OCR A Level Physics A (H556) Physics B (H557)

PAG 7: Investigating ionising radiation
Practice Exam Questions and Mark Scheme

1. * A group of students are investigating the decay of protactinium.
A fresh sample of protactinium is prepared. The activity of the sample was measured at intervals of 1.0 minutes for 6.0 minutes.
The table shows the activity corrected for background radiation.

time *t* / min	0	1.0	2.0	3.0	4.0	5.0	6.0
activity *A* / Bq	943	523	287	161	79	61	20

Fig. 20 shows the variation of ln(*A*) with time *t*.

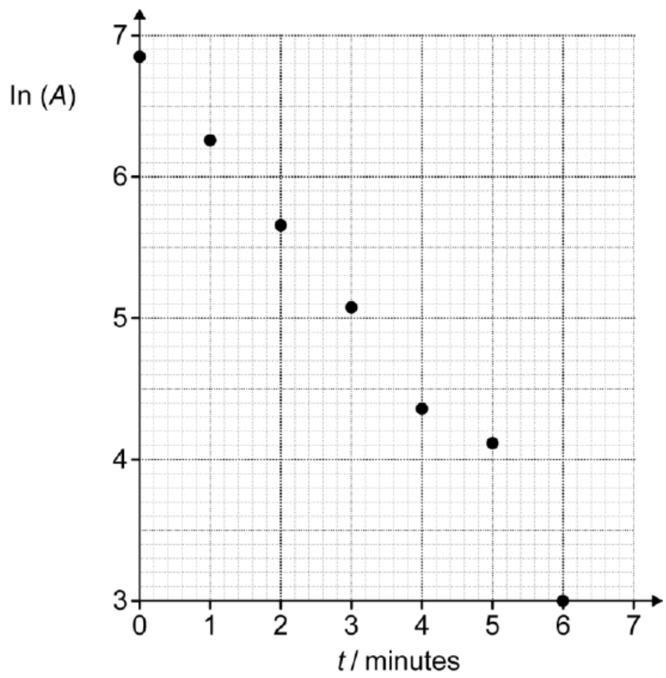

Fig. 20

Explain how the graph in Fig. 20 can be used to determine the half-life of protactinium.

Determine the half-life of protactinium. Include an uncertainty in your value.

[6]

2. *Fig. 5 shows a thin slice of rock mounted on the face of a lead holder. The rock contains several different radioactive elements.

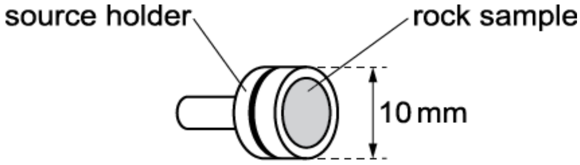

Fig. 5

Plan one or more experiments to determine the **nature** of the emissions from the sample.

A space has been left for you to draw one or more diagrams to show the arrangement of your apparatus

[6]

3. $^{60}_{27}Co$ is produced by irradiating the stable isotope $^{59}_{27}Co$ with neutrons.

Each nucleus of $^{60}_{27}Co$ then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.

Students want to carry out an investigation into gamma photon absorption using a source of $^{60}_{27}Co$.
They add sheets of lead between the source **S** and a radiation detector **T**, to give a total thickness *d* of lead. **S** and **T** remain in fixed positions, as shown in Fig. 2.1.

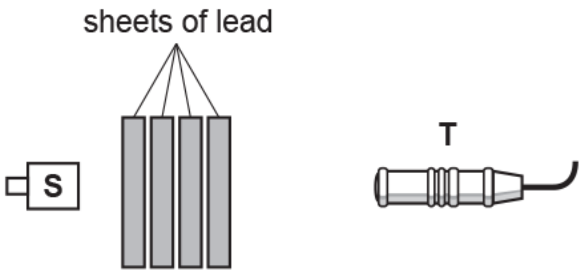

Fig. 2.1

i. The $^{60}_{27}Co$ source emits beta radiation as well as gamma radiation.

Explain why this would not affect the experiment.

[1]

ii. The students record the number *N* of gamma photons detected by **T** in 10 minutes for each different thickness *d* of lead. The background count is negligible.

The results are shown in a table. The table includes values of ln *N*, including the absolute uncertainties.

