PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 11: NUCLEAR RADIATION

NUCLEAR RADIATION AND RADIOACTIVE DECAY

SCORE	PERCENTAGE
/384	%

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Mark Scheme

Q1.

Question Number	Answers	Mark
	The only correct answer is A ***B** is incorrect because an incorrect calibration would give a consistently high or low reading* ***C** is incorrect because temperature does not affect the background count rate* ***D** is incorrect because a systematic error would be a constant difference between the actual and the recorded count rate*	1

Q2.

Question Number	Answer	Mark
	D	**1**

Q3.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Counting for 1 minute is too short a time **Or** he should count for at least 3 minutes (1) (1) • He hasn't recorded the background count rate (1) • More than one reading taken and a mean calculated **Or** should have taken more than two readings (to calculate mean)		3

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
	MAX 5 An explanation that makes reference to the following points: • The student has calculated the coun rate rather than the activity of the source (1) • The counts haven't been corrected for background (so there is systematic error in his data) (1) • The GM tube is too far away from the source (1) • α-radiation won't reach the GM-tube as it only has a short range in air (1) • Radiation spreads out from the source, so not all the emitted radiation reaches the GM-tube (1) • GM tube won't detect all the gammas which enter it (1)		5

Q5.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of $\ln 2 = \lambda t_{1/2}$ • $\lambda = 4.92 \times 10^{-18}$ (s^{-1})	(1) (1)	Example of calculation $\lambda = \ln 2 / 1.41 \times 10^{17}$ s $= 4.92 \times 10^{-18}$ s^{-1}	2
(ii)	• Calculate rate = counts / time • Subtract background radiation • Use of $A = -\lambda N$ • Calculates $N \times$ atomic mass • Calculates percentage by mass • Answer = 0.17% (ecf for λ from (a)(i))	(1) (1) (1) (1) (1) (1)	Example of calculation background rate = 525 / (10 × 60) s = 0.875 s^{-1} vase count rate = 3623 / (5 × 60) s = 12.077 s^{-1} corrected rate = 11.2 s^{-1} for whole vase = 11.2 s^{-1} × 0.0177 m^2 / 6.36×10^{-5} m^2 = 3117 s^{-1} N = 3117 / 4.91×10^{-18} s^{-1} = 6.348×10^{20} Mass = $6.348 \times 10^{20} \times 238 \times 1.66 \times 10^{-27}$ kg = 2.51×10^{-4} kg Percentage = 2.51×10^{-4} kg × 100 / 0.149 = 0.17%	6
(iii)	**Max 2** from: • Alpha particles could have been absorbed by the glass • Alpha particles will be emitted in all directions, not just towards the detector • Some alpha particles could have been detected from other parts of the vase • The count could include radiation from decay products	(1) (1) (1) (1)		2
	• Some alpha particles could be absorbed by the GM tube window			

Q6.

Question Number	Acceptable Answer		Additional Guidance	Mark
	A description that makes reference to the following: • (Remove the source and) record background count for specified time and subtract from equivalent quantity • Divide by time to give a count rate.	(1) (1)	There needs to be two clear steps. Subtract a count from a count, or a count rate from a count rate and divide a count by time to obtain a count rate.	2

Q7.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C because the corrected count rate at 30 cm is 40 counts per minute, the corrected rate at twice the distance is a quarter of this value, which is 10 counts per minute, and adding the background gives the value of 34 A is not the correct answer because it is 16 C is not the correct answer because it is 32 D is not the correct answer because it is 44	1

Q8.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of ratio of atoms and atoms per g • Number of nuclei = 2.9×10^{17}	(1) (1)	$N = 0.3\ g \times 8.1 \times 10^{21}\ g^{-1} \times 0.012/100$ $= 2.9 \times 10^{17}$	2

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• use of $\ln 2 = \lambda t_{1/2}$ • use of activity = λN (ecf from (b)(i)) • activity = 5.1 (Bq) (use of show that value gives 5.3 Bq)	(1) (1) (1)	$\ln 2 = \lambda \times 1.25 \times 10^9$ years $= \lambda \times (1.25 \times 10^9 \times 365 \times 24 \times 60 \times 60)$ s $\lambda = 1.76 \times 10^{-17}\ s^{-1}$ $A = 1.76 \times 10^{-17}\ s^{-1} \times 2.9 \times 10^{17}$ = 5.1 Bq	3

Question Number	Acceptable answers		Additional guidance	Mark
(iii)	• use of count rate = (counts – background counts) / time • calculates percentage of activity from (b)(ii) **Or** applies 7.5% to activity from (b)(ii) • Comparative statement consistent with their values	(1) (1) (1)	**MP3** can only be awarded if Activity from (ii) is used. A clear comparison with the corresponding value must be made e.g. percentage = 0.8 % which is < 7.5 % so not efficient **Or** detects 176 but should detect 379 counts in 10 min, so not efficient **Or** should detect a rate of at least 0.63 Bq, so not efficient Example of calculation Recorded count rate = (176 - 150) ÷ 600 s = 0.04 Bq 0.04 Bq × 100 ÷ 5.1 Bq = 0.78 % (ecf from (b)(ii) for MP3)	3

Question Number	Acceptable answers	Additional guidance	Mark
(iv)	**Max two from** • emissions are in all directions (1) • some emitted particles may be absorbed by the material in the sample (1) • some emitted particles may be absorbed by the window (1) • some emitted particles pass (right) through detector (1)		**2**

Q9.

Question Number	Answer	Mark
	D	1

Q10.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Smooth best fit curve drawn on graph (1) • Time for count rate to fall by half once (1) • Time for count rate to fall by half twice and mean time calculated (1) • $t_{1/2}$ = 60 s → 80 s (1)	Alternative approaches for MP2 and MP3 Read 2 values from graph and use exponential equation **Or** draw tangent to curve at $t = 0$ and read off the time intercept Example of calculation 9.0 s^{-1} → 4.5 s^{-1} t = 75 s 4.5 s^{-1} → 2.25 s^{-1} t = 75 s If background count is taken into consideration, t will be lower	**4**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • There will be background radiation **Or** decay is exponential and so count rate will "never" reach zero **(1)** • The data logger output includes counts due to background radiation as well as the source radiation **Or** The count rate can't be corrected automatically **(1)**	MP2: accept references to GM-tube	**2**

Mark Scheme

Q1.

Question Number	Answer	Mark
(a)(i)	Alpha particles ionise the air **Or** alpha particles strip electrons from air molecules (1) The ions/electrons move (in the electric field between the plates) (1)	2
(a)(ii)	Smoke particles capture electrons (and reduce the free charge able to move) **Or** alpha particles collide with smoke particles and reduce amount of ionisation (1)	1
(b)(i)	Random means we cannot identify which atom/nucleus will be the next to decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction that will decay in the next time interval (1) Spontaneous means that the decay cannot be influenced by any (external) factors. (1)	2
(b)(ii)	$_{95}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np} + {}^{4}_{2}\alpha$ Top line correct (1) Bottom line correct (1)	2
	Total for question	7

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
	MAX 5 An explanation that makes reference to the following points: • The student has calculated the coun rate rather than the activity of the source (1) • The counts haven't been corrected for background (so there is systematic error in his data) (1) • The GM tube is too far away from the source (1) • α-radiation won't reach the GM-tube as it only has a short range in air (1) • Radiation spreads out from the source, so not all the emitted radiation reaches the GM-tube (1) • GM tube won't detect all the gammas which enter it		5

Q3.

