

AQA A level Radioactivity and half life

Matching solutions and teaching prompts for the class review

Specification points covered

• 3.8.1.2 α , β and γ radiation: absorption, thickness gauges, background correction and γ inverse-square law. Required practical 12: investigate the inverse-square law for γ radiation.

• 3.8.1.3 Radioactive decay: random decay, constant probability, $A = \lambda N$, $N = N_0 e^{-\lambda t}$, $A = A_0 e^{-\lambda t}$, $T = \ln 2/\lambda$, decay curves and log graphs. A-level-only content.

Teaching focus

Use source decay, transmission and detector efficiency as distinct effects. Subtract background before interpreting a source signal.

Train precise exponential and log-gradient language. Require a defensible model test, not merely the statement that radiation becomes weaker with distance.

Selecting and identifying radiation

1. State what is meant by the random nature of radioactive decay. [1 mark]

Answer / mark points: It is impossible to predict when a particular unstable nucleus will decay. [1] A surviving nucleus has a constant probability of decay per unit time; large populations nevertheless give predictable mean decay curves.

Teacher prompt / common error: Require an individual nucleus and its decay time; a fluctuating detector reading is a consequence, not the definition.

2. Define the half-life of a radioactive nuclide in terms of its undecayed nuclei. [1 mark]

Answer / mark points: The half-life is the time taken for the number of undecayed nuclei of a nuclide in a sample to decrease to half its initial value. [1] It is not the time for every nucleus to decay.

Teacher prompt / common error: Specify the remaining parent nuclei. Total sample mass need not halve when parent nuclei decay.

3. A manufacturer needs a transmission gauge for thin aluminium foil: some radiation must pass through the foil, but the detected rate must change appreciably when its thickness changes. Choose α , β or γ radiation and explain why the other two types are less suitable. [2 marks]

Answer / mark points: Choose β radiation: partial transmission through the thin foil gives a detected rate that responds to thickness changes. [1] α is stopped by the foil (and has a short range in air), whereas γ is too penetrating to give a sufficiently sensitive response to small thickness changes in this thin foil. [1 for both alternatives]

Teacher prompt / common error: Most penetrating is not always most suitable; γ gauges can suit thicker steel.

Table 1 Mean raw readings at fixed geometry

Absorber	None	Paper	5 mm aluminium	25 mm lead
Count rate / s ⁻¹	310	310	10	10

4. Table 1 tests a spare source that emits only one of α , β or γ radiation. Its background count rate is 10 s⁻¹. Identify the radiation and justify your answer using both the paper and aluminium results. [2 marks]

Answer / mark points: β radiation. [1] The paper does not reduce the reading, so the source is not α ; the 5 mm aluminium reduces it to background, which is consistent with β rather than γ . [1 for both observations] The remaining 10 s⁻¹ does not show that some source radiation has passed through: it is background.

Teacher prompt / common error: Paper passes β ; aluminium stops it. Subtract background first.

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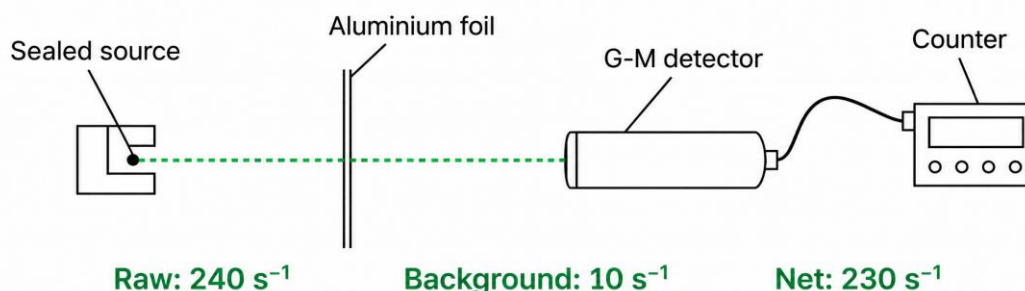
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Keeping the foil at the correct thickness

5. Figure 1 shows the foil gauge. With standard foil in place, the detector records 14 400 counts in 60.0 s. With the source removed, it records 2400 counts in 240 s. Calculate the count rate due to the source through the foil. [2 marks]



Answer / mark points: Background rate = $2400/240 = 10.0 \text{ s}^{-1}$. [1] Raw rate = $14\,400/60.0 = 240 \text{ s}^{-1}$, so net rate $R = 240 - 10.0 = 230 \text{ s}^{-1}$. [1] Subtract rates, not counts measured over unequal durations.