N	***d* / mm**	**ln *N***
4300 ± 440	0	8.37 ± 0.10
2500 ± 250	0	7.82 ± 0.10
1400 ± 150	20	7.24 ± 0.11
800 ± 90	30	6.68 ± 0.11
500 ± 60	40	6.21 ± 0.12
300 ± 40	50	

N and *d* are related by the equation $N = N_0 e^{-\mu}$ where N_0 and μ are constants.

1. The students decide to plot a graph of ln *N* against *d*.

Show that this should give a straight line with gradient = $-\mu$ and *y*-intercept = ln N_0.

[1]

2. Complete the missing value of ln N in the table, including the absolute uncertainty.

Show your calculation of the absolute uncertainty in the space below.

[2]

3. In Fig. 2.2, five of the data points have been plotted, including error bars for ln N.

- Plot the missing data point and error bar.
- Draw a straight line of best fit and one of worst fit.

[2]

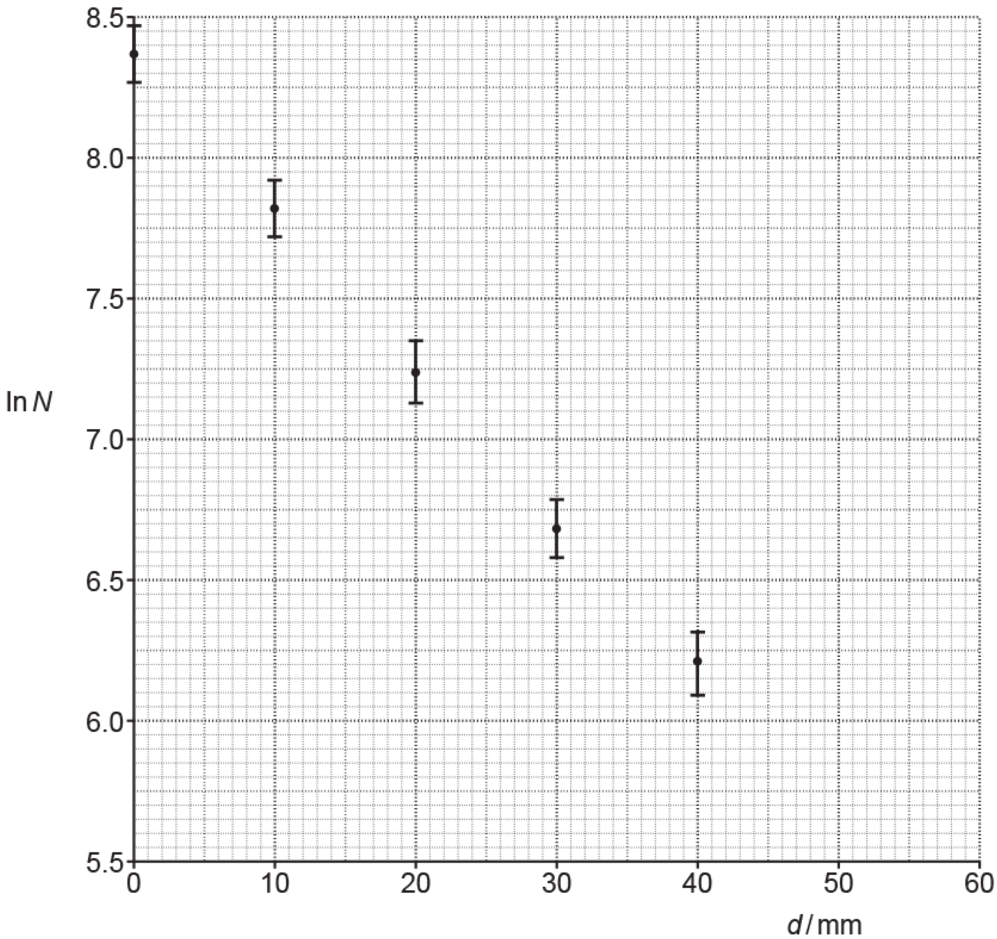

Fig. 2.2

4. Use Fig. 2.2 to determine the value of μ in m^{-1}, including the absolute uncertainty.

μ =....................± .... m^{-1} **[4]**

5. Determine the thickness, $d_{½}$, of lead which halves the number of gamma photons reaching **T**.

$d_{½}$ = ... m **[2]**

4(a). This question is about the attenuation of gamma radiation as it passes through lead.