Question Number	Acceptable answers		Additional guidance	Mark
	• Alpha won't penetrate the plastic so the gas can't escape	(1)	For MP1, accept answers in terms of the small range of alpha particles in the air in the bag	2
	• Alpha won't penetrate the plastic so there is no risk	(1)		

Q4.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of $\ln 2 = \lambda t_{1/2}$	(1)	Example of calculation $\lambda = \ln 2 / 1.41 \times 10^{17}$ s $= 4.92 \times 10^{-18}$ s^{-1}	2
	• $\lambda = 4.92 \times 10^{-18}$ (s^{-1})	(1)		
(ii)	• Calculate rate = counts / time	(1) (1)	Example of calculation background rate = 525 / (10 × 60) s = 0.875 s^{-1} vase count rate = 3623 / (5 × 60) s = 12.077 s^{-1} corrected rate = 11.2 s^{-1} for whole vase = 11.2 s^{-1} × 0.0177 m^2 / 6.36×10^{-5} m^2 = 3117 s^{-1} N = 3117 / 4.91×10^{-18} s^{-1} = 6.348×10^{20} Mass = $6.348 \times 10^{20} \times 238 \times 1.66 \times 10^{-27}$ kg = 2.51×10^{-4} kg Percentage = 2.51×10^{-4} kg × 100 / 0.149 = 0.17%	6
	• Subtract background radiation	(1) (1)		
	• Use of $A = -\lambda N$	(1) (1)		
	• Calculates N × atomic mass	(1)		
	• Calculates percentage by mass			
	• Answer = 0.17% (ecf for λ from (a)(i))			
(iii)	**Max 2** from: • Alpha particles could have been absorbed by the glass	(1)		2
	• Alpha particles will be emitted in all directions, not just towards the detector	(1)		
	• Some alpha particles could have been detected from other parts of the vase	(1)		
	• The count could include radiation from decay products	(1) (1)		

	• Some alpha particles could be absorbed by the GM tube window		

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• correct values of *A* and *Z* for α and β • 5 α • 4 β	Example of calculation: $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + x\ {}^{4}_{2}\alpha + y\ {}^{0}_{-1}\beta$ $226 - 206 = 4x$ $x = 5$ $88 - 82 - (5 \times 2) = -y$ $y = 4$ $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + 5\ {}^{4}_{2}\alpha + 4\ {}^{0}_{-1}\beta$	**(3)**

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• α-particles would only travel a few cm (in air), and so wouldn't reach the GM-tube **(1)** • β-particles would probably not pass through the sides of the GM-tube, and so wouldn't be detected so suggestion is correct. **(1)**	Accept a reference to α-particles not passing through the side of the tube (even if they reached it when d was small) and so not contributing to the count (rate) For 2 marks expect a valid conclusion, as well as a statement of the likelihood of the α-particles and β-particles contributing to the count (rate)	**2**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of ratio of atoms and atoms per g **(1)** • Number of nuclei = 2.9×10^{17} **(1)**	$N = 0.3\ g \times 8.1 \times 10^{21}\ g^{-1} \times 0.012/100 = 2.9 \times 10^{17}$	**2**

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• use of ln 2 = $\lambda t_{1/2}$	(1)	ln 2 = $\lambda \times 1.25 \times 10^9$ years = $\lambda \times (1.25 \times 10^9 \times 365 \times 24 \times 60 \times 60)$ s $\lambda = 1.76 \times 10^{-17}$ s^{-1} $A = 1.76 \times 10^{-17}$ s^{-1} × 2.9×10^{17} = 5.1 Bq	3
	• use of activity = λN (ecf from (b)(i))	(1)		
	• activity = 5.1 (Bq) (use of show that value gives 5.3 Bq)	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(iii)	• use of count rate = (counts – background counts) / time	(1)	**MP3** can only be awarded if Activity from (ii) is used. A clear comparison with the corresponding value must be made e.g. percentage = 0.8 % which is < 7.5 % so not efficient **Or** detects 176 but should detect 379 counts in 10 min, so not efficient **Or** should detect a rate of at least 0.63 Bq, so not efficient <u>Example of calculation</u> Recorded count rate = (176 - 150) ÷ 600 s = 0.04 Bq 0.04 Bq × 100 ÷ 5.1 Bq = 0.78 % (ecf from (b)(ii) for MP3)	3
	• calculates percentage of activity from (b)(ii) **Or** applies 7.5% to activity from (b)(ii)	(1)		
	• Comparative statement consistent with their values	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(iv)	**Max two from**			2
	• emissions are in all directions	(1)		
	• some emitted particles may be absorbed by the material in the sample	(1)		
	• some emitted particles may be absorbed by the window	(1)		
	• some emitted particles pass (right) through detector	(1)		

Q8.

<table>
<tr><th>Question Number</th><th>Answer</th><th>Mark</th></tr>
<tr><td>(a)(i)</td><td>Ionising radiation removes electrons from atoms/molecules (1)</td><td>1</td></tr>
<tr><td>(a)(ii)</td><td>
<table>
<tr><td colspan="3">Least ionising → most ionising</td></tr>
<tr><td>γ</td><td>β</td><td>α</td></tr>
</table>
(1)</td><td>1</td></tr>
<tr><td>(b)(i)</td><td>
<table>
<tr><td></td><td>Paper</td><td>0.5 cm aluminium</td><td>0.5 cm lead</td></tr>
<tr><td>α radiation</td><td>stopped</td><td>stopped</td><td>stopped</td></tr>
<tr><td>β radiation</td><td>passes through</td><td>stopped</td><td>stopped</td></tr>
<tr><td>γ radiation</td><td>passes through</td><td>passes through</td><td>passes through</td></tr>
</table>
(1)
(1)
(1)</td><td>3</td></tr>
<tr><td>(b)(ii)</td><td>(There is the possibility of) exposure to neutrons (1)
Uncharged particles are not (directly) ionising (1)</td><td>2</td></tr>
<tr><td></td><td>Total for question</td><td>7</td></tr>
</table>

Q9.

Question Number	Answer	Mark
	B	1

Q10.

Question Number	Answer		Mark
(a)(i)	Use of $\lambda t_{1/2} = \ln 2$	(1)	
	$\lambda = 5.8 \times 10^{-8}$ (s^{-1})	(1)	
	Use of $\frac{\Delta N}{\Delta t} = -\lambda N$	(1)	
	$\frac{\Delta N}{\Delta t} = (-)1.5\times10^{8}$ Bq [accept s^{-1} **Or** counts s^{-1}]	(1)	**4**
	Example of calculation $\lambda = \frac{0.693}{(138\times24\times3600)s} = 5.81\times10^{-8}s^{-1}$ $\frac{\Delta N}{\Delta t} = -5.81\times10^{-8}s^{-1}\times2.54\times10^{15} = -1.48\times10^{8}$ Bq		
(a)(ii)	Use of $N = N_0 e^{-\lambda t}$	(1)	
	Fraction of nuclei remaining = 0.90	(1)	
	10% of nuclei have decayed [accept 0.1 **Or** 1/10]	(1)	**3**
	Example of calculation t = 21 × 24 × 3600 s = 1 814 400 s $\frac{N}{N_0} = e^{-5.81\times10^{-8}s^{-1}\times1.81\times10^{6}s}$ $\frac{N}{N_0} = e^{-0.105} = 0.900$ Fraction decayed = 1- 0.9 = 0.1		

(b)	Idea that α-particles are not able to penetrate the (dead layer of) skin (from outside the body)	(1)	
	Damage/danger if energy is transferred to cells/DNA **Or** damage/danger to cells/DNA due to ionisation	(1)	**2**
(c)(i)	$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}\alpha$		
	Top line correct	(1)	
	Bottom line correct	(1)	**2**
(c)(ii)	So that momentum is conserved	(1)	**1**
(d)	Spontaneous means that the decay cannot be influenced by any external factors.	(1)	
	Random means that we cannot identify which atom/nucleus will (be the next to) decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction of the total number that will decay in the next time interval	(1)	**2**

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(e)	Idea that traces of the isotope will be excreted from the body (and deposited in the surroundings) (1) Idea that the half life is long enough for the activity to be detectable for a long time (1)	**2**
	Total for question	**16**

Q11.

