: accept idea that it takes a long time to decay for "unstable nuclei are present…or a long period of time"
IC3 When a nucleus decays there is a	IC3 accept a reference to binding energy increasing

		(small) decrease in mass Δm		
	IC4	Energy is released according to $\Delta E = c^2 \Delta m$		
	IC5	Δm is small but c is large, so a significant amount of energy is released		
	IC6	Energy released by the decay becomes kinetic energy of the atoms in the sample (hence sample is above the temperature of the surroundings		6

Q17.

Question Number	Answer	Mark
(a)(i)	$^{7}_{3}\text{Li} + ^{1}_{1}\text{X} \rightarrow 2 \times ^{4}_{2}\text{He}$ **(1)** X is a proton [Accept X is hydrogen/H] **(1)**	**2**
(a)(ii)	Attempt at calculation of mass difference **(1)** Use of 1 MeV = 1.60×10^{-13} J **(1)** $\Delta E = 2.77 \times 10^{-12}$ (J) **(1)** <u>Example of calculation:</u> $\Delta m = 6533.8\text{MeV/c}^2 + 938.3\text{MeV/c}^2 - (2 \times 3727.4\text{MeV/c}^2) = 17.3\text{MeV/c}^2$ $\Delta E = 17.3\text{MeV}$ $\Delta E = 17.3\text{MeV} \times 1.60 \times 10^{-13}\,\text{J MeV}^{-1} = 2.768 \times 10^{-12}\,\text{J}$	**3**
(b)	**Max 4** • Extremely high temperature and density needed **(1)** • High temperature because nuclei need high <u>energy</u> to overcome the (electrostatic) repulsive force **(1)** • Since nuclei must come very close for fusion to occur **Or** since nuclei must come close enough for (strong) nuclear force to act **(1)** • Very high density is needed to maintain a sufficient collision rate **(1)** • Reference to extreme conditions leading to containment problems **(1)**	**4**

Q18.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Calculate no of nuclei • Use of ln 2 = $t_{½} \times \lambda$ • Use of $A = \lambda N$ • $A = 3.97 \times 10^4$ Bq)	(1) (1) (1) (1)	<u>Example of calculation</u> $N = (5.18 \times 10^{-5}$ g/230 g) $\times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7)$ s = ln 2 $\lambda = 2.92 \times 10^{-13}$ s^{-1} $A = 2.92 \times 10^{-13}$ s$^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4$ Bq	4
(ii)	• Calculates decays in one year (ecf from (b)(i)) • Use of $pV = NkT$ • uses $T = 295$ K • $V = 5.09 \times 10^{-14}$ m^3	(1) (1) (1) (1)	<u>Example of calculation</u> ecf λ from (a) decays in one year = 3.97×10^4 Bq $\times$ 3.15×10^7 s $= 1.25 \times 10^{12}$ 1.00×10^5 Pa $\times V = 1.25 \times 10^{12} \times 1.38 \times 10^{-23}$ J K$^{-1} \times 295$ K $V = 5.09 \times 10^{-14}$ m^3	4
(iii)	• Use of ½ m <c^2> = 3/2 kT **Or** Use of $pV = \frac{1}{3}Nm < c^2 >$ (allow ecf for N, V from (b)(ii)) • uses $m = 4u$ • $\sqrt{<c^2>} = 1360$ m s^{-1}	(1) (1) (1)	<u>Example of calculation</u> ½ m <c^2> = 3/2 kT ½ $\times (4 \times 1.66 \times 10^{-27}$ kg) $\times$ <c^2> = 3/2 $\times 1.38 \times 10^{-23}$ J K$^{-1} \times 295$ K <c^2> = 1 840 000 m^2 s^{-2} $\sqrt{<c^2>} = 1360$ m s^{-1} Accept the use of proton/neutron mass instead of u	3

Q19.

Question Number	Answer		Mark
(a)(i)	$N + \alpha \rightarrow {}^{17}_{8}O + {}_{1}p$ All values correct	(1)	1
(a)(ii)	In nuclear fission a chain reaction can be set up **Or** in a chain reaction the (total) energy released can be very large **Or** heavier/larger nuclei release much more energy **Or** a very high reaction rate releases much more energy	(1)	1
(b)	Attempt at mass deficit calculation Use of $\Delta E = c^2 \Delta m$ (Allow use of 1 u = 1.66 x 10^{-27} kg) Use of 1 MeV = 1.6 × 10^{-13} J (Allow use of 1u = 931.5 MeV/c^2) ΔE = 174 MeV Example of calculation $\Delta m = (390.29989 - 233.99404 - 152.64708 - (2 \times 1.67493)) \times 10^{-27}\,\text{kg}$ $\Delta m = 3.0891 \times 10^{-28}\,\text{kg}$ $\Delta E = (3.00 \times 10^{8}\,\text{m s}^{-1})^2 \times 3.0891 \times 10^{-28}\,\text{kg} = 2.780 \times 10^{-11}\,\text{J}$ $\Delta E = \frac{2.780 \times 10^{-11}\,\text{J}}{1.60 \times 10^{-13}\,\text{J MeV}^{-1}} = 173.8\,\text{MeV}$	(1) (1) (1) (1)	4
(c)(i)	Same number of protons [do not accept atomic/proton number], Different numbers of neutrons [do not accept mass/nucleon/neutron number]	(1) (1)	2
(c)(ii)	Correct calculation for ω [see 6283 or 2000π or $\frac{60\,000 \times 2\pi}{60}$] a = (-) 5.9 × 10^{6} m s^{-2} Example of calculation $a = -\left(\frac{60000 \times 2\pi}{60\,\text{s}}\right)^2 \times 15 \times 10^{-2}\,\text{m} = 5.92 \times 10^{6}\,\text{m s}^{-2}$	(1) (1)	2
(c)(iii)	**Max 2** Stiff/stiffness Strong/strength Low density	(1) (1) (1)	2
(d)	Use of ΔE = mcΔθ Rate at which energy is removed = 3.1 × 10^{9} (W) Use of the efficiency equation [must have 2.2 × 10^{9} (W) on top line] Efficiency = 42% [accept 0.42] Example of calculation $\Delta E = 70000\,\text{kg} \times 3990\,\text{J kg}^{-1}\,\text{K}^{-1} \times 11\,\text{K} = 3.07 \times 10^{9}\,\text{J}$ $\%\,\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100 = \frac{2.2 \times 10^{9}\,\text{W}}{(2.2 + 3.1) \times 10^{9}\,\text{W}} \times 100 = 41.5\%$	(1) (1) (1) (1)	4