Fig. 4.1 shows the experimental set up using a Geiger-Müller tube to detect gamma radiation emitted from a sample of cobalt-60. Different thicknesses of lead sheet are placed between the source and the Geiger-Müller tube and a counter is used to measure the number of counts per minute (cpm).

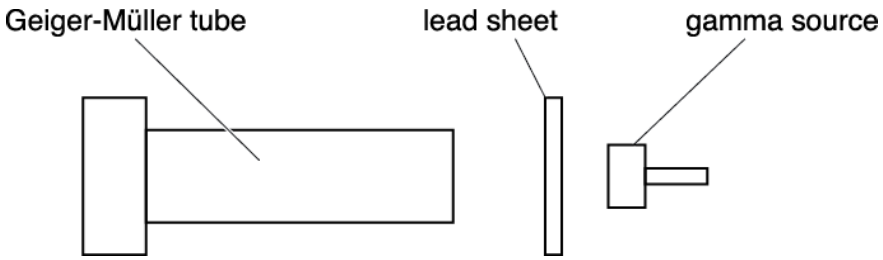

Fig. 4.1

Describe the safety precautions necessary for handling the gamma source.

[2]

(b). The values in the table below have been corrected for background radiation.

thickness of *lead x* / cm	**Intensity *I* / cpm**
0.5	890
1.0	651
1.5	442
2.0	310
2.5	222
3.0	154
3.5	112

i. Explain why it is important to correct for background radiation.

[2]

Fig. 4.2 shows a plot of I against x.

