Question Number	Answer	Mark
1(a)(i)	Reverse direction for temperature [at least 2 values seen] (1) Logarithmic/power temperature variation [at least 3 realistic values seen increasing by the same factor] (1)	**2**
1(a)(ii)	QWC – Work must be clear and organised in a logical manner using technical wording where appropriate **Area 1: Max 2** The Sun is fusing/burning hydrogen (into helium in its core) (1) When (hydrogen) fusion/burning ceases the core of the Sun cools [accept radiation pressure drops when fusion/burning ceases in the core] (1) The core collapses/contracts (under gravitational forces) (1) **Area 2: Max 2** The Sun expands and becomes a red giant (1) The core becomes hot enough for helium fusion/burning to begin (in the core) (1) Helium begins to run out and the core collapses again (under gravitational forces) (1) **Area 3: Max 2** Idea that outer layers of Sun are ejected into space (1) The temperature doesn't rise enough for further fusion to begin (1) The core/Sun becomes a (white) dwarf star (1)	**6**
1(b)(i)	Idea of a very high temperature [accept value of about 10^7 K] (1) To overcome repulsive/electrostatic forces between protons/nuclei **Or** so that protons/nuclei get close enough together for the strong (nuclear) force to act **Or** so that protons/nuclei get close enough to fuse (1) Idea of a very high density [accept pressure] to give a sufficient collision rate (1)	**3**
1(b)(ii)	Attempt at calculation of mass deficit (1) Use of $\Delta E = c^2 \Delta m$ (1) Attempt at conversion from J to (M)eV (1) $\Delta E = 12.9$ (MeV) (1) [If correct mass defect in kg is converted into u and then 1u = 931 Mev used, then full marks may be awarded] <u>Example of calculation</u> $\Delta m = ((5.008238 \times 2) - 6.646483 - (1.673534 \times 2)) \times 10^{-27}$ kg	**4**

	$\Delta m = 2.2925 \times 10^{-29}$ kg $\Delta E = \left(3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}\right)^{2} \times 2.2925 \times 10^{-29}\,\mathrm{kg} = 2.063 \times 10^{-12}\,\mathrm{J}$ $\Delta E = \dfrac{2.063 \times 10^{-12}\,\mathrm{J}}{1.60 \times 10^{-13}\,\mathrm{J\,MeV^{-1}}} = 12.9\,\mathrm{MeV}$	
	Total for question	**15**

Question Number	Answer		Mark
2(a)	**Similarity**: Same number of protons **Or** same magnitude of charge **Or** both have 1 proton **Difference:** Different number of neutrons / nucleons **Or** different mass **Or** D has 1 neutrons and T has 2 neutrons	**(1)** **(1)**	**2**
2(b)	Use of $P = \frac{\Delta E}{\Delta t}$ (do not penalise a power of ten error) Energy = 7.5×10^6 (J) <u>Example of calculation</u> $E = 500 \times 10^{12}\ \text{W} \times 15 \times 10^{-9}\ \text{s} = 7.5 \times 10^6\ \text{J}$	**(1)** **(1)**	**2**
2(c)(i)	${}^2_1\text{D} + {}^3_1\text{T} \rightarrow {}^4_2\text{He} + {}^1_0\text{n}$ Top line: 2, 3, 4, 1 Bottom line: 1, 1, 2, 0	**(1)** **(1)**	**2**
2(c)(ii)	Attempt at calculation of mass difference Energy released = 17.5 (MeV) [17.5 must be clearly identified as an energy] <u>Example of calculation</u> Δm= (1875.6 + 2808.9 – 3727.4 – 939.6) MeV/c^2 = 17.5 MeV/c^2 ΔE = 17.5 MeV	**(1)** **(1)**	**2**
2(c)(iii)	Conversion of energy to consistent units Number of nuclei = 3×10^{18} <u>Example of calculation</u> In each fusion $\Delta E = 17.5 \times 10^6\ \text{eV} \times 1.6 \times 10^{-19}\ \text{J eV}^{-1} = 2.8 \times 10^{-12}\ \text{J}$ $\therefore N = \frac{7.5 \times 10^6\ \text{J}}{2.8 \times 10^{-12}\ \text{J}} = 2.68 \times 10^{18}$	**(1)** **(1)**	**2**