Question Number	Answer	Mark
(a)	A radioactive atom has an unstable nucleus **(1)** which emits α, β, or γ radiation [at least one of α β γ named] **(1)**	**2**
(b)	$C \rightarrow {}^{11}_{5}B + {}^{0}_{1}e^{+} + \nu_e$ Top line correct **(1)** Bottom line correct **(1)**	**2**
(c)	Attempt at mass diference calculation **(1)** Attempt at conversion from (M)eV to J **(1)** $\Delta E = 1.4 \times 10^{-13}$ (J) **(1)** Example of calculation: $\Delta E = 10\,253.6 - 10252.2\text{-}0.5 = 0.889$ MeV $\Delta E = 0.889 \text{ MeV} \times 1.6 \times 10^{-13} \text{ J MeV}^{-1} = 1.42 \times 10^{-13}$ J	**3**
(d)	The idea that the sample will not produce radiation for very long (because carbon-11 has a relatively short half-life) **(1)** β particles are not very ionising **Or** positrons are not very ionising **Or** boron is safe in small amounts **(1)**	**2**
(e)	Use of $\lambda t_{1/2} = \ln 2$ **(1)** $(\lambda = 5.68 \times 10^{-4} \text{ s}^{-1})$ Use of $A = A_0 e^{-\lambda t}$ **(1)** Use $A = 1.58 \times 10^{6}$ Bq in $A = A_0 e^{-\lambda t}$ **(1)** $A_0 = 1.2 \times 10^{7}$ Bq **(1)** Example of calculation: $\lambda = \frac{0.693}{1220 \text{ s}} = 5.68 \times 10^{-4} \text{ s}^{-1}$ $1.58 \times 10^{6} \text{ Bq} = A_0 e^{-5.68 \times 10^{-4} \text{ s}^{-1} \times 60 \times 60 \text{ s}}$ $A_0 = 1.22 \times 10^{7}$ Bq	**4**
	Total for question	**13**

Q12.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An explanation that makes reference to the following: • use a GM tube and counter to measure the number of counts in a known time (1) • place a piece of aluminium a few mm thick between the source and the detector (1) • α and β will not penetrate aluminium but γ will (1) • so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226 (1)	Answers may refer to the use of a ratemeter instead of a counter	
	<u>OR</u> use a GM tube and counter to measure the number of counts in a known time • place a strong magnet near the source (1) • α and β will be deviated but γ will not (1) • so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226 (1)		**(4)**

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	An explanation that makes reference to a precaution and the reason for it • make sure the source remains at a distance of at least 30 cm from your body to minimise exposure	(1)		**(2)**
	<u>OR</u> make sure the source is always pointed away from you to minimise exposure	(1)		
	<u>OR</u> only use one source at a time to minimise exposure	(1)		
	• the sources emit ionising radiation which can be harmful to your cells	(1)		

Q13.

Question Number	Answer	Mark
	C	**1**

Q14.

Question Number	Answer	Mark
	C	**1**

Q15.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B because alpha is the most ionising and gamma is the most penetrating A is not correct because although alpha is the most ionising, gamma and not alpha is the most penetrating C is not correct because alpha, not gamma, is the most ionising and gamma, not alpha is the most penetrating D is not correct because alpha, not gamma is the most ionising, even though gamma is the most penetrating		1

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• 8 alpha • 6 beta	(1) (1)	Example of calculation 238−206 = 32 32 ÷ 4 = 8 alpha 92−82 = 10, 8 × 2 = 16 16 – 10 = 6 beta	2
(ii)	• Use of $\ln 2 = t_{½} \times \lambda$ • Use of $N = N_0 e^{-\lambda t}$ • $t = 4.3 \times 10^9$ (year)	(1) (1) (1)	Example of calculation $\ln 2 = 4.47 \times 10^9$ year $\times \lambda$ $\lambda = 1.55 \times 10^{-10}$ year^{-1} $53 = 103\ e^{-1.55 \times 10^{-10}\ \text{year}^{-1} \times t}$ $\ln 53 = \ln 103 - 1.55 \times 10^{-10}$ year$^{-1} \times t$ $t = 4.3 \times 10^9$ year	3

Q2.

Question Number	Answer		Mark
(a)(i)	Alpha particles ionise the air **Or** alpha particles strip electrons from air molecules	(1)	
	The ions/electrons move (in the electric field between the plates)	(1)	2
(a)(ii)	Smoke particles capture electrons (and reduce the free charge able to move) **Or** alpha particles collide with smoke particles and reduce amount of ionisation	(1)	1
(b)(i)	Random means we cannot identify which atom/nucleus will be the next to decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction that will decay in the next time interval	(1)	
	Spontaneous means that the decay cannot be influenced by any (external) factors.	(1)	2
(b)(ii)	${}_{95}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np} + {}^{4}_{2}\alpha$ Top line correct Bottom line correct	(1) (1)	2
	Total for question		7

Q3.

Question Number	Acceptable answers		Additional guidance	Mark
	• Top line correct • Bottom line correct	(1) (1)	Example of calculation: ${}^{87}_{37}\mathrm{Rb} \rightarrow {}^{87}_{38}\mathrm{Sr} + {}^{0}_{-1}\beta^{-} + \bar{\nu}_e$	2

Q4.

Question Number	Acceptable answers		Additional guidance	Mark
	• top: 40, 0 • bottom: 20, -1	(1) (1)		2

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Top line correct (1) • Bottom line correct (1)	Example of equation $^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}e$	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) • Use of 5000 m^3 (1) • Use of $A = A_0 e^{-\lambda t}$ (1) • $t = 1400$ year (1)	Example of calculation $\lambda = \frac{\ln 2}{30 \text{ year}} = 0.0231 \text{ year}^{-1}$ $100 \text{ Bq} = (5000 \times 2.35 \times 10^{12}) \text{Bq} \times e^{-0.0231 \text{ year}^{-1} \times t}$ $\therefore t = \frac{\ln (8.51 \times 10^{-15})}{-0.0231 \text{ year}^{-1}} = 1402 \text{ year}$	4

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• correct values of A and Z for α and β • 5 α • 4 β	Example of calculation: $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + x\ {}^{4}_{2}\alpha + y\ {}^{0}_{-1}\beta$ $226 - 206 = 4x$ $x = 5$ $88 - 82 - (5 \times 2) = -y$ $y = 4$ $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + 5\ {}^{4}_{2}\alpha + 4\ {}^{0}_{-1}\beta$	(3)

Q7.