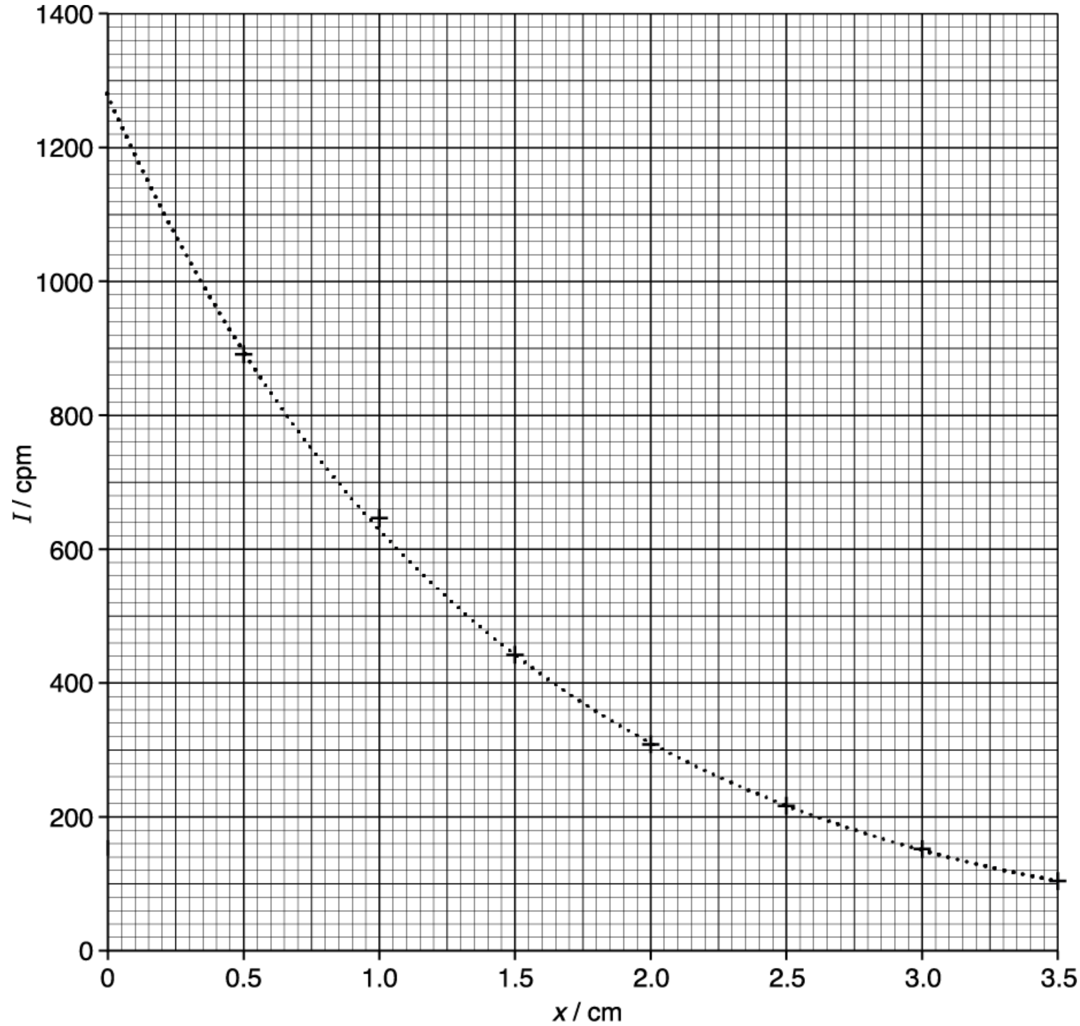

Fig. 4.2

ii. The *half-thickness* is the thickness of a shielding material required to halve the intensity received by the Geiger-Müller tube. Use the graph to calculate a reliable value for the half-thickness of lead.

half-thickness = ... cm **[3]**

(c). The attenuation of gamma radiation in lead can be described by the equation:

$$I = I_0 e^{-\mu x}$$

where: I is the intensity of radiation reaching the Geiger-Müller tube
I_0 is the intensity of radiation with no lead sheet
x is the thickness of lead in cm
μ is the attenuation coefficient in cm^{-1}.

i. Show that this equation can be written as

$$\ln(I) = -\mu x + \ln(I_0).$$

[1]

The table shows the data with the values of ln (I / cpm) calculated.

thickness of lead *x* / cm	**Intensity *I* / cpm**	**ln (*I* / cpm)**
0.5	890	6.79
1.0	651	6.48
1.5	442	6.09
2.0	310	5.74
2.5	222	5.40
3.0	154	5.04
3.5	112	4.72

ii. Plot a graph on the grid provided in Fig. 4.3 of ln (I / cpm) against x . Three points have already been plotted. Draw a line of best fit through the points.

[2]

iii. Calculate the gradient and intercept of the line of best fit and use your answer to **(c)(i)** to determine I_0 and μ.

I_0 = ... cpm

μ = ... cm^{-1}

[4]