Top line	2	3	4	1
Bottom line	1	1	2	0

Energy MJ (b)	**Energy MeV (c)(ii)**	**N × 10^{18}**
7.5	17.5	2.7
7.5	20	2.3
8	17.	2.9
8	20	2.5

2(c)(iv)	Application of momentum conservation Deduction that $V_N = 4\ V_\alpha$ [$v_N = 3.967\ v_\alpha$] Use of $E_K = \frac{1}{2}mv^2$ (ratio as shown **or** sum = 17.5 MeV) Energy = 14 MeV (ecf (c)(ii), 14.1 MeV, if $v_N = 3.967\ v_\alpha$ 16 MeV if 20 MeV used) **Or** Application of momentum conservation Use of $E_k = p^2/2m$ Deduction that $E_N = 4\ E_\alpha$ Energy = 14 MeV Example of calculation (1st method) $m_N V_N = m_\alpha V_\alpha$ $V_N = \frac{m_\alpha}{m_N} \times V_\alpha = 4V_\alpha$ $\frac{E_N}{E_\alpha} = \frac{\frac{1}{2}m_N V_N^2}{\frac{1}{2}m_\alpha V_\alpha^2} = \frac{1}{4} \times \left(\frac{4}{1}\right)^2 = 4$ $\therefore E_N = \frac{4}{5} \times 17.5\ \text{MeV} = 14\ \text{MeV}$ Example of calculation (2nd method) $p_\alpha = p_N$ $p_\alpha^2 = p_N^2$ $E_\alpha \times 2m_\alpha = E_N \times 2m_N$ $\therefore E_\alpha = E_N \times \frac{m_N}{m_\alpha} = \frac{E_N}{4}$ Also, $E_\alpha + E_N = 17.5\ \text{MeV}$ $\therefore \frac{E_N}{4} + E_N = 17.5\ \text{MeV}$ $\therefore E_N = \frac{4}{5} \times 17.5\ \text{MeV} = 14\ \text{MeV}$	(1) (1) (1) (1) (1) (1) (1) (1)	4
2(d)	**Max 3** A heavy **nucleus** absorbs a neutron. [accepts "collides with" / "fired into" for "absorbs"] The **nucleus** becomes unstable **and** splits into two (roughly equal sized) fragments [accept "decays" / "breaks up" for "splits"] Idea that a few neutrons are also emitted in the fission process These neutrons cause further fissions **Or** these neutrons cause a chain reaction (if atom is used instead of nucleus **only penalise once**)	(1) (1) (1) (1)	3
	Total for question		**17**

