A Level AQA Physics

19 Radioactivity – answers

Question	Answers	Extra information	Mark	AO	Spec reference
01.1	Most of the alpha particles went through the gold foil but a few came back This confirmed that most of the atom was empty space / very small massive nucleus	Correct evidence Indication of change from previous model	1 1	1	3.8.1.1
01.2	Electrons do not spiral into the nucleus/line spectra of hydrogen suggest discrete energy levels	One piece of evidence	1	1	3.8.1.1
01.3	Decay constant $= \frac{\ln 2}{t_{½}} = \frac{0.693}{1600 \times 3.15\times10^{7}}$ $= 1.37\times10^{-11}\,\text{s}^{-1}$	Use of $t_{½}$ Answer	1 1	2	3.8.1.3
01.4	$M = M_0 e^{-\lambda t}$ t = 120 years = $120 \times 3.15\times10^{7} = 3.78\times10^{7}$ s mass of radium in sample = 0.58 × 30.0 mg = 17.4 mg $M = 17.4 \times e^{-1.37\times10^{-11} \times 3.78\times10^{7}}$ $= 17.4 \times e^{-0.052}$ $= 16.5\,\text{mg} = 1.65\times10^{-4}\,\text{g}$	Use of equation Answer	1 1 1	3	3.8.1.3
01.5	$A = -\lambda N$ Change in mass = 9.0×10^{-4} g Change in number of atoms = $\frac{6.0\times10^{23} \times 9.0\times10^{-4}\,\text{g}}{226\,\text{g}} = 2.34 \times 10^{18}$atoms Change in activity = $-\lambda \Delta N$ $= 1.37\times10^{-11} \times 2.34\times10^{18}$ $= 3.2\times10^{7}$ Bq	 Calculation of number of atoms Answer	 1 1	3	3.8.1.3
02.1	The probability of 'decay' is ½, so in each throw, half the remaining tokens will 'decay', leaving half remaining The actual number does not match because throwing the sweets is a random process		1 1	1	3.8.1.3

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<table>
<tr><th>Question</th><th>Answers</th><th>Extra information</th><th>Mark</th><th>AO</th><th>Spec reference</th></tr>
<tr><td>02.2</td><td>The number of tokens that ‘decay’ in each throw is ΔN
If there are N remaining, then the number that ‘decay’ in Δt throws = $\lambda N \Delta t$, where λ = probability of ‘decay’
$\Delta N = \lambda N \Delta t$
The rate of ‘decay’ = $\frac{\Delta N}{\Delta t} = \lambda N$, so the rate of ‘decay’ is proportional to the number of ‘undecayed’ sweets</td><td>Indication of number decaying per throw related to λN

Link between change in number per throw and λN</td><td>1

1</td><td>1</td><td>3.8.1.3</td></tr>
<tr><td>02.3</td><td>Matter/atoms/nuclei do not disappear/conservation of mass
A spherical token cannot ‘decay’ so represents a stable atom; this represents decay to a stable isotope
The four-sided token represents another unstable nucleus with a smaller probability of decay/longer half-life</td><td></td><td>1
1
1</td><td>3</td><td>3.8.1.3</td></tr>
<tr><td>02.4</td><td>If the probability of decay is λ then λN will decay in each throw
$\lambda \times 250 = 250 - 219 = 31$
$\lambda = \frac{31}{250} = 0.124$
Number of sides = $\frac{31}{0.124} = 8$
Or
Plot graph using:
<table>
<tr><th>Throw</th><th>ln(number)</th></tr>
<tr><td>0</td><td>5.521461</td></tr>
<tr><td>1</td><td>5.389072</td></tr>
<tr><td>2</td><td>5.252273</td></tr>
<tr><td>3</td><td>5.117994</td></tr>
<tr><td>4</td><td>4.990433</td></tr>
</table></td><td>Use of λ as probability from data or graph