Teacher prompt / common error: Convert both measurements to rates before subtracting because the counting durations differ.

6. For unchanged source activity and geometry, a batch gives a lower net count rate than the standard foil. Explain whether the foil is thicker or thinner, and whether the gap between the rollers must be increased or decreased to restore the standard thickness. [2 marks]

Answer / mark points: The foil is thicker: it absorbs more β radiation, giving a lower transmitted net count rate. [1] Decrease the roller gap so the foil is rolled thinner and the transmitted rate returns towards the standard value. [1] This conclusion requires the unchanged activity and geometry stated in the question.

Teacher prompt / common error: Use the sequence thickness increases, absorption increases, transmitted net count rate decreases.

7. Two consecutive 60.0 s readings for the same foil are 14 400 and 14 240 counts. Explain why this difference alone does not establish a change in thickness. Suggest how to obtain stronger evidence. [2 marks]

Answer / mark points: The number of decays detected in a fixed interval fluctuates randomly, even at unchanged thickness. [1] Repeat readings and compare mean background-corrected rates and their spread, or count over a longer period to reduce fractional statistical fluctuations. [1] Longer counting does not make radioactive decay deterministic.

Teacher prompt / common error: Random scatter is expected. More readings give better evidence, not certainty about individual decays.

8. For this foil and geometry, the detector counts a fraction 2.00×10^{-4} of the source decays. Using your net count rate from Question 5, determine the source activity and explain why the raw detector count rate cannot be used as its activity. [2 marks]

Answer / mark points: $R = \text{fraction} \times A$, so $A = 230/(2.00 \times 10^{-4}) = 1.15 \times 10^6 \text{ Bq} = 1.15 \text{ MBq}$. [1] The raw rate includes background and detects only a small fraction of all source decays; activity is the total decay rate of the source. [1] Do not equate a background-corrected detector reading with activity without allowing for detection fraction.

Teacher prompt / common error: Activity counts source decays; the detector records a geometry- and efficiency-dependent fraction plus background.

9. The production source B initially has activity 1.60 MBq and half-life 8.00 years. Calculate its activity after 4.00 years. Assume only the parent nuclide contributes to the measured signal. [1 mark]

Answer / mark points: $A = A_0 \times (1/2)^{t/T} = 1.60 \times (1/2)^{4.00/8.00} = 1.13 \text{ MBq}$. [1] Equivalently use $A = A_0 e^{-\lambda t}$ with $\lambda = \ln 2/8.00 \text{ year}^{-1}$. Half a half-life does not imply half the activity.

Teacher prompt / common error: Use the fractional number of half-lives rather than a linear decrease.

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Source lifetime and the remaining nuclei

10. Source B must be replaced when its activity reaches 1.00 MBq. Calculate the time after installation at which this occurs. Show how you deal with a time that is not a whole number of half-lives. [2 marks]

Answer / mark points: $A/A_0 = e^{-\lambda t}$; $t = \ln(A_0/A)/\lambda = 8.00 \ln(1.60/1.00)/\ln 2$. [1] $t = 5.42$ years after installation. [1] The exponential gives a mean prediction, not the exact future sequence of individual decays.

Teacher prompt / common error: Take a natural logarithm or use a fractional half-life; do not wait for the next whole half-life.

11. Using 1 year = 3.16×10^7 s, determine the decay constant of source B in s^{-1} . [2 marks]

Answer / mark points: $T = 8.00 \times 3.16 \times 10^7 = 2.528 \times 10^8$ s. [1] $\lambda = \ln 2/T = 2.74 \times 10^{-9} s^{-1}$. [1] Keeping λ in $year^{-1}$ would not give activity in Bq when multiplied by a number of nuclei.

Teacher prompt / common error: Convert the half-life to seconds before finding λ for an activity in Bq.