Question Number	Answer		Mark
(a)(i)	Top line correct Bottom line correct $^{2}_{1}\mathrm{H}+^{3}_{1}\mathrm{H}\rightarrow^{4}_{2}\mathrm{He}+^{1}_{0}\mathrm{n}$	(1) (1)	2
(a)(ii)	Attempt at mass deficit calculation $\Delta E = 0.0175$ GeV (accept 2.8×10^{-12} J) Example of calculation: $\Delta m = (3.7274 + 0.939566 - 2.8089 - 1.8756)$ GeV/c^2 = 0.0175 GeV/c^2 $\Delta E = 0.0175$ GeV	(1) (1)	2
(a)(iii)	Momentum is conserved Mass of neutron is smaller, so speed is greater $E_k = ½ mv^2$, so E_k is larger **Or** Momentum is conserved $E_k = p^2/2m$ m of neutron is smaller, so E_k is larger	(1) (1) (1) (1) (1) (1)	3

(b)	Use of $\lambda = \frac{\ln 2}{t_{½}}$ Use of $A = A_0 e^{-\lambda t}$ t = 41 (years) Example of calculation: $\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{12.3 \text{ year}} = 0.0563 \text{ year}^{-1}$ $A = A_0 e^{-\lambda t} \quad \therefore t = \frac{\ln\left(A/A_0\right)}{-\lambda} = \frac{\ln(0.1)}{-0.0563 \text{ year}^{-1}} = 40.9 \text{ years}$	(1) (1) (1)	3

* (c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** There is little possibility of a runaway fusion reaction (unlike fission) (1) There would not be any radioactive waste produced in the fusion process **Or** the flux of neutrons would produce radioactive isotopes when absorbed by materials in the reactor (1) A very/extremely high temperature (plasma) is required (1) Plasma must not touch reactor walls, so strong magnetic fields are required (1) If plasma touches the walls of the reactor its temperature falls (and fusion stops) (1)		5
	Total for question		**15**

Q8.

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**

Q9.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is **C**: mass decrease by 20 → 5 α, which is a charge decrease of 10, but total charge decrease is 6, so 4 β A is not correct because there are too few alpha and too many beta B is not correct because there are too few alpha and too many beta D is not correct because there are too many beta	1

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **C** emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2 A is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 2 and the proton number has been increased by 4 B is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 4 and the proton number has been increased by 2 D is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been decreased by 2 and the proton number has been decreased by 4		**1**

Mark Scheme

Q1.

Question Number	Answer	Mark
(a)(i)	Alpha particles ionise the air **Or** alpha particles strip electrons from air molecules (1) The ions/electrons move (in the electric field between the plates) (1)	2
(a)(ii)	Smoke particles capture electrons (and reduce the free charge able to move) **Or** alpha particles collide with smoke particles and reduce amount of ionisation (1)	1
(b)(i)	Random means we cannot identify which atom/nucleus will be the next to decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction that will decay in the next time interval (1) Spontaneous means that the decay cannot be influenced by any (external) factors. (1)	2
(b)(ii)	${}_{95}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np} + {}^{4}_{2}\alpha$ Top line correct (1) Bottom line correct (1)	2
	Total for question	7

Q2.

Question Number	Answer	Mark
	A	1

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of ratio of atoms and atoms per g (1) • Number of nuclei = 2.9×10^{17} (1)	$N = 0.3\ \mathrm{g} \times 8.1 \times 10^{21}\ \mathrm{g}^{-1} \times 0.012/100 = 2.9 \times 10^{17}$	2

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• use of ln 2 = $\lambda t_{1/2}$	(1)	ln 2 = $\lambda \times 1.25 \times 10^9$ years = $\lambda \times (1.25 \times 10^9 \times 365 \times 24 \times 60 \times 60)$ s $\lambda = 1.76 \times 10^{-17}$ s^{-1} $A = 1.76 \times 10^{-17}$ s^{-1} × 2.9×10^{17} = 5.1 Bq	3
	• use of activity = λN (ecf from (b)(i))	(1)		
	• activity = 5.1 (Bq) (use of show that value gives 5.3 Bq)	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(iii)	• use of count rate = (counts – background counts) / time	(1)	**MP3** can only be awarded if Activity from (ii) is used. A clear comparison with the corresponding value must be made e.g. percentage = 0.8 % which is < 7.5 % so not efficient **Or** detects 176 but should detect 379 counts in 10 min, so not efficient **Or** should detect a rate of at least 0.63 Bq, so not efficient Example of calculation Recorded count rate = (176 - 150) ÷ 600 s = 0.04 Bq 0.04 Bq × 100 ÷ 5.1 Bq = 0.78 % (ecf from (b)(ii) for MP3)	3
	• calculates percentage of activity from (b)(ii) **Or** applies 7.5% to activity from (b)(ii)	(1)		
	• Comparative statement consistent with their values	(1)		

Question Number	Acceptable answers		Additional guidance	Mark
(iv)	**Max two from**			2
	• emissions are in all directions	(1)		
	• some emitted particles may be absorbed by the material in the sample	(1)		
	• some emitted particles may be absorbed by the window	(1)		
	• some emitted particles pass (right) through detector	(1)		

Q4.

Question Number	Answer		Mark
(a)(i)	Use of $\lambda t_{1/2} = \ln 2$	(1)	
	$\lambda = 5.8 \times 10^{-8}$ (s^{-1})	(1)	
	Use of $\frac{\Delta N}{\Delta t} = -\lambda N$	(1)	
	$\frac{\Delta N}{\Delta t} = (-)1.5\times10^{8}$ Bq [accept s^{-1} **Or** counts s^{-1}]	(1)	**4**
	Example of calculation $\lambda = \frac{0.693}{(138\times24\times3600)s} = 5.81\times10^{-8}s^{-1}$ $\frac{\Delta N}{\Delta t} = -5.81\times10^{-8}s^{-1}\times2.54\times10^{15} = -1.48\times10^{8}$ Bq		
(a)(ii)	Use of $N = N_0 e^{-\lambda t}$	(1)	
	Fraction of nuclei remaining = 0.90	(1)	
	10% of nuclei have decayed [accept 0.1 **Or** 1/10]	(1)	**3**
	Example of calculation t = 21 × 24 × 3600 s = 1 814 400 s $\frac{N}{N_0} = e^{-5.81\times10^{-8}s^{-1}\times1.81\times10^{6}s}$ $\frac{N}{N_0} = e^{-0.105} = 0.900$ Fraction decayed = 1- 0.9 = 0.1		

(b)	Idea that α-particles are not able to penetrate the (dead layer of) skin (from outside the body)	(1)	
	Damage/danger if energy is transferred to cells/DNA **Or** damage/danger to cells/DNA due to ionisation	(1)	**2**
(c)(i)	$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}\alpha$		
	Top line correct	(1)	
	Bottom line correct	(1)	**2**
(c)(ii)	So that momentum is conserved	(1)	**1**
(d)	Spontaneous means that the decay cannot be influenced by any external factors.	(1)	
	Random means that we cannot identify which atom/nucleus will (be the next to) decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction of the total number that will decay in the next time interval	(1)	**2**

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(e)	Idea that traces of the isotope will be excreted from the body (and deposited in the surroundings) (1) Idea that the half life is long enough for the activity to be detectable for a long time (1)	**2**
	Total for question	**16**

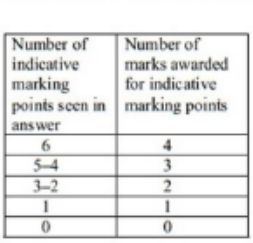
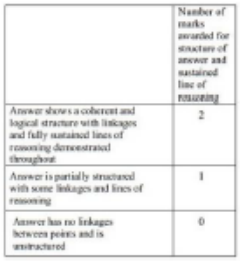
Q5.

