Radiation MS1

Question Number	Answer	Mark
1(a)	β-particles can (easily) penetrate the body/skin (1) Since they are not very ionising OR reference to what will stop them (1)	**(2)**
1(b)(i)	Use idea that number of unstable atoms halves every 8 days OR that 24 days represents 3 half-lives (1) Correct answer (1) Example calculation: $N_0 \quad \rightarrow \quad \frac{N_0}{2} \quad \rightarrow \quad \frac{N_0}{4} \quad \rightarrow \quad \frac{N_0}{8}$ $t=0 \qquad t=t_{1/2} \qquad t=2t_{1/2} \qquad t=3t_{1/2}$ Fraction decayed = 100% - 12.5% = 87.5%	**(2)**
1(b)(ii)	Use of $\lambda T_{1/2} = \ln 2$ (1) Use of an appropriate decay equation (1) Correct answer (1) Example of calculation: $\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{8\,\text{day}} = 0.0866\,\text{day}^{-1}$ $1.50\,\text{MBq} = A_0\, e^{-0.0866\,\text{day}^{-1} \times 1\,\text{day}}$ $A_0 = 1.50\,\text{MBq}\, e^{0.0866} = 1.64\,\text{MBq}$	**(3)**
	Total for question 1	**(7)**

Question Number	Answer	Mark
2(a)	Alpha-radiation only has a range of a few cm in air / cannot penetrate walls of container / skin (1)	**(1)**
2(b)(i)	Top line: ^{241}Am ^{237}Np $^{4}\alpha$ (1) Bottom line: $_{95}Am$ $_{93}Np$ $_{2}\alpha$ (1)	**(2)**
2(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)**
2(c)	Reference to half-life and typical lifespan (1)	**(1)**
	Total for question 2	**(7)**

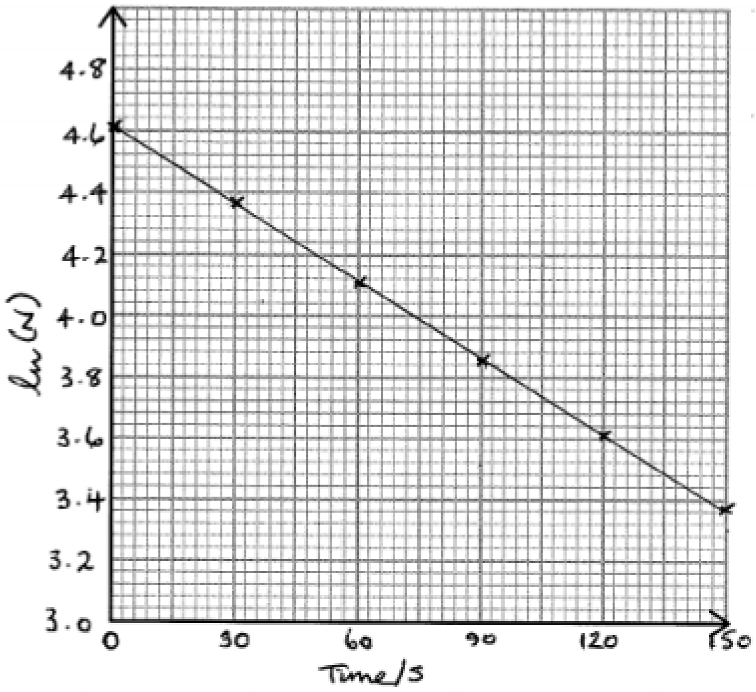
Question Number	Answer	Mark
3(a)*	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Appropriate reference to the following: ▪ The penetrating power of beta radiation ▪ The ionising effects of the beta radiation ▪ The shielding effect that the cylinder might have had ▪ The constant activity over the 5 day period Examples of responses: Beta radiation is (moderately) ionising Beta radiation is able to penetrate the body Once inside the body beta radiation may damage / kill / mutate / alter DNA of cells Beta radiation is absorbed by a few mm of aluminium Cylinder may have reduced the radiation to safe levels / absorbed the beta radiation Greater risk of exposure if cylinder damaged or cracked Long half life means that: source stays active for a long time/activity unlikely to lower over 5 days	**max 3**
3(b)	Top line: ^{137}Ba $^{0}\beta^{-}$ (1) Bottom line: $_{56}\text{Ba}$ $_{-1}\beta^{-}$ (1)	**2**
3(c)(i)	Cannot identify which atom/nucleus/particle will be the next to decay OR cannot say when a given atom/nucleus/particle will decay OR cannot state exactly how many atoms/nuclei/particles will decay in a set time OR can only estimate the fraction of the total number that will decay in the next time interval (1)	**1**