12. Determine the initial number of undecayed parent nuclei in source B. State the initial rate of change of this number, including its sign. [2 marks]

Answer / mark points: $N_0 = A_0/\lambda = (1.60 \times 10^6)/(2.7419 \times 10^{-9}) = 5.84 \times 10^{14}$ nuclei. [1] Initially $dN/dt = -\lambda N_0 = -A_0 = -1.60 \times 10^6 s^{-1}$. [1] Activity is the positive magnitude of the decay rate; the remaining parent population decreases.

Teacher prompt / common error: N is a count of parent nuclei; A is positive while dN/dt is negative.

13. Explain why warming source B cannot restore its activity. [1 mark]

Answer / mark points: The nuclear decay probability per unit time/decay constant is not changed by ordinary heating, so warming does not restore the lost parent nuclei or increase their mean decay rate. [1] Heating can change detector behaviour or material dimensions, but that is not restoration of the source activity.

Teacher prompt / common error: Do not confuse nuclear decay with a temperature-dependent chemical reaction.

14. Two sealed candidate sources contain the same number of undecayed parent nuclei. One has half-life 8.00 years and the other 4.00 years. Determine the ratio of their activities, $A(4\text{-year})/A(8\text{-year})$, and explain why their activities differ. [2 marks]

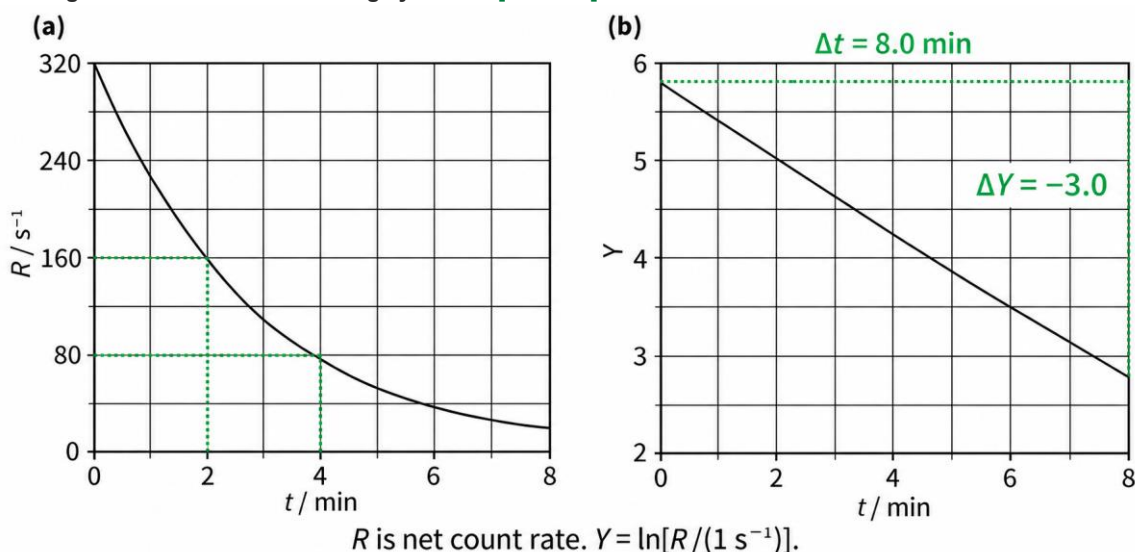
Answer / mark points: For equal N, $A = \lambda N$ and $\lambda = \ln 2/T$, so $A(4\text{-year})/A(8\text{-year}) = 8.00/4.00 = 2.00$. [1] The 4-year source has twice the decay constant/probability per unit time, so twice the activity for the same population. [1] A shorter half-life does not mean more nuclei are present.

Teacher prompt / common error: Compare populations and decay constants separately. Equal populations need not mean equal activities.



Decay curves and logarithmic graphs

15. The laboratory studies two short-lived nuclides, C and D, distinct from source B. Figure 2(a) is the net count-rate curve for C; Figure 2(b) is a log graph for D. Both use constant detector efficiency. Use graph (a) to estimate the half-life of C over two successive halving intervals. Show the readings you use. [2 marks]



Answer / mark points: For example, R falls from 320 to 160 s^{-1} between $t = 0$ and 2.0 min, giving $T = 2.0$ min. [1] It then falls from 160 to 80 s^{-1} between $t = 2.0$ and 4.0 min, again giving 2.0 min. [1] Accept any two successive halving intervals consistent with the curve, to its reading precision (about 1.9–2.1 min). The right-hand graph uses a linear scale for Y , not a linear scale for R .