Question Number	Answer	Mark
(a)	A radioactive atom has an unstable nucleus **(1)** which emits α, β, or γ radiation [at least one of α β γ named] **(1)**	**2**
(b)	$C \rightarrow {}^{11}_{5}B + {}^{0}_{1}e^{+} + \nu_e$ Top line correct **(1)** Bottom line correct **(1)**	**2**
(c)	Attempt at mass diference calculation **(1)** Attempt at conversion from (M)eV to J **(1)** $\Delta E = 1.4 \times 10^{-13}$ (J) **(1)** Example of calculation: $\Delta E = 10\,253.6 - 10252.2\text{-}0.5 = 0.889$ MeV $\Delta E = 0.889 \text{ MeV} \times 1.6 \times 10^{-13} \text{ J MeV}^{-1} = 1.42 \times 10^{-13}$ J	**3**
(d)	The idea that the sample will not produce radiation for very long (because carbon-11 has a relatively short half-life) **(1)** β particles are not very ionising **Or** positrons are not very ionising **Or** boron is safe in small amounts **(1)**	**2**
(e)	Use of $\lambda t_{1/2} = \ln 2$ **(1)** $(\lambda = 5.68 \times 10^{-4} \text{ s}^{-1})$ Use of $A = A_0 e^{-\lambda t}$ **(1)** Use $A = 1.58 \times 10^{6}$ Bq in $A = A_0 e^{-\lambda t}$ **(1)** $A_0 = 1.2 \times 10^{7}$ Bq **(1)** Example of calculation: $\lambda = \frac{0.693}{1220 \text{ s}} = 5.68 \times 10^{-4} \text{ s}^{-1}$ $1.58 \times 10^{6} \text{ Bq} = A_0 e^{-5.68 \times 10^{-4} \text{ s}^{-1} \times 60 \times 60 \text{ s}}$ $A_0 = 1.22 \times 10^{7}$ Bq	**4**
	Total for question	**13**

Q6.

Question Number	Answer	Mark
	C	**1**

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. **Indicative content:** IC1 There is a fixed probability (λ) of an individual nucleus undergoing decay (in the next second) IC2 For a sample with large number of unstable nuclei there is a predictable pattern IC3 The fraction of nuclei decaying in the next second is equal to the decay constant (λ)	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.  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 Total marks awarded is the sum of marks for indicative content and the marks for 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	**6**

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	IC4 Hence the number of nuclei decaying (in the next second) depends on the number of (unstable) nuclei **Or** activity = λN IC5 The number of unstable nuclei decreases exponentially (with time) **Or** number of (unstable) nuclei = $N_0 e^{-\lambda t}$ IC6 So the rate of decay decreases exponentially (with time) **Or** rate of decay = $A_0 e^{-\lambda t}$		

Q8.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• decay happens without any external stimulus **Or** decay is unaffected by external factors (such as temperature) **(1)**	Do not credit references to the randomness of the decay	1

Q9.

Question Number	Answer	Mark
	D	1

Q10.

Question Number	Answer		Mark
(a)	Activity is the rate of decay of (unstable) nuclei **Or** activity is the number of (unstable) nuclei that decay in unit time	**(1)**	1

(b)(i)	Background radiation/count will increase the recorded count **Or** background count must be subtracted from the recorded count **Or** background radiation contributes systematic error to the count [Do not accept "to correct for background radiation"]	**(1)**	**1**
(b)(ii)	Radioactive decay is a random process (so count for a fixed period will vary) [Ignore references to spontaneous, accurate, reliable] Idea that repeating enables a mean/average value to be calculated	**(1)** **(1)**	**2**
(b)(iii)	Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ Use of $A = A_0 e^{-\lambda t}$ [allow 2.5 Bq for A_0 here; allow use of $N = N_0 e^{-\lambda t}$] $A = 0.47$ Bq [Allow calculation of number of half lives elapsed and use of $A = A_0\left(\frac{1}{2}\right)^{t/t_{1/2}}$ for mp1 and mp2] Example of calculation: $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{8.0\,\text{d}} = 0.0866\,\text{d}^{-1}$ $A = A_0 e^{-\lambda t} = 6.38 \times \text{e}^{-0.0866\,\text{d}^{-1} \times 30\,\text{d}} = 6.38\,\text{Bq} \times 0.074 = 0.47\,\text{Bq}$	**(1)** **(1)** **(1)**	**3**
(b)(iv)	Idea that people have to be close to or ingest seaweed for any degree of risk **Or** β particles are moderately ionising **Or** β particles can enter body through the skin The half-life is short **Or** after a month the activity has decayed to negligible levels **Or** the radioisotope doesn't remain in the seaweed for very long	**(1)** **(1)**	**2**
	Total for Question		**9**

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• 8 alpha • 6 beta	(1) (1)	Example of calculation 238−206 = 32 32 ÷ 4 = 8 alpha 92−82 = 10, 8 × 2 = 16 16 – 10 = 6 beta	2
(ii)	• Use of ln 2 = $t_{½} \times \lambda$ • Use of $N = N_0 e^{-\lambda t}$ • $t = 4.3 \times 10^9$ (year)	(1) (1) (1)	Example of calculation ln 2 = 4.47 × 10^9 year × λ $\lambda = 1.55 \times 10^{-10}$ $year^{-1}$ $53 = 103\ e^{-1.55 \times 10^{-10}\ year^{-1} \times t}$ ln 53 = ln 103 – 1.55×10^{-10} $year^{-1} \times t$ $t = 4.3 \times 10^9$ year	3

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Calculation of number of half-lives elapsed (1) • Use of number of half-lives to calculate number of iodine nuclei remaining (1) • Calculation of number of iodine nuclei decayed (1) • Conversion of temperature to kelvin (1) • Use of $ppVV = NNNNTT$ (1) • Pressure is 1.1 × 10^5 Pa (compared with 1.0 × 10^5) and so there is sufficient gas (1) **Or** 1.1 × 10^{28} gas atoms needed to give required pressure compared with 1.2 × 10^{28} actual gas atoms, so there is sufficient gas	MP1 & MP2: Allow use of $\lambda = \frac{\ln 2}{t_{1/2}}$ and $A = A_0 e^{-\lambda t}$ Example of calculation $N = \frac{N_0}{2^4} = \frac{1.25 \times 10^{28}}{16} = 7.81 \times 10^{26}$ $N = 1.25 \times 10^{28} - 7.81 \times 10^{26} = 1.17 \times 10^{28}$ $p \times 450\ m^3 = 1.17 \times 10^{28} \times 1.38 \times 10^{-23}\ J\ K^{-1} \times (20 + 273)K$ $\therefore p = \frac{4.73 \times 10^7\ J}{450\ m^3} = 1.05 \times 10^5\ Pa$	6

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• so the proportion of unstable nuclei does not change significantly over time **(1)** **Or** activity does not change significantly over time		**1**

Q4.

