Past-paper walk-through

Radioactive decay ▪ 23.2

eXercise

Questions in this set

- 9702/44 N25 Q8 ▪ 15 marks
- 9702/41 J25 Q9 ▪ 10 marks
- 9702/42 J25 Q10 ▪ 9 marks
- 9702/43 J25 Q9 ▪ 10 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 8

9702/44 N25 ▪ Q8 ▪ 15 marks

Oxygen-15 ($^{15}_{8}$O) is radioactive and has a half-life of 2.04 minutes.
The decay of oxygen-15 produces positrons. For this reason, oxygen-15 is sometimes used as a tracer in positron emission tomography (PET scanning).

(a) State what is meant by a tracer. **[2]**

(b)(i) State the values of the integers *P*, *Q*, *R* and *S*. **[2]**

(b)(ii) State the name of particle Z. **[1]**

(c)(i) Define the activity of a sample. **[1]**

(c)(ii) Calculate the decay constant of oxygen-15. Give a unit with your answer. **[2]**

(c)(iii) Determine the rate at which positrons are produced in a sample of oxygen-15 that has a mass of 2.85×10^{-6} kg. **[4]**

(d)(i) State the name of the particles that are detected. **[1]**

(d)(ii) Explain how these particles are formed inside the body. **[2]**

Solution 8

(a)

Mark scheme

- (radioactive) substance introduced into the body **B1**
- substance absorbed by the tissues being studied **B1**

Solution 8

(b)(i)

Mark scheme

- P = 15 and R = 0 **A1**
- Q = 7 and S = (+)1 **A1**

(b)(ii)

Mark scheme

- (electron) neutrino **B1**

Solution 8

(c)(i)

Mark scheme

- number of nuclear disintegrations per unit time **B1**

Solution 8

(c)(ii) Worked steps

- $\lambda = \dfrac{\ln 2}{t_{1/2}}$, with the half-life in **seconds**: 2.04 min $= 122.4$ s.
- $\lambda = \dfrac{0.693}{122.4}$
- $\lambda = 5.66 \times 10^{-3}$ s^{-1}

Solution 8

The unit is asked for, and it is per second — a decay constant is a probability per unit time, never a plain number.

Mark scheme

- decay constant = ln 2 / (2.04 × 60) **C1**
- = 5.66 × 10–3 s–1 **A1**

Solution 8

(c)(iii) Worked steps

Two steps: how many nuclei there are, then how fast they decay.

- Mass of one oxygen-15 nucleus $= 15 \times 1.66 \times 10^{-27}$ kg.
- $N = \dfrac{2.85 \times 10^{-6}}{15 \times 1.66 \times 10^{-27}} = 1.14 \times 10^{20}$
- Activity $A = \lambda N = 5.66 \times 10^{-3} \times 1.14 \times 10^{20}$
- $A = 6.48 \times 10^{17}$ s^{-1}

Solution 8

Each decay of oxygen-15 emits one positron, so that activity **is** the rate at which positrons are produced.

Mark scheme

- N = (2.85 × 10–6) / (15 × 1.66 × 10–27) C1
- A = λN C1
- rate = (5.66 × 10–3) × (2.85 × 10–6) / (15 × 1.66 × 10–27) C1
- = 6.48 × 1017 s–1 A1

Solution 8

(d)(i)

Mark scheme

- gamma photons **B1**

(d)(ii)

Mark scheme

- positron collides with electron (in body) **B1**
- annihilation results in their masses becoming photon energy **B1**

Question 9

9702/41 J25 ▪ Q9 ▪ 10 marks

(a) Define activity of a radioactive sample. **[1]**

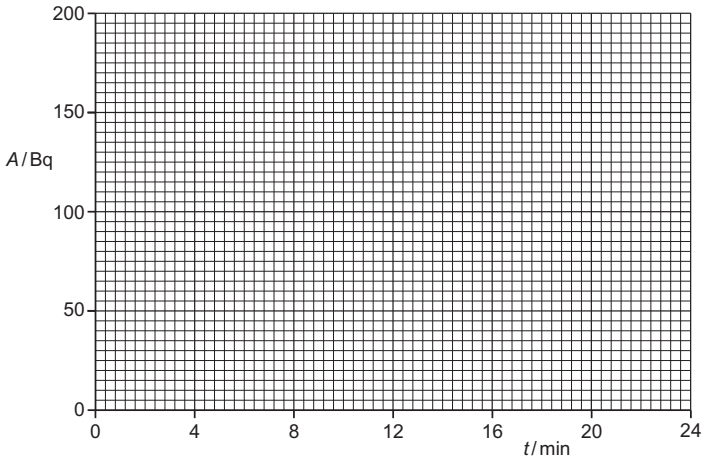
(b) Explain why the variation with time of the activity of a radioactive sample is exponential in nature. **[3]**

(c)(i) Determine the decay constant, in min^{-1}, of the radioactive isotope. **[2]**

(c)(ii) Use your answer in **(c)(i)** to determine the half-life, in min, of the radioactive isotope. **[1]**

(c)(iii) On Fig. 9.1, sketch the variation of the activity A of the sample with t for values of t between $t = 0$ and $t = 24$ min. **[3]**

Question 9



Solution 9

(a)

Mark scheme

- number of nuclear disintegrations per unit time **B1**

Solution 9

(b)

Mark scheme

- activity is proportional to the number of undecayed nuclei **B1**
- activity = (–) rate of change of number of undecayed nuclei **B1**
- N is proportional to the rate of change of N (so exponential variation) **B1**

Solution 9

(c)(i) Worked steps

The decay law for activity has the same form as the one for the number of nuclei:

$$A = A_0\, e^{-\lambda t}$$

- Put in the two readings the question gives: $A_0 = 180$ at $t = 0$, and $A = 120$ at $t = 8.4$ min.
- $120 = 180\, e^{-\lambda \times 8.4}$, so $e^{-8.4\lambda} = \dfrac{120}{180} = 0.667$.
- Take natural logs: $-8.4\lambda = \ln 0.667 = -0.405$.
- $\lambda = \dfrac{0.405}{8.4} = 0.048$ min^{-1}.