Teacher prompt / common error: Measure horizontal time intervals for successive halvings of net R , not equal vertical decrements.

16. Determine λ for sample C in min^{-1} , then predict its net count rate at $t = 5.00$ min. Use an exponential calculation rather than linear interpolation between readings. [2 marks]

Answer / mark points: $\lambda = \ln 2/2.00 = 0.347 \text{ min}^{-1}$. [1] $R = 320 e^{-(0.3466 \times 5.00)} = 56.6 \text{ s}^{-1}$. [1] Time and λ must use matching units. Linear interpolation between (4,80) and (6,40) would incorrectly give 60 s^{-1} .

Teacher prompt / common error: A quantity decreases exponentially here, not linearly. Keep λ and t in matching time units.

17. Graph (b) plots $Y = \ln[R/(1 \text{ s}^{-1})]$ against t in minutes for nuclide D. Use two widely separated points on its straight best-fit line to determine its gradient. Hence determine λ for D and state which nuclide, C or D, has the shorter half-life. [2 marks]

Answer / mark points: A suitable large triangle uses approximately (0, 5.8) and (8.0, 2.8). Gradient = $(2.8 - 5.8)/(8.0 - 0) = -0.375 \text{ min}^{-1}$. [1] From $\ln[R/(1 \text{ s}^{-1})] = \ln[R_0/(1 \text{ s}^{-1})] - \lambda t$, gradient = $-\lambda$, so $\lambda \approx 0.38 \text{ min}^{-1}$. D has the larger λ and therefore the shorter half-life compared with C ($\lambda \approx 0.35 \text{ min}^{-1}$). [1 for λ and comparison] Accept 0.36–0.39 min^{-1} for a reasonable large triangle. λ itself is positive.

Teacher prompt / common error: Read Y values directly; they are already natural logarithms. Use a large triangle and $\lambda = \text{minus gradient}$.

18. The experiment is repeated using an otherwise identical detector with half the original, constant efficiency. Explain whether the half-life obtained from the log-graph gradient changes. [2 marks]

Answer / mark points: The half-life is unchanged. [1] Halving the constant efficiency halves every net R and subtracts $\ln 2$ from every Y , shifting the log line vertically without changing its gradient $-\lambda$. [1] Detector efficiency is not the decay probability of a nucleus.

Teacher prompt / common error: A constant multiplicative efficiency changes the intercept, not the log slope or half-life.

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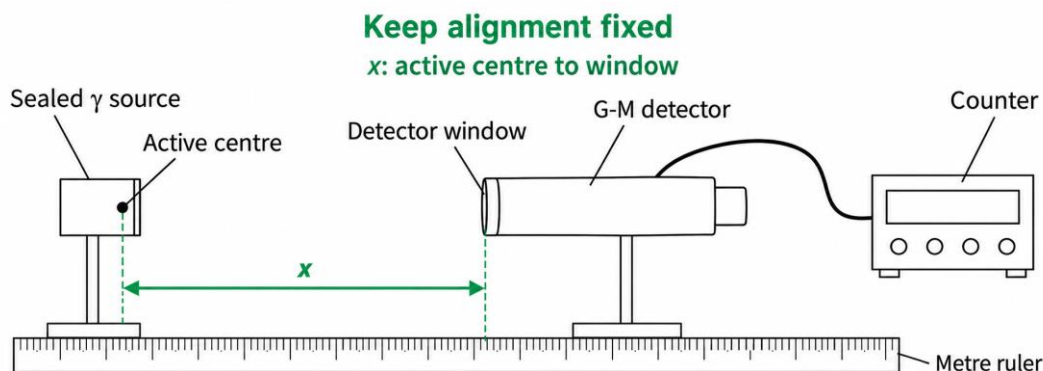
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Required practical 12 Testing the inverse-square law

19. Required practical 12. Figure 3 shows a sealed γ source and detector, operated by an authorised teacher. Write a method to test $R = k/x^2$. Use the headings measurement and background correction; distance and control of conditions; analysis and risk reduction. Explain how the results would support an inverse-square relationship. Treat the source as approximately point-like, and keep the detector within its reliable count-rate range. [6 marks]