Question Number	Answer		Mark
(a)	Use of $\lambda = \ln 2/t_{1/2}$ $\lambda = 1.22 \times 10^{-4}$ (yr^{-1}) [$\lambda = 3.86 \times 10^{-12}$ (s^{-1}), $\lambda = 2.31 \times 10^{-10}$ (min^{-1})] Use of $A = A_0e^{-\lambda t}$ $t = 950$ (yr) [if $\lambda = 1.2 \times 10^{-4}$, then $t = 960$ (yr)] [credit answers that use a constant ratio method to find the number of half lives elapsed] <u>Example of calculation</u> $\lambda = \frac{0.693}{5700\ \text{yr}} = 1.22 \times 10^{-4}\ \text{yr}^{-1}$ $14.7\,\text{s}^{-1} = 16.5\,\text{s}^{-1} \times e^{-1.22\times10^{-4}\ \text{yr}^{-1}\times t}$ $t = \frac{\ln\left(\frac{14.7\,\text{s}^{-1}}{16.5\,\text{s}^{-1}}\right)}{-1.22\times10^{-4}\ \text{yr}^{-1}} = 947\ \text{yr}$	**(1)** **(1)** **(1)** **(1)**	**4**
(b)	Initial value of count rate should be bigger than 16.5 min^{-1} **Or** greater count rate from living wood in the past [e.g. A/A_0 smaller] **Or** initial value of count rate underestimated in the calculation **Or** Initial number of undecayed atoms greater [e.g. N/N_0 smaller] Age of sample has been underestimated **Or** ship is older than 950 yr **Or** sample has been decaying for a longer time [If a calculation has been carried out to show that a greater value of initial activity leads to a greater age, then award both marks]	**(1)** **(1)**	**2**

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Top line correct **(1)** • Bottom line correct **(1)**	<u>Example of equation</u> $^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\bar{\nu}_e$	**2**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) • Use of 5000 m^3 (1) • Use of $A = A_0 e^{-\lambda t}$ (1) • $t = 1400$ year (1)	Example of calculation $\lambda = \frac{\ln 2}{30 \text{ year}} = 0.0231 \text{ year}^{-1}$ $100 \text{ Bq} = (5000 \times 2.35 \times 10^{12}) \text{Bq} \times e^{-0.0231 \text{ year}^{-1} \times t}$ $\therefore t = \frac{\ln (8.51 \times 10^{-15})}{-0.0231 \text{ year}^{-1}} = 1402 \text{ year}$	4

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $\ln 2 = \lambda t_{1/2}$ (1) • $\lambda = 4.92 \times 10^{-18}$ (s^{-1}) (1)	Example of calculation $\lambda = \ln 2 / 1.41 \times 10^{17}$ s $= 4.92 \times 10^{-18}$ s^{-1}	2
(ii)	• Calculate rate = counts / time (1) • Subtract background radiation (1) • Use of $A = -\lambda N$ (1) • Calculates $N \times$ atomic mass (1) • Calculates percentage by mass (1) • Answer = 0.17% (ecf for λ from (a)(i)) (1)	Example of calculation background rate = 525 / (10 × 60) s = 0.875 s^{-1} vase count rate = 3623 / (5 × 60) s = 12.077 s^{-1} corrected rate = 11.2 s^{-1} for whole vase = 11.2 s^{-1} × 0.0177 m^2 / 6.36×10^{-5} m^2 = 3117 s^{-1} N = 3117 / 4.91×10^{-18} s^{-1} = 6.348×10^{20} Mass = $6.348 \times 10^{20} \times 238 \times 1.66 \times 10^{-27}$ kg = 2.51×10^{-4} kg Percentage = 2.51×10^{-4} kg × 100 / 0.149 = 0.17%	6
(iii)	**Max 2** from: • Alpha particles could have been absorbed by the glass (1) • Alpha particles will be emitted in all directions, not just towards the detector (1) • Some alpha particles could have been detected from other parts of the vase (1) • The count could include radiation from decay products (1) • Some alpha particles could be absorbed by the GM tube window (1)		2

Q7.

Question Number	Answer		Mark
(a)(i)	Top line correct Bottom line correct $^{2}_{1}\mathrm{H}+^{3}_{1}\mathrm{H}\rightarrow^{4}_{2}\mathrm{He}+^{1}_{0}\mathrm{n}$	(1) (1)	2
(a)(ii)	Attempt at mass deficit calculation $\Delta E = 0.0175$ GeV (accept 2.8×10^{-12} J) Example of calculation: $\Delta m = (3.7274 + 0.939566 - 2.8089 - 1.8756)$ GeV/c^2 = 0.0175 GeV/c^2 $\Delta E = 0.0175$ GeV	(1) (1)	2
(a)(iii)	Momentum is conserved Mass of neutron is smaller, so speed is greater $E_k = ½ mv^2$, so E_k is larger **Or** Momentum is conserved $E_k = p^2/2m$ m of neutron is smaller, so E_k is larger	(1) (1) (1) (1) (1) (1)	3
(b)	Use of $\lambda = \frac{\ln 2}{t_{½}}$ Use of $A = A_0 e^{-\lambda t}$ t = 41 (years) Example of calculation: $\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{12.3 \text{ year}} = 0.0563 \text{ year}^{-1}$ $A = A_0 e^{-\lambda t} \quad \therefore t = \frac{\ln\left(A/A_0\right)}{-\lambda} = \frac{\ln(0.1)}{-0.0563 \text{ year}^{-1}} = 40.9 \text{ years}$	(1) (1) (1)	3

* (c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** There is little possibility of a runaway fusion reaction (unlike fission) **(1)** There would not be any radioactive waste produced in the fusion process **Or** the flux of neutrons would produce radioactive isotopes when absorbed by materials in the reactor **(1)** A very/extremely high temperature (plasma) is required **(1)** Plasma must not touch reactor walls, so strong magnetic fields are required **(1)** If plasma touches the walls of the reactor its temperature falls (and fusion stops) **(1)**	**5**
	Total for question	**15**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of ratio of atoms and atoms per g **(1)** • Number of nuclei = 2.9×10^{17} **(1)**	$N = 0.3\ g \times 8.1 \times 10^{21}\ g^{-1} \times 0.012/100$ $= 2.9 \times 10^{17}$	**2**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	• use of $\ln 2 = \lambda t_{1/2}$ **(1)** • use of activity = λN (ecf from (b)(i)) **(1)** • activity = 5.1 (Bq) (use of show that value gives 5.3 Bq) **(1)**	$\ln 2 = \lambda \times 1.25 \times 10^9$ years $= \lambda \times (1.25 \times 10^9 \times 365 \times 24 \times 60 \times 60)$ s $\lambda = 1.76 \times 10^{-17}\ s^{-1}$ $A = 1.76 \times 10^{-17}\ s^{-1} \times 2.9 \times 10^{17}$ $= 5.1$ Bq	**3**

Question Number	Acceptable answers	Additional guidance	Mark
(iii)	• use of count rate = (counts – background counts) / time **(1)** • calculates percentage of activity from (b)(ii) **Or** applies 7.5% to activity from (b)(ii) **(1)** • Comparative statement consistent with their values **(1)**	**MP3** can only be awarded if Activity from (ii) is used. A clear comparison with the corresponding value must be made e.g. percentage = 0.8 % which is < 7.5 % so not efficient **Or** detects 176 but should detect 379 counts in 10 min, so not efficient **Or** should detect a rate of at least 0.63 Bq, so not efficient Example of calculation Recorded count rate = (176 - 150) ÷ 600 s = 0.04 Bq 0.04 Bq × 100 ÷ 5.1 Bq = 0.78 % (ecf from (b)(ii) for MP3)	**3**

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Question Number	Acceptable answers	Additional guidance	Mark
(iv)	**Max two from** • emissions are in all directions **(1)** • some emitted particles may be absorbed by the material in the sample **(1)** • some emitted particles may be absorbed by the window **(1)** • some emitted particles pass (right) through detector **(1)**		**2**

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• subtracts background from counts in 60 s (1) • use of half life × λ = ln 2 (1) • use of $A = A_0\, e^{-\lambda t}$ (1) • correct logarithmic conversion (1) • year = 1987 (1)	Example of calculation: 12227 - 22 = 12205 322 - 15 = 307 $307 = 12205 \times e^{-\ln 2t/5.3\ y}$ ln 307 = ln 12205 - ln2 × t / 5.3 y t = 28 years Year = 2015 - 28 = 1987	**(5)**

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	An explanation that makes reference to one of the following pairs: • if the measurement in 2015 were at a larger distance than X, the count rate would be less	(1)	Allow reverse arguments	**(2)**
	• the source would appear to be older than it really is	(1)		
	<u>OR</u> • 307 is a relatively small count	(1)		
	• the equations apply for large numbers of decays therefore you cannot be sure of the accuracy of the age	(1)		
	<u>OR</u> • if the sensitivity of the GM tube were greater in 2015, the count rate would be larger	(1)		
	• the source would appear to be younger than it really is	(1)		

Q10.