Question Number	Answer	Mark
3(a)(i)	Use of m =1.67 x 10^{-27} kg **(1)** Use of ½ $m\langle c^2\rangle$ = 3/2 kT **(1)** c_{rms} = 2,800(m s^{-1}) (no ue) **(1)** <u>Example of calculation</u> $\langle c^2\rangle = \frac{3kT}{m} = \frac{3 \times 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}} \times 310\ \mathrm{K}}{1.0087 \times 1.66 \times 10^{-27}\ \mathrm{kg}} = 7.66 \times 10^6\ \mathrm{m^2\ s^{-2}}$ $\langle c^2\rangle = 7.66 \times 10^6\ \mathrm{m^2\ s^{-2}}$ $c_{rms} = \sqrt{7.66 \times 10^6\ \mathrm{m^2 s^{-2}}} = 2.77 \times 10^3\ \mathrm{m\ s^{-1}}$	**3**
3(a)(ii)	$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{236}_{92}\mathrm{U} \rightarrow {}^{138}_{55}\mathrm{Cs} + {}^{96}_{37}\mathrm{Rb} + 2 \times {}^{1}_{0}\mathrm{n}$ Nucleon, proton numbers correct [236, 55] **(1)** Number of neutrons correct [2] **(1)**	**2**
3(a)(iii)	Attempt at calculation of mass defect **(1)** Use of $\Delta E = c^2 \Delta m$ OR use of 1 u = 931.5 MeV **(1)** Use of $fission\ \ rate = \frac{power\ \ output}{energy\ per\ \ fission}$ **(1)** Fission rate = 8.8 × 10^{19} s^{-1} **(1)** <u>Example of calculation</u> $\Delta m = (235.0439 - 137.9110 - 95.9343 - 1.0087)\ \mathrm{u}$ $\Delta m = 0.1899 \times 1.66 \times 10^{-27}\ \mathrm{kg} = 3.15 \times 10^{-28}\ \mathrm{kg}$ $\Delta E = (3 \times 10^8\ \mathrm{m\ s^{-1}})^2 \times 3.15 \times 10^{-28}\ \mathrm{kg} = 2.84 \times 10^{-11}\ \mathrm{J}$ Fission rate$= \frac{2.5 \times 10^9\ \mathrm{W}}{2.84 \times 10^{-11}\ \mathrm{J}} = 8.8 \times 10^{19}\ \mathrm{s^{-1}}$	**4**

*3(b)(i)	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.) Max THREE from first 5 marking points • Very high temperatures (>10^7 K)needed **(1)** • To overcome electrostatic repulsion / forces **(1)** • <u>Nuclei</u> come close enough to fuse / for strong (nuclear) force to act **(1)** • Very high densities needed **(1)** • (Together with high nuclei speeds) this gives a sufficient collision rate **(1)** • (Very high) temperatures lead to confinement problems **(1)** • Contact with container causes temperature to fall (and fusion to cease) **(1)**	**Max 4**
3(b)(ii)	$^2_1D + {}^2_1D \rightarrow {}^3_1H + {}^1_1X$ X is a proton [accept hydrogen nucleus] **(1)**	**1**
3(b)(iii)	Any **TWO** from • (Hydrogen) fuel for fusion is (virtually) unlimited whereas fission relies upon (uranium) a relatively limited resource **(1)** • Fusion results in few radioactive products, but radioactive products produced in fission present significant disposal problems **(1)** • For a given mass of fuel, the energy released by fusion is greater than the energy released by fission **(1)**	**Max 2**
	Total for question	**15**

Question Number	Answer	Mark
4(a)	Alpha-radiation only has a range of a few cm in air / cannot penetrate walls of container / skin (1)	**(1)**
4(b)(i)	Top line: ^{241}Am ^{237}Np $^{4}\alpha$ (1) Bottom line: $_{95}Am$ $_{93}Np$ $_{2}\alpha$ (1)	**(2)**
4(b)(ii)	Attempt at calculation of mass defect (1) Use of $(\Delta)E=c^2(\Delta)m$ OR use of 1 u = 931.5 MeV (1) Correct answer [5.65 MeV; accept 5.6 – 5.7 MeV] (1) Example of calculation: $\Delta m = 241.056822\,u - 237.048166\,u - 4.002603\,u = 0.006053\,u$ $\Delta m = 0.006053\,u \times 1.66 \times 10^{-27}\ kg\,u^{-1} = 1.005 \times 10^{-29}\ kg$ $E = 1.005 \times 10^{-29}\ kg \times \left(3 \times 10^{8}\ ms^{-1}\right)^2 = 9.04 \times 10^{-13}\ J$ $E = \dfrac{9.04 \times 10^{-13}\ J}{1.6 \times 10^{-13}\ MeV\,J^{-1}} = 5.65\,MeV$	**(3)**
4(c)	Reference to half-life and typical lifespan (1)	**(1)**
	Total for question	**(7)**