3(c)(ii)	Use of $\lambda T_{1/2} = \ln 2$ (1) Decay constant, $\lambda = 7.3 \times 10^{-10}$ (s^{-1}) (1) Example of calculation $\lambda = \frac{\log_e 2}{T_{½}} = \frac{0.693}{30 \times 365 \times 24 \times 3600\,s} = 7.32 \times 10^{-10}\,s^{-1}$	**2**
3(d)	Use of $\frac{dN}{dt} = \left(\frac{dN}{dt}\right)_0 e^{-\lambda t}$ (1) activity = 3.3×10^{13} Bq [3.3×10^{13} Bq if show that value used] (1) Use of dN/dt = λN (1) $N = 4.5 \times 10^{22}$ [4.8×10^{22} if show that value used] (1) OR Use of dN/dt = λN_o (1) $N_o = 7.1 \times 10^{22}$ [$N_o = 7.4 \times 10^{22}$ if show that value used] (1) Use of $N = N_0 e^{-\lambda t}$ (1) $N = 4.5 \times 10^{22}$ [4.8×10^{22} if show that value used] (1) Example of calculation $\frac{dN}{dt} = \left(\frac{dN}{dt}\right)_0 e^{-\lambda t} = 5.2 \times 10^{13}\,Bq \times e^{-7.32 \times 10^{-10}\,s^{-1} \times 20 \times 365 \times 24 \times 3600\,s}$ $= 3.28 \times 10^{13}\,Bq$ $N = \frac{dN/dt}{\lambda} = \frac{3.28 \times 10^{13}\,s^{-1}}{7.32 \times 10^{-10}\,s^{-1}} = 4.48 \times 10^{22}$	**4**
3(e)(i)	${}^{95}_{37}Rb \quad + \quad 4 \times {}^{1}_{0}n$ (1)	**1**
3(e)(ii)	Idea that at least one neutron needs to be available to be absorbed for a chain reaction to be sustained (1) Appreciation of the need to control/limit/restrict the number of neutrons (which can go on to produce another fission) (1)	**2**
	Total for question 3	**12**

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

(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)** • Nuclei 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**
(b)(ii)	$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{1}H + ^{1}_{1}X$$ **(1)** X is a proton [accept hydrogen nucleus]	**1**
(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 1	**15**

Question Number	Answer	Mark
5 (a)	A radioactive isotope has an unstable nucleus **(1)** (Which decays and) emits radiation **Or** α/β/γ (radiation) specified **(1)**	**2**
5 (b)	**Max 2** We can't know when an individual nucleus will decay **(1)** We can't know which nucleus will decay next **(1)** (In a given time interval) each nucleus has a fixed probability of decay **Or** (In a given time interval) a fixed fraction of nuclei undergo decay **(1)** [accept atom for nucleus, but there is a one mark penalty for using particle, molecule or isotope]	**2**
5 (c)	Identify half life = 5730 years **(1)** Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ **(1)** Decay constant = 1.21×10^{-4} (yr^{-1}) [3.84×10^{-12} (s^{-1})] **(1)** $N/N_0 = 0.60$ **(1)** Use of $N = N_0 e^{-\lambda t}$ **(1)** Age = 4220 yr [1.34×10^{11} s] **(1)** <u>Example of calculation</u> $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{5730} = 1.21 \times 10^{-4}\ \text{yr}^{-1}$ $\frac{N}{N_0} = 0.6 = e^{-1.21 \times 10^{-4} t}$ $\therefore \ln(0.6) = -1.21 \times 10^{-4} t$ $\therefore t = \frac{\ln(0.6)}{-1.21 \times 10^{-4}} = 4220\ \text{yr}$	**6**
5(d)	Ratio of C-14 to C-12 (in living material) was greater in the past **(1)** Appreciation that we are not comparing 'like with like' e.g. ratio used is from current matter **(1)** (Hence) the age of Stonehenge has been underestimated **(1)**	**3**
	Total for question 5	**13**