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)	Example of calculation $N = (5.18 \times 10^{-5}\text{ g}/230\text{ g}) \times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7)\text{ s} = \ln 2$ $\lambda = 2.92 \times 10^{-13}\text{ s}^{-1}$ $A = 2.92 \times 10^{-13}\text{ s}^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4\text{ Bq}$	4
(ii)	• Calculates decays in one year (ecf from (b)(i)) • Use of $pV = NkT$ • uses $T = 295$ K • $V = 5.09 \times 10^{-14}\text{ m}^3$	(1) (1) (1) (1)	Example of calculation ecf λ from (a) decays in one year = $3.97 \times 10^4\text{ Bq} \times 3.15 \times 10^7\text{ s}$ $= 1.25 \times 10^{12}$ $1.00 \times 10^5\text{ Pa} \times V = 1.25 \times 10^{12} \times 1.38 \times 10^{-23}\text{ J K}^{-1} \times 295\text{ K}$ $V = 5.09 \times 10^{-14}\text{ m}^3$	4
(iii)	• Use of $½\,m\langle c^2\rangle = 3/2\,kT$ **Or** Use of $pV = \frac{1}{3}Nm\langle c^2\rangle$ (allow ecf for N, V from (b)(ii)) • uses $m = 4u$ • $\sqrt{\langle c^2\rangle} = 1360\text{ m s}^{-1}$	(1) (1) (1)	Example of calculation $½\,m\langle c^2\rangle = 3/2\,kT$ $½ \times (4 \times 1.66 \times 10^{-27}\text{ kg}) \times \langle c^2\rangle = 3/2 \times 1.38 \times 10^{-23}\text{ J K}^{-1} \times 295\text{ K}$ $\langle c^2\rangle = 1\,840\,000\text{ m}^2\text{ s}^{-2}$ $\sqrt{\langle c^2\rangle} = 1360\text{ m s}^{-1}$ Accept the use of proton/neutron mass instead of u	3

Q11.

Question Number	Answer		Mark
(a)(i)	Use of $\lambda t_{1/2} = \ln 2$	(1)	
	$\lambda = 5.8 \times 10^{-8}$ (s^{-1})	(1)	
	Use of $\frac{\Delta N}{\Delta t} = -\lambda N$	(1)	
	$\frac{\Delta N}{\Delta t} = (-)1.5\times10^{8}$ Bq [accept s^{-1} **Or** counts s^{-1}]	(1)	**4**
	Example of calculation $\lambda = \frac{0.693}{(138\times24\times3600)s} = 5.81\times10^{-8}s^{-1}$ $\frac{\Delta N}{\Delta t} = -5.81\times10^{-8}s^{-1}\times2.54\times10^{15} = -1.48\times10^{8}$ Bq		
(a)(ii)	Use of $N = N_0 e^{-\lambda t}$	(1)	
	Fraction of nuclei remaining = 0.90	(1)	
	10% of nuclei have decayed [accept 0.1 **Or** 1/10]	(1)	**3**
	Example of calculation t = 21 × 24 × 3600 s = 1 814 400 s $\frac{N}{N_0} = e^{-5.81\times10^{-8}s^{-1}\times1.81\times10^{6}s}$ $\frac{N}{N_0} = e^{-0.105} = 0.900$ Fraction decayed = 1- 0.9 = 0.1		

(b)	Idea that α-particles are not able to penetrate the (dead layer of) skin (from outside the body)	(1)	
	Damage/danger if energy is transferred to cells/DNA **Or** damage/danger to cells/DNA due to ionisation	(1)	**2**
(c)(i)	$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}\alpha$		
	Top line correct	(1)	
	Bottom line correct	(1)	**2**
(c)(ii)	So that momentum is conserved	(1)	**1**
(d)	Spontaneous means that the decay cannot be influenced by any external factors.	(1)	
	Random means that we cannot identify which atom/nucleus will (be the next to) decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction of the total number that will decay in the next time interval	(1)	**2**

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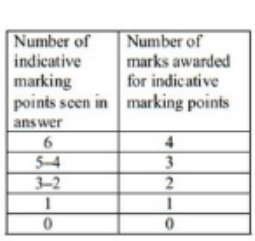
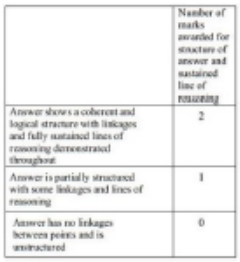
(e)	Idea that traces of the isotope will be excreted from the body (and deposited in the surroundings) (1) Idea that the half life is long enough for the activity to be detectable for a long time (1)	**2**
	Total for question	**16**

Q12.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• a π^0 may be $u\bar{u}$ **Or** $d\bar{d}$ (1) • it must be a quark combined with its own antiquark so that overall charge is 0 (1) OR it can only contain up or down quarks (as it is not a strange particle)	Allow $s\bar{s}$	**(2)**
(a)(ii)	mesons are made up of quarks, whereas leptons are fundamental particles (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	• use of v = s/t (1) • t = 5.05 × 10^{-5} s (1)	Example of calculation: $t = \frac{s}{v} = \frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{ms}^{-1}} = 5.05\times10^{-5}\text{s}$	**(2)**
(b)(ii)	• use of $\lambda t_{1/2} = 0.693$ (1) • λ = 3.15 × 10^{5} s^{-1} (1) • use of $N = N_0 e^{-\lambda t}$ (1) • $\frac{N}{N_0} = 1.23\times10^{-7}$ (1)	Example of calculation: $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{2.2\times10^{-6}\text{s}} = 3.15\times10^{5}\text{s}^{-1}$ $\frac{N}{N_0} = e^{-\lambda t} = e^{-3.15\times10^{5}\text{s}^{-1}\times5.05\times10^{-5}\text{s}} = 1.23\times10^{-7}$ $\frac{N}{N_0} = 1.1\times10^{-7}$ if "show that" value used	**(4)**
(b)(iii)	• This is much smaller than 10% indicating the muon lifetime is much greater than the expected value (1) • The high speed of the muon has led to relativistic effects (1)		**(2)**

Q13.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. **Indicative content:** IC1 There is a fixed probability (λ) of an individual nucleus undergoing decay (in the next second) IC2 For a sample with large number of unstable nuclei there is a predictable pattern IC3 The fraction of nuclei decaying in the next second is equal to the decay constant (λ)	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.  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 Total marks awarded is the sum of marks for indicative content and the marks for 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	6
	IC4 Hence the number of nuclei decaying (in the next second) depends on the number of (unstable) nuclei **Or** activity = λN IC5 The number of unstable nuclei decreases		

	exponentially (with time) **Or** number of (unstable) nuclei = $N_0e^{-\lambda t}$ IC6 So the rate of decay decreases exponentially (with time) **Or** rate of decay = $A_0e^{-\lambda t}$		

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $\lambda t_{½} = \ln 2$ **(1)** • Use of $dN/dt = -\lambda N$ **(1)** • $N = 9.5 \times 10^{10}$ **(1)**	$\lambda \times (1600 \times 365 \times 24 \times 60 \times 60)$ s = ln 2 $\lambda = 1.37 \times 10^{-11}$ s^{-1} 1.3 Bq = 1.37×10^{-11} s$^{-1} \times N$ $N = 9.46 \times 10^{10}$	3
(ii)	• Use of $A = A_0\, e^{-\lambda t}$ **(1)** • Use of $\ln A = \ln A_0 - \lambda t$ or equivalent **(1)** • $t = 8.58 \times 10^{10}$ s = 2700 years **(1)**	ecf λ calculated in (i) ln 0.4 = ln1.3 -1.37×10^{-11} s$^{-1} \times t$ $t = 8.58 \times 10^{10}$ s = 2721 years	3

Q15.