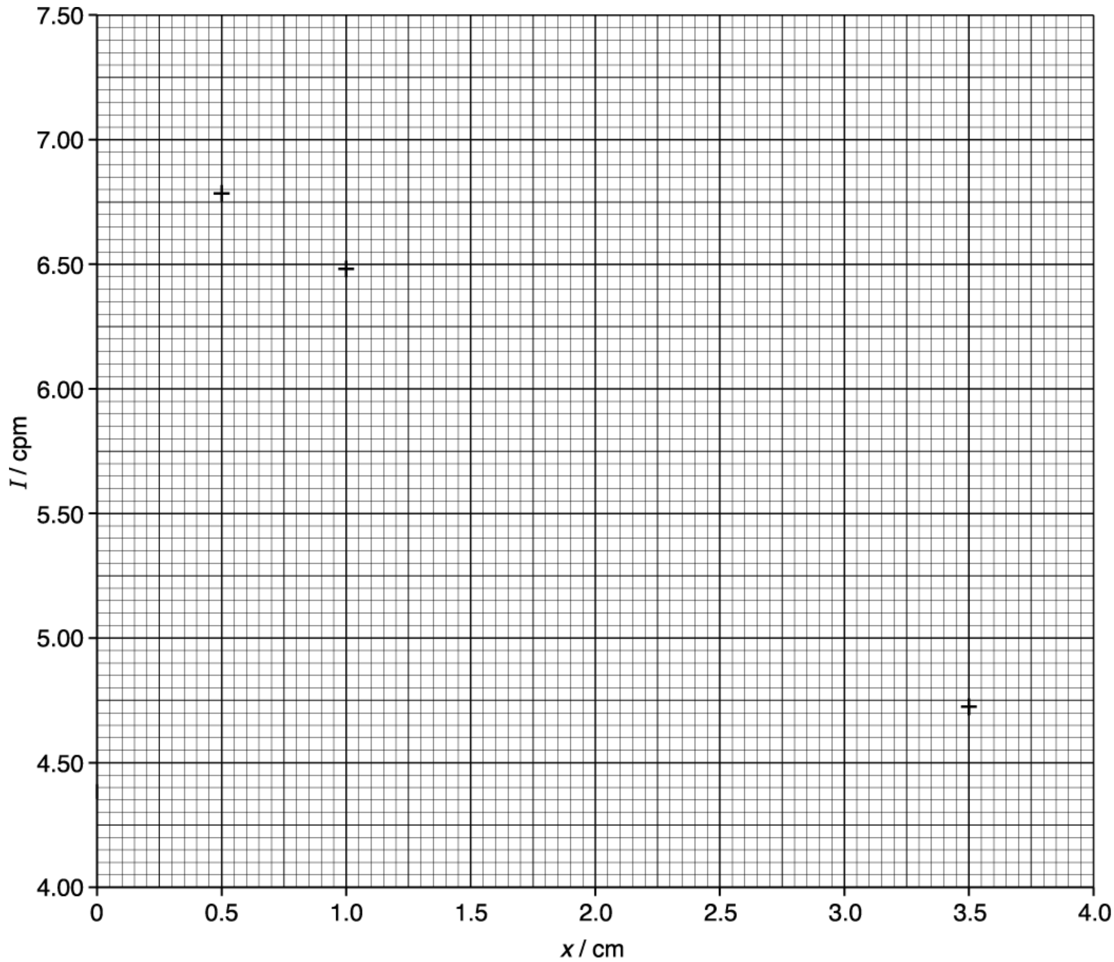

Fig. 4.3

(d).

i. Use the value of μ calculated in **(c)(iii)** to calculate the half-thickness of lead.

half-thickness = ... cm **[3]**

ii. Suggest and explain which of the methods used, in parts **(b)(ii)** and **(d)(i)**, to determine the half-thickness is the most reliable.

[3]

5. An experiment is carried out to find the half–life of a solid radioactive isotope **X** which emits beta radiation.

The results obtained from the experiment are given in the table below.

Time *t* / s	**Count rate / Bq**	**Corrected count rate A / Bq**	**ln (*A* / Bq)**
25	9.2	8.0	2.08
50	7.5	6.3	1.84
75	6.0	4.8	1.57
100	4.8		1.28
125	4.1	2.9	
150	3.4	2.2	
175	3.0		0.59
200	2.7	1.5	0.41
225	2.4	1.2	0.18

(i) Explain what is meant by "Corrected count rate" **and** complete this column in the table.

[2]

(ii) Complete the fourth column of the table by calculating the missing values for ln (*A* / Bq).

[1]

(iii) A graph of ln (A / Bq) (y–axis) and t (x–axis) is drawn in Fig. 2.