Question Number	Answer	Mark
6 (a)	**Max 4 with at least ONE similarity and ONE difference** **Similarities**: • Radioactive decay and corn popping are both random events **Or** the time at which any given nucleus will decay **and** any kernel will pop cannot be predicted **Or** can't tell which nucleus will decay **nor** which kernel will pop next **(1)** • (With a large number) the rate of decay / popping for both depends upon the number of unchanged nuclei / kernels **(1)** • Both have a decreasing rate of decay **(1)** • The rate of decay / popping depends upon the type of nucleus (isotope) / size of kernel **(1)** • Radioactive decay is an irreversible change, as is corn popping **(1)** **Differences:** • Not all the kernels are identical, whereas (for a given isotope) all the nuclei are identical **(1)** • Popping of corn depends on external factors and radioactive decay does not. (examples such as heating acceptable) **(1)** • The kernels do not emit standard fragments when they decay whereas radioactive nuclei emit radiation. **(1)**	**4**
6 (b)(i)	Log graph drawn **(1)** Suitable scales [not starting from 0 on y-axis] **(1)** Correct plotting of 6 points **(1)** Valid attempt at gradient calculation **(1)** Use of $t_{1/2}$ = ln 2/gradient **(1)** $t_{1/2} = 82 \pm 3$ s **(1)** <u>Example of Calculation</u>  	**6**

$$gradient = \frac{(4.4-3.4)}{(26-145)\,s} = 8.4\times10^{-3}\,s^{-1}$$

$$t_{½} = \frac{0.693}{8.4\times10^{-3}\,s^{-1}} = 82\ s$$

Or [Max 4]

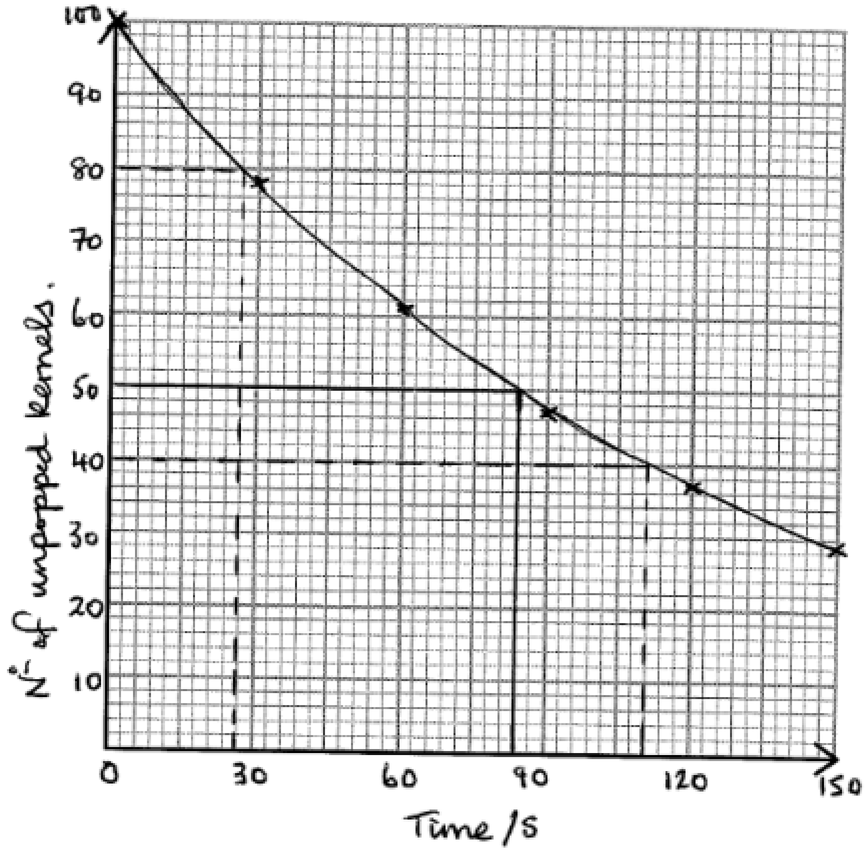
Suitable scales **(1)**

Correct plotting **(1)**

$t_{1/2}$ = 82 ± 3 s accurate from their graph **(1)**

Half life found from curve for at least two initial values of N **(1)**

Example of calculation



$t_{½}$ = (84 – 0) s = 84 s
$t_{½}$ = (111 – 27) s = 84 s

6 (b)(ii) (Identify that ¼ of kernels **or** 25 kernels are left, so 2 half lives have elapsed)
2 × answer in (i) **Or** read from graph **Or** 160 s **(1)**

