23. Nuclear Physics

23.2 Radioactive decay

Paper 4

Marking Scheme

Q1.

(a)	time for activity (of sample) to halve	**B1**
(b)(i)	activity (of X at time t)	**B1**
(b)(ii)	• Y is a stable isotope • total number of nuclei is constant • half-life (of X) is 13.6 s • decay constant (of X) is 0.051 s^{-1} • amount (of X) at t = 0 is 0.066 mol • activity (of X) at t = 0 is 2.0×10^{21} Bq *Any three points, 1 mark each*	**B3**
(c)	mass of 1 nucleus = $(7.3 \times 10^{-4}) / (4.0 \times 10^{22})$	**C1**
	nucleon number = mass of nucleus / (1.66×10^{-27})	**C1**
	= $(7.3 \times 10^{-4}) / (4.0 \times 10^{22} \times 1.66 \times 10^{-27})$ = 11 **and** given as an integer	**A1**

Q2.

(a)(ii)	λ = ln 2 / (110 × 60) = 1.05×10^{-4} s^{-1}	**A1**
(a)(iii)	$N = M / (18\text{ u})$ **or** (M in grams × N_A / 18) $N = (2.1 \times 10^{-12}) / (18 \times 1.66 \times 10^{-27})$ **or** $(2.1 \times 10^{-9} \times 6.02 \times 10^{23}) / 18$ $(= 7.0 \times 10^{13})$	**C1**
	$A = \lambda N$	**C1**
	$= 1.05 \times 10^{-4} \times 7.0 \times 10^{13}$ $= 7.4 \times 10^{9}$ Bq	**A1**

Q3.

(a)(i)	cannot predict when a particular nucleus will decay **or** cannot predict which nucleus will decay next	**B1**
(a)(ii)	(decay is) not affected by external (environmental) factors	**B1**
(a)(iii)	fluctuations in (measured) count rate	**B1**

Q4.

(a)	time for activity (of sample) to halve	**B1**
(b)	sketch: line with positive gradient starting at (0,0) and extending to t = 80 min	**B1**
	exponential curve, extending from t = 0 to t = 80 min, with gradient of steadily decreasing magnitude	**B1**
	line passing through (0,0), (20, $0.5N_0$) and (40, $0.75\ N_0$)	**B1**
(c)(i)	every (undecayed) nucleus has the same probability of decay	**M1**
	fewer (undecayed) nuclei remaining (with time), so fewer will decay (in a given time interval)	**A1**
(c)(ii)	• sample emits in all directions but detector only captures emissions in one direction • some emissions are absorbed before reaching detector • some emissions are scattered within the sample • simultaneous arrival of multiple particles only registers once • some particles may reach detector but not cause ionisation *Any two points, 1 mark each*	**B2**
	measured count rate is less than the activity	**B1**

Q5.

(c)(i)	$A = \lambda N$ **and** $\lambda = \ln 2 / T$	**C1**
	$N = n \times N_A$	**C1**
	2 photons produced from each decay, so $R_0 = 2 \times \lambda \times n \times N_A$ $R_0 = (2 \ln 2)\ nN_A / T$ (*allow 0.693 for ln 2*)	**A1**
(c)(ii)	sketch: exponential decay curve from $t = 0$ to $t = 2T$, starting at (0, R_0) and with a negative gradient of continuously decreasing magnitude	**B1**
	line with negative gradient passing through (T, $R_0 / 2$) and ($2T$, $R_0 / 4$)	**B1**

Q6.

(a)	spontaneous emission of (ionising) radiation	**B1**
	emission from unstable nucleus	**B1**
(b)(i)	curve with decreasing negative gradient passing through (0, N_0)	**B1**
	curve passing through (T, $0.5N_0$)	**B1**
	curve passing through ($2T$, $0.25N_0$) **and** ($3T$, $0.125N_0$)	**B1**
(b)(ii)	line through origin with positive gradient	**B1**
	straight line passing through (N_0, A_0)	**B1**
(c)(i)	activity	**B1**
(c)(ii)	decay constant	**B1**
(d)	$N = N_0 \exp(-\ln 2 \times 1.70T / T)$	**C1**
	$N / N_0 = 0.31$	**A1**

Q7.

(a)(i)	cannot predict when a (particular) nucleus will decay **or** cannot predict which nucleus will decay next	**B1**
(a)(ii)	not affected by external / environmental factors	**B1**
(b)(i)	line fluctuates **or** trend is a straight line	**B1**
(b)(ii)	straight line of best fit drawn on Fig. 10.1	**B1**
(b)(iii)	$M = M_0 \exp(-\lambda t)$ so $\ln M = \ln M_0 - \lambda t$ so gradient = $-\lambda$ (and magnitude of gradient = λ)	**B1**
(b)(iv)	gradient = (–) (8.0 – 4.8) / (11.6 – 0) (*allow any correct pair of values from Fig. 10.1*)	**C1**
	$\lambda = 0.28\ s^{-1}$	**A1**
(b)(v)	half-life = $0.693 / \lambda$ = 0.693 / 0.28 = 2.5 s	**A1**

Q8.