Plot the remaining points on the graph and draw the line of best fit. **[2]**

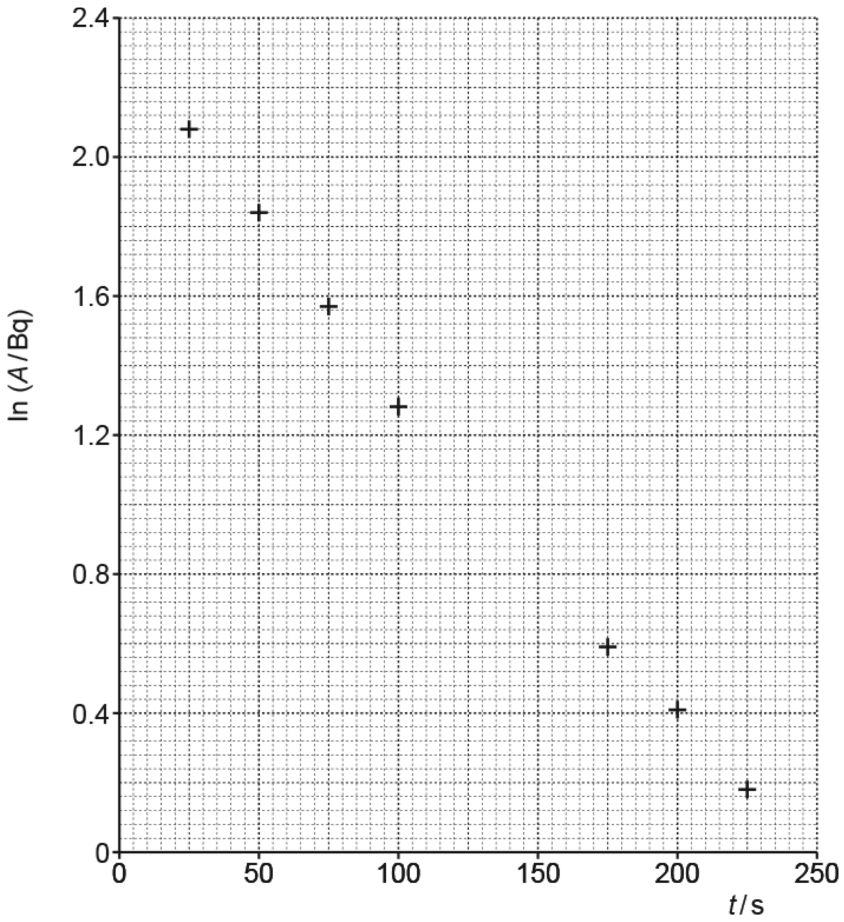

Fig. 2

(iv) Use your graph to find the value of half–life for the radioactive isotope **X** and explain the advantages of using ln (A / Bq) against t over an A against t graph to find half–life. **[6]**

6. This question is about the decay of protactinium.

Fig. 38.1 shows a graph of the natural log of corrected count rate A against time in seconds.

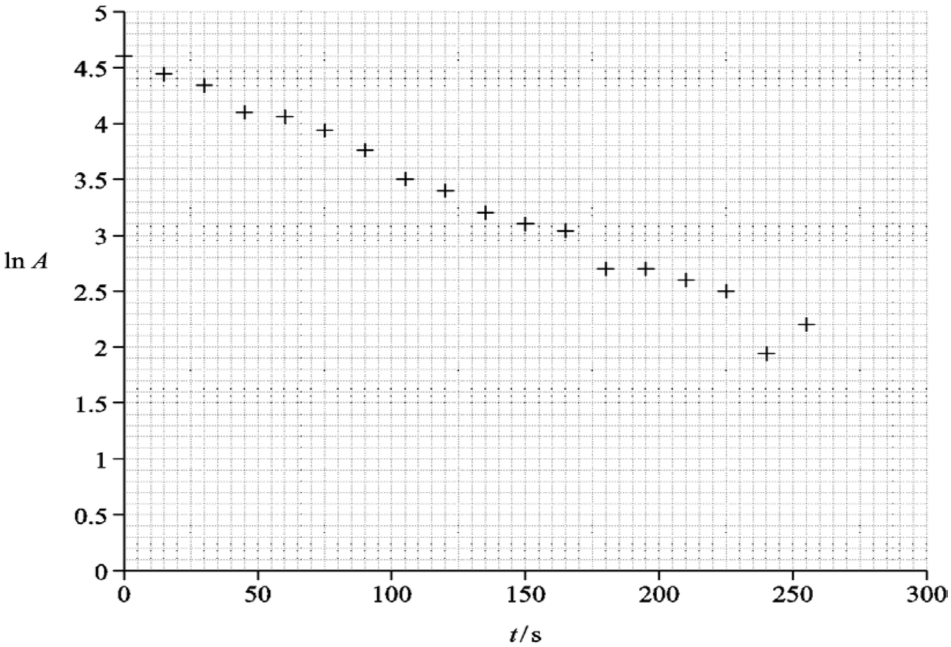

Fig. 38.1

i. Draw a best fit line on **Fig. 38.1**.

The equation of the line is $\ln A = \ln A_0 - \lambda t$ where λ is the decay constant and A_0 is the initial activity of the source.

Use this to show that the decay constant of the protactinium is about $0.01\ s^{-1}$.

[3]

ii. Use the value from **(i)** to calculate the half-life of the source.

half-life of source = ... s **[2]**

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			**Level 3 (5–6 marks)** Correct explanation Correct determination of λ and half-life Correct determination of uncertainty (Maximum 6 marks) Any point omitted or incorrect (5 marks). *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Mostly correct explanation Mostly correct determination of λ and half-life Some attempt of determining uncertainty (Maximum 4 marks) Any point omitted or incorrect (3 marks). *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Basic explanation Some attempt to determine λ or half-life No attempt at uncertainty. (Maximum 2 marks) *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 x 6	**Explanation** 1. $A = A_0e^{-\lambda t}$ 2. $\ln A = \ln A_0 - \lambda t$ 3. A graph of $\ln A$ against t will be a straight line with gradient (−) λ 4. half-life = ln2/λ **Determination** 1. Line of best fit drawn 2. Gradient determined using a large triangle 3. decay constant in the range 0.5 to 0.7 min^{-1} 4. half-life in the range 1.0 to 1.4 min **Uncertainty** 1. Worst line of fit drawn 2. Correct attempt to determine uncertainty
			Total	**6**	
2			**Level 3 (5–6 marks)** Clear set up and description of chosen experiment(s) **and** clear interpretation of observations *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)**	B1 × 6	**Indicative scientific points may include:** **1**. range/penetration/absorption/deflection experiment suggested **2**. suitable arrangement and choice of apparatus e.g. on diagram; allow GM tube as detector for all particles **3**. description of range/penetration/absorption experiment: **a**. α place detector very close/ 2cm from