Example of calculation

$$N = 100 - 75 = 25 \therefore \frac{N}{N_0} = \frac{25}{100} = \frac{1}{4}$$

t = 2 × 82 s = 164 s

Total for question 6 **11**

<table>
<tr><th>Question Number</th><th>Answer</th><th>Mark</th></tr>
<tr><td>7(a)</td><td>Similarity: Same number of protons Or same magnitude of charge Or both have 1 proton (1)

Difference: Different number of neutrons / nucleons Or different mass Or D has 1 neutrons and T has 2 neutrons (1)</td><td>2</td></tr>
<tr><td>7(b)</td><td>Use of $P = \frac{\Delta E}{\Delta t}$ (do not penalise a power of ten error) (1)
Energy = 7.5×10^6 (J) (1)

<u>Example of calculation</u>
$E = 500\times10^{12}\ \text{W}\times15\times10^{-9}\ \text{s} = 7.5\times10^{6}\ \text{J}$</td><td>2</td></tr>
<tr><td>7(c)(i)</td><td>${}^{2}_{1}\text{D} + {}^{3}_{1}\text{T} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$

<table><tr><td>Top line</td><td>2</td><td>3</td><td>4</td><td>1</td></tr><tr><td>Bottom line</td><td>1</td><td>1</td><td>2</td><td>0</td></tr></table>(1)
(1)</td><td>2</td></tr>
<tr><td>7(c)(ii)</td><td>Attempt at calculation of mass difference (1)
Energy released = 17.5 (MeV) [17.5 must be clearly identified as an energy] (1)

<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</td><td>2</td></tr>
<tr><td>7(c)(iii)</td><td>Conversion of energy to consistent units (1)
Number of nuclei = 3×10^{18} (1)

<u>Example of calculation</u>
In each fusion $\Delta E = 17.5\times10^{6}\ \text{eV}\times1.6\times10^{-19}\ \text{J eV}^{-1} = 2.8\times10^{-12}\ \text{J}$
$\therefore N = \frac{7.5\times10^{6}\ \text{J}}{2.8\times10^{-12}\ \text{J}} = 2.68\times10^{18}$
<table><tr><th>Energy MJ (b)</th><th>Energy MeV (c)(ii)</th><th>N × 10^{18}</th></tr><tr><td>7.5</td><td>17.5</td><td>2.7</td></tr><tr><td>7.5</td><td>20</td><td>2.3</td></tr><tr><td>8</td><td>17.5</td><td>2.9</td></tr><tr><td>8</td><td>20</td><td>2.5</td></tr></table></td><td>2</td></tr>
</table>

7 (c)(iv)	Application of momentum conservation	(1)	
	Deduction that $V_N = 4\,V_\alpha$ [$v_N = 3.967\,v_\alpha$]	(1)	
	Use of $E_k = \frac{1}{2}mv^2$ (ratio as shown **or** sum = 17.5 MeV)	(1)	
	Energy = 14 MeV (ecf (c)(ii), 14.1 MeV, if $v_N = 3.967\,v_\alpha$ 16 MeV if 20 MeV used)	(1)	
	Or		
	Application of momentum conservation	(1)	
	Use of $E_k = p^2/2m$	(1)	
	Deduction that $E_N = 4\,E_\alpha$	(1)	
	Energy = 14 MeV	(1)	4
	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, $E_\alpha + E_N = 17.5\text{ MeV}$ $\therefore \frac{E_N}{4} + E_N = 17.5\text{ MeV}$ $\therefore E_N = \frac{4}{5} \times 17.5\text{ MeV} = 14\text{ MeV}$		
7 (d)	**Max 3**		
	A heavy **nucleus** absorbs a neutron. [accepts “collides with” / “fired into” for “absorbs”]	(1)	
	The **nucleus** becomes unstable **and** splits into two (roughly equal sized) fragments [accept “decays” / “breaks up” for “splits”]	(1)	
	Idea that a few neutrons are also emitted in the fission process	(1)	
	These neutrons cause further fissions **Or** these neutrons cause a chain reaction	(1)	3
	(if atom is used instead of nucleus **only penalise once**)		
	Total for question 7		**17**