(c)	from $t = 0$ to $t = 45$ s: curve with positive gradient of decreasing magnitude starting at (0, 0)	**B1**
	line passing through (15, ½N_0)	**B1**
	line passing through (30, $0.75N_0$) and (45, $0.88N_0$)	**B1**

Q9.

(c)	$1.0T_{½}$ shown at $½N_0$ **and** $2.0T_{½}$ shown at $¼N_0$	**B1**
	line starting at (0, 0) and reaching (T, N_0–N)	**B1**
	line starting at (0, 0) and reaching original curve at ($1.0T_{½}$, $½N_0$)	**B1**

Q10.

(a)	probability of decay (of a nucleus)	**M1**
	per unit time	**A1**
(b)	$A = \lambda N$	**C1**
	N = mass / (nucleon number $\times$ u)	**C1**
	$2.92 \times 10^9 = (\lambda \times 5.87 \times 10^{-10}) / (131 \times 1.66 \times 10^{-27})$ $\lambda = 1.08 \times 10^{-6}$ s^{-1}	**A1**
(c)	• sample emits radiation in all directions • some radiation is absorbed by air/detector window • self-absorption within the source • dead time/inefficiency of detector *Any two points, 1 mark each*	**B2**

Q11.

(a)(i)	cannot predict when a particular nucleus will decay **or** cannot predict which nucleus will decay next	**B1**
(a)(ii)	(decay is) not affected by external (environmental) factors	**B1**
(b)(i)	$A = A_0 \exp(-\lambda t)$ and so $\ln A = \ln A_0 - \lambda t$ gradient of line = $(-)\lambda$	**C1**
	$\lambda = (36.4 - 35.0) / (20 - 0)$ $(= 0.07(0)$ min$^{-1})$	**C1**
	half-life $= \ln 2 / \lambda$ $= \ln 2 / 0.070$ $= 10$ min	**A1**
	or	
	$A_0 = \exp(-36.4) = 6.43 \times 10^{15}$ (Bq)	**(C1)**
	$A_0 / 2 = 3.21 \times 10^{15}$ (Bq), so $\ln (A_0 / 2) = 35.7$	**(C1)**
	read off half-life = 10 min	**(A1)**
	or	
	(at one half-life,) $\ln A = 36.4 - \ln 2$	**(C1)**
	$= 35.7$	**(C1)**
	read off half-life = 10 min	**(A1)**
(b)(ii)	$A = \lambda N$	**C1**
	N = mass / (nucleon number $\times$ u) **or** N = (mass / nucleon number) $\times$ N_A	**C1**
	$\exp(36.4) = (1.17 \times 10^{-3} \times 5.66 \times 10^{-7}) /$ (nucleon number $\times 1.66 \times 10^{-27}$) **or** $\exp(36.4) = (1.17 \times 10^{-3} \times 5.66 \times 10^{-4} \times 6.02 \times 10^{23}) /$ nucleon number nucleon number = 62	**A1**

Q12.

(a)(i)	time at which a nucleus will decay cannot be predicted **or** constant probability of decay of a nucleus	**B1**
(a)(ii)	decay (of a nucleus) not affected by environmental factors	**B1**
(b)	$A = A_0e^{-\lambda t}$ **and** $\lambda = \ln 2 / t_{½}$	**C1**
	$= 3.6 \times 10^5 \times \exp [-(2 \times \ln 2) / 1.4]$	**C1**
	or	
	$A = A_0 \times 0.5^N$	**(C1)**
	$= 3.6 \times 10^5 \times 0.5^N$ where $N = 2 / 1.4$	**(C1)**
	$A = 1.3 \times 10^5$ Bq	**A1**
(c)(i)	smooth curve, starting at $(0, 3.6 \times 10^5)$ and passing through $(1.4, 1.8 \times 10^5)$ and $(2.0, 1.3 \times 10^5)$	**B1**
(c)(ii)	(activity of sample is greater than activity of X so) there must be an additional source of activity	**C1**
	the decay product (of isotope X) is radioactive	**A1**

Q13.

(a)(i)	unstable nucleus	**B1**
	emits ionising radiation **or** decays spontaneously	**B1**
(a)(ii)	probability of decay (of a nucleus)	**M1**
	per unit time	**A1**
(b)	$A = \lambda N$	**C1**
	$560 = 9.9 \times 10^{-7} \times N$ $N = 5.7 \times 10^8$	**A1**
(c)	$A = A_0\ e^{-\lambda t}$ $170 = 560 \exp(-9.9 \times 10^{-7} \times t)$	**C1**
	$t = 1.2 \times 10^6$ s	**C1**
	= 14 days	**A1**

Q14.