			Limited set up and description of chosen experiment **and** limited interpretation of observations *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Very basic description of chosen experiment **and** limited interpretation of observations *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		source; measure count rate, use paper screen or move back to 10 cm or more, measure count rate, interpret result; contrast to background count level and/or other emissions from same source **b**. β place detector e.g. 10 cm from source measure count rate, add thin sheets of Al until count drops to very low or almost constant value e.g. γ present; interpret result; **c**. γ place detector e.g. 10 cm from source measure count rate, add thin sheets of Pb until count drops to very low/background level; interpret result **4**. deflection experiment: needs vacuum for α experiment;source for radiation passes through region of E- or B-field; deflection or not of particles detected by detector to distinguish emissions; detail of directions; amount of curvature determines energy of emission; and nature of particle
			Total	**6**	
3		i	Beta radiation would not penetrate/ would be absorbed by the lead	B1	**Not** gamma radiation would be stopped **Ignore** reference to alpha radiation
		ii	$\ln N = -\mu d + \ln N_0$ compared to y = mx + c (so m = - μ and c = $\ln N_0$)	B1	**or** $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$
		iii	5.70 ± 0.14	B1 B1	Both answers must be to 2d.p. **Allow** ± 0.13 not second B1 mark without correct working shown e.g. ln300 – ln260 or (5.83-5.56)/2 **Allow** $\Delta N/N$ (= 40/300) but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted
		iv	Point plotted correctly to within ½ small square Best fit and worst fit line(s) drawn	B1 B1	**Ignore** accuracy of length of error bar **ECF (ii)2** for incorrect value(s) in table **ECF (ii)2** for incorrect value(s) in table Best fit line should have an equal scatter of points about the line Worst fit line should be steepest/shallowest possible line that passes through all the error

					bars (allow ±½ small square tolerance vertically)
		v	gradient of best fit line = (-) μ = (-) 54 (m^{-1}) large triangle used to determine gradient of best fit line calculation of absolute uncertainty using <u>their</u> values in the formula (|wfl gradient – bfl gradient|) uncertainty and value of μ to same number of dp	B1 B1 B1 B1	**Allow** 51 to 56 **Allow** value of μ up to 4 SF **ECF(ii)3** for wrongly plotted point Δd > 25mm (seen from graph or working) **ECF (ii)3** for worst fit line **Ignore** any POT error in gradients **Allow** value of absolute uncertainty up to 3 SF only e.g. 53.4 ± 5.6 or 54 ± 6
		vi	$\mu d_{½}$ = ln2 (or 0.693) $d_{½}$ = 0.013 (m)	C1 A1	**ECF (ii)4** for ½ <u>Alternative method</u>: ln(N_0 /2) =7.67 (C1) then use of graph to give $d_{½}$ = 0.013±0.001 (m) (A1)
			Total	**12**	
4	a		Any 2 from: ✓✓ Handle radioisotope with tongs; Always point open side away from body; Keep exposure time as short as possible; Always store in lead lined containers.	2	
	b	i	Background radiation is always present/from cosmic rays and natural radioactive materials ✓ (The value for background count has to be subtracted from all readings) to avoid a systematic error ✓	1 1	
		ii	Half thickness calculated Method ✓ Evaluated ✓ More than one value found from the graph and mean calculated ✓	 1 1 1	Anticipated values in the range 0.9 to 1.1cm
	c	i	Ln taken on both sides and rearranged ✓	1	Expect to see $\ln(I) = \ln(I_0 e^{-\mu x})$ $\ln(I) = \ln(I_0 + \ln(e^{-\mu x})$
		ii	All 4 data points plotted correctly ✓ Line of best fit drawn through the plots ✓	1 1	
		iii	Gradient correctly calculated from two points on the line drawn ✓	1	