Changing probability to number of sides</td><td>1

1</td><td>3</td><td>3.8.1.3</td></tr>
</table>

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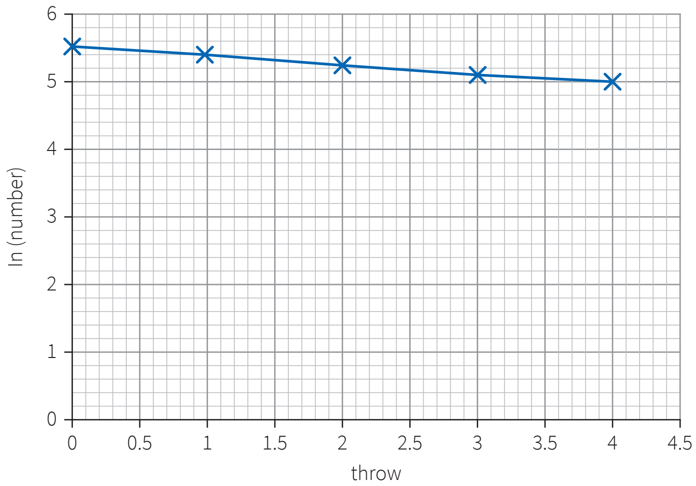
Question	Answers	Extra information	Mark	AO	Spec reference
	 Gradient = $\frac{5.52 - 4.99}{4} = 0.135$ Gradient = probability; number of sides = $\frac{31}{0.135} = 7.6$ So 8 sides to the dice				
03.1	Two sources such as: • medical sources such as X-rays • cosmic radiation • rocks such as granite • Sun/stars		2	1	3.8.1.2
03.2	$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{1.3\times10^{9} \times 3.1\times10^{7}} = 1.72\times10^{-17}\,s^{-1}$		1	2	3.8.1.3
03.3	$A = -\lambda N = 1.72\times10^{-17}\,s^{-1} \times 8.7\times10^{17} = 1.5\,Bq$ Yes, it would be noticeable		1 1	2	3.8.1.3
03.4	The activity of the beta source is higher, but beta radiation is less ionising/less damaging to the cells of the human body/less likely to cause cancer		1	3	3.8.1.2

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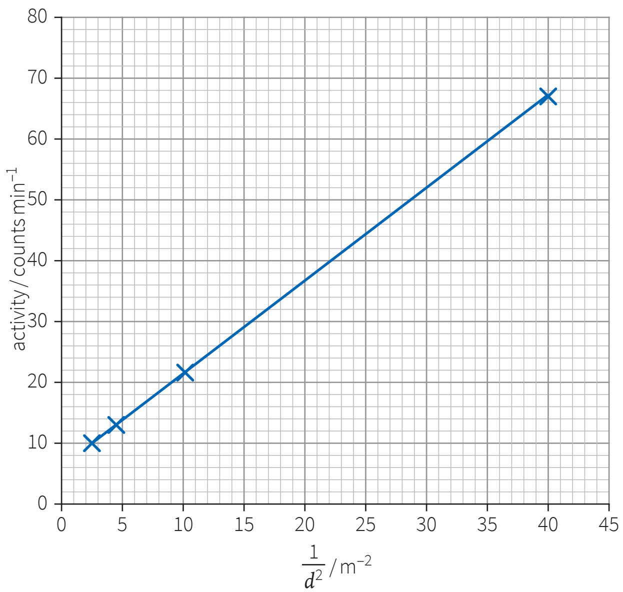
A Level AQA Physics
19 Radioactivity – answers

Question	Answers	Extra information	Mark	AO	Spec reference
04.1	Put the source in front of a Geiger counter Place paper between the source and the counter, and the Geiger counter reading will not change Place a sheet of aluminium between the source and the counter, and the Geiger counter reading will not change	Use of paper with effect Use of aluminium with effect	1 1	1	3.8.1.2
04.2	With the source a long way from the Geiger counter, measure the background count in becquerels (counts per second) Place a source on a desk at the zero mark on a ruler Place a Geiger counter at a distance from the source and record the activity, in Becquerels, and the distance Repeat for different distances from the source Repeat the whole experiment three times and take an average activity for each distance Subtract the background count from each activity	Measurement of background count Repeated measurements of activity at different distances and mean taken Subtraction of background count	1 1 1	1	3.8.1.1
04.3		Graph plotted – points correct with straight line Appropriate scales/labels	1 1 1	2	3.8.1.2

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A Level AQA Physics
19 Radioactivity – answers

OXFORD Revise

Question	Answers	Extra information	Mark	AO	Spec reference
04.4	A graph of activity against $\frac{1}{(\text{distance})^2}$ is a straight line which does not go through (0, 0) The y-intercept = background count Intercept = 7 counts min^{-1} Background count = $\frac{7}{60}$ = 0.12 Bq	Use of y-intercept How to find the background count Answer	1 1 1	2	3.8.1.2
05.1	$\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{1.3 \times 10^9 \times 365.25 \times 24 \times 60^2} = 1.70 \times 10^{-17}\,\text{s}^{-1}$ $A = \lambda N$ so $N = \frac{A}{\lambda}$ $N = \frac{0.48}{\lambda}$ $= 2.84 \times 10^{16}$ atoms	Calculation of decay constant Use of $A = \lambda N$ Answer	1 1 1	2	3.8.1.3
05.2	$N = N_0 e^{-\lambda t}$ $t = 3.2 \times 10^9 \times 365 \times 24 \times 60^2 = 1.01 \times 10^{17}$ s $N_0 = \frac{N}{e^{-\lambda t}} = \frac{\text{student's answer from } \mathbf{05.1}}{e^{-(1.70 \times 10^{-17}) \times (1.01 \times 10^{17}\,\text{s})}}$ $= 1.58 \times 10^{17}$ atoms when the rock formed Atoms of argon = $1.58 \times 10^{17} - 2.84 \times 10^{16} = 1.30 \times 10^{17}$ Mass = $\frac{40 \times 1.26 \times 10^{17}}{6.02 \times 10^{23}}$ $= 8.62 \times 10^{-6}$ g Assuming all the potassium decayed to argon / no argon was lost from the rock	Use of equation to find original number of atoms Subtraction to find atoms of argon and answer One assumption	1 1 1	2	3.8.1.3
05.3	If the potassium did not all decay to argon, there would be less argon than anticipated, and the sample would be deemed to be younger than it actually is	Reasoning for younger	1	3	3.8.1.3