(a)(i)	$\Delta N / \Delta T$	**B1**
(a)(ii)	$\Delta N / N$	**B1**
(a)(iii)	$\Delta N / (N \Delta T)$	**B1**

Q15.

(c)(i)	$A = A_0e^{-\lambda t}$ **and** $\ln 2 = \lambda t_{½}$	**C1**
	$0.40 = \exp(-\ln 2 \times t / 3.9)$	**C1**
	or	
	$(0.5)^n = 0.40$	**(C1)**
	$n = 1.32$ **and** $t = 1.32 \times 3.9$	**(C1)**
	$t = 5.2$ hours	**A1**
(c)(ii)	daughter product may be radioactive **or** random nature of decay	**B1**

Q16.

(a)(i)	(decay is) unpredictable/cannot be predicted	**B1**
(a)(ii)	probability of decay (of a nucleus)	**M1**
	per unit time	**A1**
(b)	$A = \lambda N$	**C1**
	(for 1.00 m^3) $A = 0.600 / 4.80 \times 10^{-3}$ (= 125 Bq)	**C1**
	$N = 125 / ([7.55 \times 10^{-3}] / 3600)$ (= 5.96×10^7)	**C1**
	so ratio = $(2.52 \times 10^{25}) / (5.96 \times 10^7)$	**C1**
	or	
	(for 4.80×10^{-3} m^3) N for air = $2.52 \times 10^{25} \times 4.80 \times 10^{-3}$ (= 1.21×10^{23})	**(C1)**
	N for radon = $0.600 / ([7.55 \times 10^{-3}] / 3600)$ (= 2.86×10^5)	**(C1)**
	so ratio = $(1.21 \times 10^{23}) / (2.86 \times 10^5)$	**(C1)**
	ratio = 4.2×10^{17}	**A1**

Q17.

(a)	emission of particles/radiation by unstable nucleus	**B1**
	spontaneous emission	**B1**
(b)(i)	use of graph to determine half-life = 14 minutes	**B1**
	hence $\lambda = \ln 2 / (14 \times 60)$ (s^{-1})	**C1**
	N at 14 minutes = 4.4×10^7 **and** $A = \lambda N$	**C1**
	activity $= 4.4 \times 10^7 \times \ln 2 / (14 \times 60)$ $= 3.6 \times 10^4$ Bq	**A1**
	or	
	correct tangent drawn at time t = 14 minutes	**(B1)**
	magnitude of gradient of tangent identified as activity	**(C1)**
	correct working for gradient leading to activity	**(C1)**
	activity = 3.6×10^4 Bq	**(A1)**
(b)(ii)	$3.6 \times 10^4 = \lambda \times 4.4 \times 10^7$ **or** $\lambda = \ln 2 / (14.0 \times 60)$	**C1**
	$\lambda = 8.2 \times 10^{-4}$ s^{-1}	**A1**

Q18.

(a)	emission of particles/radiation by <u>unstable nucleus</u>	**B1**
	spontaneous emission	**B1**
(b)(i)	P – the curve that starts with a high number D – the curve with the peak S – the curve that increases from zero throughout *(one correct 1 mark, all three correct 2 marks)*	**B2**
(b)(ii)	$\lambda t_{½} = 0.693$ $\lambda = 0.693 / (60.0 \times 60)$	**C1**
	$= 1.93 \times 10^{-4}$ s^{-1}	**A1**
(c)	half-life of F is much shorter than half-life of E	**B1**
	<u>nuclei</u> of F decay (almost) as soon as they are produced	**B1**

Q19.

(a)	unstable nucleus	**B1**
	emission of particles/photons	**B1**
	emission is spontaneous **or** (particles/radiation) are ionising	**B1**
(b)(i)	tangent drawn and gradient calculation attempted	**B1**
	activity = 1.3×10^6 Bq (*1 mark for answer within* $\pm 0.2 \times 10^6$ Bq, *2 marks for answer within* $\pm 0.1 \times 10^6$ Bq)	**A2**
(b)(ii)	$A = \lambda N$	**C1**
	$\lambda = (1.3 \times 10^6) / (3.05 \times 10^{10}) = 4.3 \times 10^{-5}\,s^{-1}$ ($\approx 4 \times 10^{-5}\,s^{-1}$)	**A1**
(c)	$A = A_0 e^{-\lambda t}$ $1.0 \times 10^3 = 4.6 \times 10^3 \exp(-5.5 \times 10^{-7} \times t)$	**C1**
	$\ln(4.6) = 5.5 \times 10^{-7} \times t$	**C1**
	$t = 2.78 \times 10^6$ s = 32 days	**A1**