Answer / mark points: 1. With the source removed or shielded in its designated storage, measure background counts over a known, sufficiently long interval and calculate the background rate. [1]

2. Align the source and detector; record source-plus-background counts for a timed interval at each of at least six distances. Repeat/average readings or use longer counts at low rates, then subtract the background rate. [1]

3. Measure x from the active source position to the detector window, not arbitrary holder edges. Use separations large compared with source/detector dimensions. [1]

4. Keep alignment, detector settings and surroundings constant; avoid absorbers and excessive rates that cause detector dead-time loss. Use a source whose activity changes negligibly during the investigation. [1]

5. Plot net R against $1/x^2$ and draw a straight best-fit line. An approximately zero intercept, within uncertainty, supports $R = k/x^2$. Alternatively, test whether Rx^2 is constant within uncertainty. [1]

6. The authorised teacher follows the approved risk assessment, uses remote handling/tongs, minimises exposure time, maximises practicable distance and returns the sealed source to its designated shielded storage when not in use. [1 for a workable risk-reduction explanation]

These are indicative points for this original scaffolded six-mark response, not an official AQA mark scheme. No numerical separation is a universal safe-distance recommendation.

Teacher prompt / common error: Require timed readings, background subtraction, correct distance endpoints, control of geometry and an actual test of the law.

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Testing the model with detector data

Table 2 Mean γ detector readings

Distance x / m	0.100	0.150	0.200	0.300
Raw count rate / s^{-1}	925	425	250	125

20. Table 2 gives mean raw count rates from the γ investigation. The background count rate is $25.0 s^{-1}$. Correct all four readings and use suitable calculations to judge whether they are consistent with an inverse-square relationship. [2 marks]

Answer / mark points: Net rates at 0.100, 0.150, 0.200 and 0.300 m are 900, 400, 225 and $100 s^{-1}$. [1 for all four corrections] Their products Rx^2 are 9.00, 9.00, 9.00 and $9.00 s^{-1} m^2$, respectively, so these mean data are consistent with an inverse-square relationship. [1 for calculations and conclusion] Real experimental readings would fluctuate and should be judged within uncertainty, rather than required to be exactly equal.

Teacher prompt / common error: Test the source contribution, not the raw readings; all four points must support the conclusion.

21. For the Table 2 setup, predict the raw count rate at $x = 0.500$ m, assuming the inverse-square model remains valid. Include background in your final answer. [2 marks]

Answer / mark points: $R(\text{net}) = k/x^2 = 9.00/(0.500)^2 = 36.0 s^{-1}$. [1] $R(\text{raw}) = 36.0 + 25.0 = 61.0 s^{-1}$. [1] Background does not decrease with the source-to-detector distance in this model.

Teacher prompt / common error: Find the net source rate first, then add the background once.

22. A student plots raw count rate vertically against $1/x^2$ horizontally. State the expected graph shape and vertical intercept. Explain how the intercept would differ if net count rate were plotted instead. [2 marks]

Answer / mark points: A straight line with vertical intercept $25.0 s^{-1}$, because $R(\text{raw}) = k(1/x^2) + R(\text{background})$. [1 for shape and intercept] For net R , subtraction of background gives a straight line through the origin, with zero intercept. [1] Neither graph is R versus x .

Teacher prompt / common error: Name both axes. A non-zero raw intercept is expected and does not contradict the inverse-square source model.

23. Another student measures distance from the front of the source holder, 20 mm in front of the active source, rather than from the active source to the detector window. At their recorded distance of 0.100 m, calculate the actual source-to-window distance. Explain why this offset produces a larger percentage distance error at short separations. [2 marks]

Answer / mark points: Actual distance = $0.100 + 0.020 = 0.120$ m. [1] The fixed 20 mm offset is a larger fraction of a shorter source-to-window distance, so the percentage distance error is larger at short separation. [1] Here the recorded value underestimates the actual distance by $0.020/0.120 \times 100 = 16.7\%$; using 0.100 m in Rx^2 gives a systematic bias.

Teacher prompt / common error: A constant absolute offset is not a constant percentage error. The source is behind the holder front.

Language and method check

Award distinct stated points and allow consistent error-carried-forward. Accept justified alternative practical methods. Graph tolerances reflect print-reading precision. This worksheet is educational, not authorisation to handle a source or a real workplace safety assessment.

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