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<table>
<tr><th>Question</th><th>Answers</th><th>Extra information</th><th>Mark</th><th>AO</th><th>Spec reference</th></tr>
<tr><td>05.4</td><td>If only 0.005 35 has decayed, that means the fraction remaining is
1 – 0.000 053 5 = 0.999 947
$N = N_0 e^{-\lambda t}$
$t = -\ln\left(\frac{N}{N_0}\right) \times \frac{1}{\lambda}$
$= -\ln(0.999947) \times \frac{1}{1.70 \times 10^{-17}} = 3.11 \times 10^{12}$ s
= 98 794 years ~ 100 000 years</td><td>Fraction that has decayed

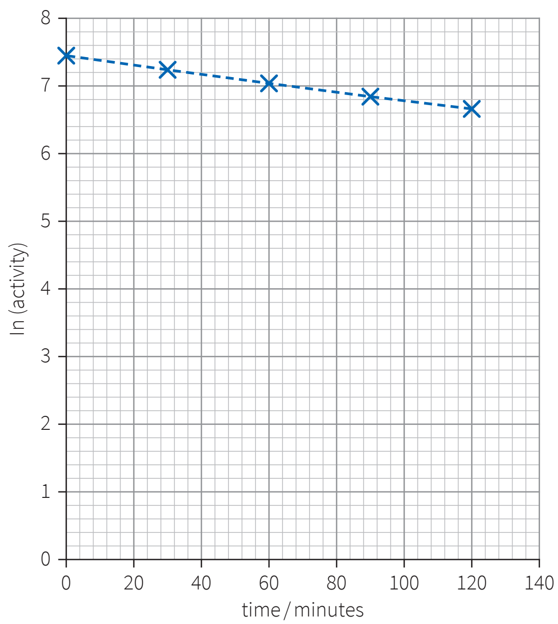
Correct use of equation

Answer</td><td>1

1

1</td><td>3</td><td>3.8.1.3</td></tr>
<tr><td>06.1</td><td>Thick gloves will absorb alpha particles and some beta particles
The lead in the glass will absorb/attenuate gamma rays (and α and β)</td><td></td><td>1
1</td><td>1</td><td>3.8.1.2</td></tr>
<tr><td>06.2</td><td>Values of ln(activity) calculated

t	**Activity**	**ln(activity)**
0	1682	7.43
30	1392	7.24
60	1151	7.05
90	953	6.86
120	788	6.67



</td><td>
Graph plotted – points correct with straight line
Appropriate scales/labels</td><td>1
1</td><td>2</td><td>3.8.1.3</td></tr>
</table>

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Question	Answers	Extra information	Mark	AO	Spec reference
	Gradient of line = $\frac{7.43 - 6.64}{0 - 120}$ = -6.58×10^{-3} min^{-1} $A = A_0 e^{-\lambda t}$ $\ln A = \ln A_0 - \lambda t$ Gradient of line = $-\lambda$ Half-life = $\frac{\ln 2}{\lambda} = \frac{0.693}{6.58 \times 10^{-3}}$ = 105 min OR 6320 s		1		
06.3	Fluorine-18 The half-lives of the other isotopes are too short		1 1	3	3.8.1.3
06.4	Conservation of momentum If one gamma ray was emitted, momentum would not be conserved		1	1	3.2.1.7
06.5	Rest energy of positron is the same as that of the electron Total rest energy = 2 × 0.510999 MeV = 2 × 0.510999 × 1.6×10^{-13} J = 1.635×10^{-13} J Energy of each gamma ray = $\frac{1.635 \times 10^{-13}}{2}$ = 8.175×10^{-14} J $E = hf$ so $f = \frac{E}{h} = \frac{8.175 \times 10^{-14}}{6.63 \times 10^{-34}}$ = 1.23×10^{20} Hz	Total energy Energy of each gamma Answer	1 1 1	2	3.2.1.3
06.6	No Neutrinos in beta decay are needed because of conservation of energy, but that is not needed in this annihilation		1	1	
07.1	Alpha particles are absorbed by the skin/would not get through body tissue to be detected outside the body		1	1	3.8.1.2
07.2	${}^{210}_{86}\text{Ra} \rightarrow {}^{206}_{84}\text{Po} + {}^{4}_{2}\alpha$	Correct symbol for α Allow He for α Correct A and Z in equation	1 1	2	3.2.1.2