Question Number	Answer		Mark
(a)	Activity is the rate of <u>decay</u> (of radioactive nuclei) **Or** the number of <u>decays</u> in a second	(1)	1
(b)	Use of $\lambda t_{1/2} = 0.693$ Use of $A = -\lambda N$ $N = 1.9 \times 10^{12}$ <u>Example of calculation:</u> $\lambda = \frac{0.693}{3.89 \times 10^{8}\ \text{s}} = 1.78 \times 10^{-9}\ \text{s}^{-1}$ $N = \frac{3450\ \text{s}^{-1}}{1.78 \times 10^{-9}\ \text{s}^{-1}} = 1.94 \times 10^{12}$	(1) (1) (1)	3
(c)(i)	Use of $A = A_0 e^{-\lambda t}$ Conversion between seconds and years t = 41 (years) <u>Example of calculation:</u> $0.1 = e^{-(1.78 \times 10^{-9} s^{-1})t}$ $t = 1.29 \times 10^{9}$ s $t = 1.29 \times 10^{9}$ s /(365×24×3600 s y^{-1}) = 41 y	(1) (1) (1)	3
(c)(ii)	This is a very long time and so: The sample's activity will stay approx. constant for the procedure **Or** tritium may be in the body long enough for damage to be caused **Or** the sample can be prepared well in advance of the procedure	(1) (1) (1)	1
	Total for question		8

Q16.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ **(1)** • (Hence) initial activity of Ac is 50% that of Bi **Or** (Hence) decay constant of Ac is 50% that of Bi **(1)** • Applies one or two half lives to show fraction of initial activity/number after 10 days for one isotope **Or** Use of exponential decay equation to show fraction of initial activity/number after 10 days for one isotope **(1)** • Demonstrates quantitatively that both isotopes have the same activity **(1)**	Alternative approach: $\lambda_{Ac} = \frac{\ln 2}{10}$ $A_{Ac} = \lambda_{Ac} N = \frac{\ln 2}{10} \times N$ After 10 days $A_{Ac} = \frac{1}{2} \times \frac{ln2}{10} \times N = \frac{\ln 2}{20} \times N$ $\lambda_{Bi} = \frac{\ln 2}{5}$ $A_{Bi} = \lambda_{Bi} N = \frac{\ln 2}{5} \times N$ After 10 days $A_{Bi} = \frac{1}{2} \times \frac{1}{2} \times \frac{\ln 2}{5} \times N = \frac{ln2}{20} \times N$ $A_{Ac} = A_{Bi}$ **MP2** can be awarded for use of **both** decay constants in exponential decay equations All four marks may be awarded for a full mathematical demonstration, e.g.: $\lambda_{Ac} = \frac{\ln 2}{10} = 0.0693 \text{ day}^{-1}$ $A_{Ac} = \lambda_{Ac} N = 0.0693 \text{ day}^{-1} \times N$ 10 days: $A_{Ac} = ½ \times 0.0693 \text{ day}^{-1} \times N = 0.0345 \text{ day}^{-1} \times N$ $\lambda_{Bi} = \frac{\ln 2}{5} = 0.139 \text{ day}^{-1}$ $A_{Bi} = \lambda_{Bi} N = 0.139 \text{ day}^{-1} \times N$ 10 days: $A_{Bi} = ½ \times ½ \times 0.139 \text{ day}^{-1} \times N = 0.0345 \text{ day}^{-1}$ $A_{Ac} = A_{Bi}$	**4**

Q17.

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Question Number	Acceptable answers	Additional guidance	Mark
(i)	• 8 alpha decays reduce the proton number by 16 **(1)** • proton number decreases by only 10, so there must be 6 β decays **(1)** **OR** • balanced equation written for overall decay **(1)** • explicit solution to give 6 β^- decays **(1)**	Example of calculation: $^{238}_{92}U \rightarrow {}^{206}_{82}Pb + 8\times{}^{4}_{2}\alpha + N\times{}^{0}_{-1}\beta^-$ $92 = 82 + (8\times2) - N$ $92 = 82 + 16 - N$ $N = 98 - 92 = 6$ Proof must be given to obtain these marks.	**2**
(ii)	• use of $\lambda t_{1/2} = \ln 2$ **(1)** • use of $N = N_0 e^{-\lambda t}$ **(1)** • $N/N_0 = 0.1$ **(1)** • $t = 2.5 \times 10^5$ years **(1)**	Example of calculation: $\lambda = \frac{0.693}{75000} = 9.24\times10^{-6}\,y^{-1}$ $\lambda t = -\ln\left(\frac{N}{N_0}\right)$ $\therefore t = \frac{-\ln(0.1)}{9.24\times10^{-6}\,y^{-1}} = 2.49\times10^5\,y$	**4**

Q18.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	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 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 IC3 When a nucleus decays there is a	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. 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 IC2: accept idea that it takes a long time to decay for "unstable nuclei are present…or a long period of time" 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

Q19.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) • Use of $N = N_0 e^{-\lambda t}$ (1) • Use of N_S/N_R to determine N/N_0 (1) • $t = 3.7 \times 10^9$ year (1) • Comparison of their value with corresponding value in question and valid conclusion (1) **Or** • Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ • Use of $N = N_0 e^{-\lambda t}$ • Use of N/N_0 to determine N_S/N_R • $\frac{N_S}{N_R} = 0.066$ if t = age of Earth • Comparison of their value with corresponding value in question and valid conclusion	Example of calculation: $\lambda = \frac{\ln 2}{4.88 \times 10^{10}\ \text{year}} = 1.42 \times 10^{-11}\ \text{year}^{-1}$ $\frac{N_0}{N} = \frac{N_R + N_S}{N_R} = 1 + \frac{N_S}{N_R} = 1.0532$ $1.0532 = e^{1.42 \times 10^{-11}\ \text{year}^{-1} \times t}$ $\therefore t = \frac{\ln (1.0532)}{1.42 \times 10^{-11}\ \text{year}^{-1}} = 3.65 \times 10^9$ year	5

Q20.

Question Number	Acceptable answers	Additional guidance	Mark
	• would be of form $Q = Q_0 e^{-kt}$ (1) • plot ln charge against time (1) • if straight line with negative gradient it's exponential (1) **Or** • would be of form $Q = Q_0 e^{-kt}$ (1) • Calculate Q/Q_0 for pairs of values with same time interval t **Or** calculates $t_{1/2}$ at least twice (1) • If equal, then it's exponential (1)	MP3 accept some indication that gradient is negative For both MS options MP3 is dependent on MP2	3