Radioactive decay calculations

Activity, half-life and a time-critical delivery

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 36 marks

Specification points covered

6.4.3(d): activity and the becquerel; $A = \lambda N$.

6.4.3(e)(i): decay constant and half-life, $\lambda t_{1/2} = \ln 2$.

6.4.3(f)(i): exponential changes in N and A, including time calculations.

For the illustrative tracer X, $t_{1/2}$ = 90.0 min. Use ln 2 = 0.693, one minute = 60 s and one hour = 3600 s. The detector signal is due only to X; detection fraction is constant unless stated.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Rates and probabilities

An isotope laboratory sends tracer X to an island measurement centre. The instrument requires a specified minimum activity when its scheduled measurement begins.

Dispatch is t = 0. The laboratory initially considers a vial with activity 480 MBq.

Every interval after dispatch counts towards the decay time. The route times in Figure 1 are also stated in Table 1.

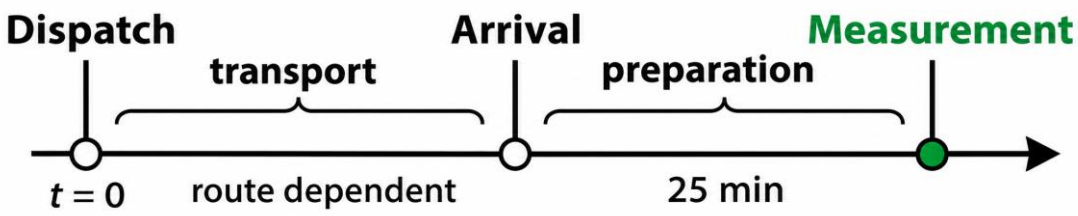


Figure 1 Include transport and preparation before the measurement

1(a) A vial has activity 480 MBq when it leaves the laboratory. State what this activity means, including the number and type of events per second. **[1 mark]**

1(b) Calculate the decay constant of X in min^{-1} and in s^{-1}. Retain an unrounded value for later calculations. **[2 marks]**

2 Choose a route using the activity on arrival

Table 1 Scheduled intervals after dispatch

Route	Transport / min	Preparation / min
Ferry	95	25
Aircraft	55	25

2(a) Use Table 1 to determine the elapsed time from dispatch until measurement for each route. **[1 mark]**

2(b) Calculate the activity at the measurement time for the ferry route, starting from 480 MBq. **[2 marks]**

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2(c) The instrument test requires at least 240 MBq when measurement starts. Calculate the aircraft-route activity and decide which route meets the requirement for this 480 MBq vial. **[2 marks]**

2(d) Calculate the fraction of the original nuclei that has decayed by the ferry measurement time. Explain why it is not the same as A/A_0. **[2 marks]**

3 How many nuclei are in the vial?

3(a) Calculate the number of undecayed X nuclei in the vial at dispatch. Use the initial activity 480 MBq. **[2 marks]**

3(b) Each X nucleus has an approximate mass of 1.99×10^{-25} kg. Calculate the mass of undecayed X in the vial at dispatch. The vial also contains a carrier liquid; do not include that liquid. **[1 mark]**

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3(c) Calculate the number of X nuclei that decay during the full ferry interval. **[2 marks]**

3(d) A second isotope Y has half-life 30.0 min. Compare its activity with X when the samples contain equal numbers of undecayed nuclei. Then compare their numbers of nuclei if instead their activities are equal. **[2 marks]**

4 Plan the dispatch, rather than hope it arrives

4(a) Calculate the minimum dispatch activity needed for the ferry route to provide 240 MBq at measurement, assuming the scheduled 120 min elapsed time. **[2 marks]**

4(b) A 600 MBq vial is now available. Find the latest elapsed time after dispatch at which it can meet the 240 MBq requirement. Show how the logarithm is used. **[3 marks]**

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4(c) For the 600 MBq vial, the ferry route takes 120 min before measurement and the aircraft route takes 80 min. Calculate how much additional delay the aircraft route can tolerate. Explain why the ferry route already fails. **[2 marks]**

4(d) For the original 480 MBq vial, calculate the activity after 4.50 h. Give a quick half-life check on the answer. **[1 mark]**

5 Check the measurement system

5(a) At one measurement time the gross rate is 3200 s^{-1} and the background is 200 s^{-1}. The apparatus records a fraction 1.25×10^{-5} of the source's decays. Calculate the activity. **[2 marks]**

5(b) Between two readings 45.0 min apart, the net rate decreases from 3000 s^{-1} to 2120 s^{-1}. Use the ratio to estimate the half-life and decide whether the reading is consistent with X. **[3 marks]**

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5(c) The source is moved closer to the detector between readings. Explain why its count rate may no longer follow the same measured exponential, even though the nuclear decay constant is unchanged. **[2 marks]**

5(d) A technician proposes warming an old vial to restore its original activity. Explain why this is not a workable way to meet the dispatch requirement. **[1 mark]**

6 Explain the shape of the decay

6(a) The same fraction of X nuclei survives each 90 min interval, but the number decaying in successive 90 min intervals becomes smaller. Explain both statements using the microscopic meaning of the decay constant and $A = \lambda N$. **[3 marks]**

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