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Question	Answers	Extra information	Mark	AO	Spec reference
07.3	Alpha particle: $A = 4$, $R = 1.25\times10^{-15} \times 4^{\frac{1}{3}}$ $= 1.9(3)\times10^{-15}$ m Radon: $A = 210$, $R = 1.25\times10^{-15} \times 210^{\frac{1}{3}}$ $= 7.3(9)\times10^{-15}$ m Despite having a mass that is over 50 times larger, the radon nucleus is less than 4 times larger in terms of radius	Suitable comment	1 1 1	2	3.8.1.5
07.4	Assuming $E = \frac{1}{2}mv^2$ $v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 6.4 \times 1.6\times10^{-13}}{4 \times 1.661\times10^{-27}}}$ $= \sqrt{3.08\times10^{14}} = 1.76\times10^{7}$ m s^{-1}		1 1	2	3.4.1.8
07.5	Conservation of momentum 0 kg m s^{-1} $= m_{\alpha}v_{\alpha} + m_{Po}v_{Po}$ $v_{Po} = \frac{-m_{\alpha}v_{\alpha}}{m_{Po}} = \frac{-4 \times 1.76\times10^{7} \text{ m s}^{-1}}{206} = -3.4(2)\times10^{5}$ m s^{-1}	Conservation of momentum (explicit or implied)	1 1	3	3.4.1.6
07.6	The strong nuclear force will act between the constituent parts of the alpha particle and the nucleus/an external force acts		1	3	3.4.1.6
08.1	The half-life is short, so the water would not stay contaminated for very long in comparison with the other isotopes/it emits both beta and gamma radiation so can differentiate between different thicknesses of pipes		1 1	1 3	3.8.1.2
08.2	A neutron decays to a proton and an electron and an antineutrino/a down quark decays to an up quark and an antineutrino To an excited state of the nucleus, which decays emitting a gamma ray		1 1	1	3.2.1.2

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OXFORD Revise

Question	Answers	Extra information	Mark	AO	Spec reference
08.3	${}^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + {}^{0}_{-1}\beta + \bar{\nu}$ Conservation of lepton number: electron has a lepton number of +1, an antineutrino has a lepton number of −1 0 = 0 + (+1) + (−1)	Correct atomic mass numbers Correct atomic numbers Lepton numbers of electron and antineutrino Indication of conservation of lepton number	1 1 1 1	2	3.2.1.2
08.4	$\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{15 \times 60 \times 60} = 1.28\times10^{-5}\,\text{s}^{-1} \sim 1.3\times10^{-5}\,\text{s}^{-1}$		1	2	3.8.1.3
08.5	Number of atoms $= \frac{1.3\times10^{-8}\,\text{g} \times 6.02\times10^{23}}{24} = 3.26\times10^{14}$ $A = \lambda N = 1.28\times10^{-5} \times 3.26\times10^{14} = 4.23\times10^{9}\,\text{Bq} = 4.23\,\text{GBq}$		1 1	2	3.8.1.3
08.6	$N = N_0\,e^{-\lambda t}$ so $A = A_0\,e^{-\lambda t}$ 'Safe' level = 50 × 0.24 = 12 Bq $t = \frac{\ln\left(\frac{N}{N_0}\right)}{\lambda} = \frac{\ln(4.23 \times 10^{9} \div 12)}{1.28\times10^{-5}} = 1.53\times10^{6}\,\text{s}$ $= \frac{17}{18}$ days It will be diluted so that the dose will be much reduced	Use of ln A Answer in s or days Comment that includes use	1 1 1	3	3.8.1.3

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Skills box answers

Question	Answer
1	The source should not be handled directly: tongs should be used and gloves worn, and the source kept at arm's length when held. Time spent handling or close to the source should be kept to a minimum. Whenever the source is not in use it should be returned to its lead-lined box.
2(a)	Background count rate = $\frac{360}{(20 \times 60)}$ = 0.3 counts s^{-1}
2(b)	Corrected count rate = (count rate – background) for each reading.
2(c)	Graph will be a straight-line graph with a gradient of 0.04 and intercept on y-axis of 0.11 $s^{0.5}$.
2(d)	e is the x-intercept = 2.8 cm.

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