			Intercept read off graph correctly or calculated using substitution into y = m x + c and coordinates of a point on the line ✓	1	
			μ = gradient ✓	1	
			I_0 e^{intercept}✓	1	There must be evidence of this calculation. i.e. not just read from Fig. 4.2
	d	i	Use of $I = \frac{I_0}{2}$ ✓	1	
		i	Either $\frac{I_0}{2} = I_0e^{-\mu x}$ **OR** $\ln\left(\frac{I_0}{2}\right) = -\mu x + \ln(I_0)$ and rearrange to $\frac{\ln 2}{\mu} = x_{1/2}$✓	1	
		i	$x_{1/2}$= ✓	1	
		ii	Any three from ✓✓✓ On an exponential scale: Need to find several values of half-thickness in different parts of curve and average in order for it to be reliable ORA Radioactive decay is a random process and at small values of A the randomness will affect readings more. On a logarithm scale: Value determined for half-thickness from logarithm graph is more reliable as it is determined from the gradient of the line reducing the effect of the random nature of radioactive decay	3	i.e. Not reliable as only one/a few value(s) of half thickness calculated
			Total	**20**	
5		i	3.6, 1.8 ✓ <u>Background</u> radiation count needs to be subtracted from all experimental readings ✓	**2**	Look at data written in 3rd column of table only.
		ii	<u>1.06</u>, <u>0.79</u> ✓	**1**	Rounding errors penalised. 2dp necessary. Look at data written in 4th column of table only.
		iii	Both points plotted to within half a small square ✓ Straight line of best fit drawn with reasonable balance of points either side of line and extends across all plotted points✓	**2**	ALLOW ecf from (b)(ii). Plots must be < half a small square in diameter. ALLOW ecf from plotting. Expect to see. y–intercept 3 squares from the top (within $^1/_2$ small square) x–intercept 2 to 3 squares from the right (within $^1/_2$ small square)
		iv	**Level 3 (5–6 marks)** ✓✓ Clearly worked half–life calculation from gradient including linearisation of equation **AND** detailed comparison of logarithmic and exponential graphs. *There is a well–developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** ✓✓ Calculation of half–life (by an appropriate method) or decay constant or gradient and some comparison of logarithmic and exponential graphs **OR** clearly worked half–life calculation from gradient including linearisation of equation **OR** detailed comparison of	**6**	**Indicative scientific points may include:** **Determination of half life** • Calculation of gradient using 2 points on the line (at least half the length of the line apart) • Gradient in range -9×10^{-3} to -10×10^{-3}. • Allow ecf of gradient from their line. • Calculation of half–life = – ln 2 ÷ gradient • half–life in range 69s to 77s • Rearrangement of $A = A_0e^{-\lambda t}$ to ln A = ln A_0 − λt • Explanation that this is a y = mx + c type straight line with gradient = −λ and intercept = ln A_0. • Approximate decay constant could be calculated from table data or single point

			logarithmic and exponential graphs. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** ✓✓ Attempted calculation of half–life **AND/OR** or some comparison of logarithmic and exponential graphs. *There is an attempt at a logical structure with a line of reasoning.* *The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		on graph and substituted into exponential/logarithmic equation. • Approximate half–life could be determined purely from table data. **Comparison of logarithmic and exponential graphs:** • Exponential plot will give a decay curve; • Curve line is more difficult to draw; • Easier to see anomalies with a straight line. • On an exponential scale – Need to find several values of half–life in different parts of curve and average. • Logarithmic graphs compress the scale so it is easier to see variation across all values of A. • Finding half–life from curve with smaller values of A will be more inaccurate than for large values of A. • Radioactive decay is a random process and at small values of A the randomness will affect readings more. • Logarithm graph reduces the effect of random nature/ value determined for half–life is more reliable. • Easier to average out random error in the points by drawing a straight line of best fit.
			Total	**11**	
6		i	Good best fit line, with ruler (1) Two pairs of points taken from line, × values separated by at least 150 s. (1) Calculation of gradient e.g. 1/100 = 0.01 s^{-1}	3	A candidate could calculate the half life by subtracting 0.693 from a y value and finding the difference in x, or by converting ln values to count rate. This is acceptable. Read offs correct to half a small square.
		ii	Half-life = 0.693/0.01 (1) = 69 (s) (1)	2	Range of values from candidates decay constant
			Total	**5**	