Solution 9

The unit is the giveaway for the whole question: λ comes out per **minute** because the time was in minutes. Convert nothing — the question asks for min^{-1}.

Mark scheme

- $120 = 180 \exp(-\lambda \times 8.4)$ **C1**
- $\lambda = 0.048$ min–1 **A1**

Solution 9

(c)(ii) Worked steps

Half-life and decay constant are linked by one relation, which follows from putting $A = \frac{1}{2}A_0$ into the decay law:

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Solution 9

- $t_{\frac{1}{2}} = \dfrac{0.693}{0.048} = 14$ min.

Use **your own** λ from (c)(i) — this part is marked on the method, so a wrong λ carried forward correctly still earns the mark.

Mark scheme

- half-life $=$ ln 2 / 0.048
- $= 14$ min **A1**

Solution 9

(c)(iii) Worked steps

The mark scheme asks for three separate features, so draw the curve to satisfy them one at a time:

1. **Starts at** $(0, 180)$ **with a negative gradient throughout** — the activity begins at A_0 and only ever falls.
2. **Passes through** $(8.4, 120)$ — the reading the question already gave you.
3. **Gradient becomes less steep as** t **increases, passing through** $(14, 90)$ — one half-life has elapsed at 14 min, so the activity is exactly half of 180.

Solution 9

That third condition is what makes it exponential rather than a straight line: the rate of decay is proportional to the activity, so as the activity falls the curve flattens.

Solution 9

Two useful extra anchors you can mark quickly: at $t = 28$ min (two half-lives) the activity would be 45, and the curve must approach the t-axis without reaching it inside the range to 24 min. A line that hits zero is the common way to lose the third mark.

Mark scheme

- line with negative gradient throughout, starting at (0, 180) **B1**
- curve with negative gradient passing through (8.4, 120) **B1**
- curve with decreasing negative gradient, from t = 0 to t = 24 min, passing through (14, 90) **B1**

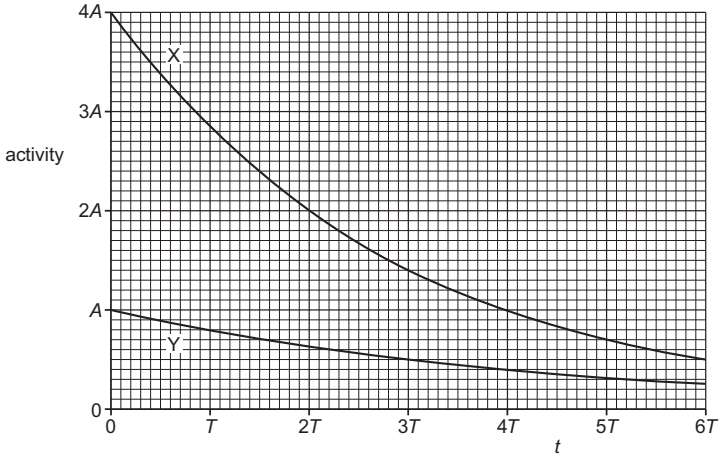
Question 10

9702/42 J25 ▪ Q10 ▪ 9 marks

Radioactive decay is a spontaneous process.

(a) State the meaning, in this context, of the term spontaneous. **[1]**

Question 10



Question 10

sample	half-life	decay constant	initial activity	initial number of nuclei
X			$4A$	
Y			A	

[3]

Question 10

9702/42 J25 ▪ Q10 ▪ 9 marks

Radioactive decay is a spontaneous process.

(b)(i) Complete Table 10.1 to give expressions, in terms of either or both of A and T, for the quantities indicated for each of the samples.

sample	half-life	decay constant	initial activity	initial number of nuclei
X			$4A$	
Y			A	

Question 10

[3]

(b)(ii) Determine, in terms of T, the time at which the two samples will have equal activities. **[3]**

Question 10

9702/42 J25 ▪ Q10 ▪ 9 marks

Radioactive decay is a spontaneous process.

(c) A radiation detector is placed near to one of the samples in (b).

Explain why the count rate measured by the detector is less than the activity of the sample. **[2]**

Solution 10

(a)

Mark scheme

- (decay is) not affected by external / environmental factors **B1**

Solution 10

(b)(i) Mark scheme

- half-life of X = 2T and half-life of Y = 3T **B1**
- both samples show decay constant, in terms of 1 / T, equal to ln 2 / half-life
- (decay constant of X = ln 2 / 2T and decay constant of Y = ln 2 / 3T if both half-lives correct) **B1**
- both samples show N0, in terms of AT, equal to initial activity / decay constant
- (N0 for X = 8AT / ln 2 and N0 for Y = 3AT / ln 2 if both decay constants correct)
- (Fully correct table:

Solution 10

- half-life decay constant **A0**
- N0
- X
- 2T ln 2 / 2T
- 4A
- 8AT / ln 2
- Y
- 3T ln 2 / 3T
- A
- 3AT / ln 2

Solution 10

-) B1

Solution 10

(b)(ii) Worked steps

Both samples obey $A = A_0 e^{-\lambda t}$, and both λ values come from the half-lives through $\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$.

Write each sample out before doing any algebra.

- Sample X: initial activity $4A$, half-life $2T$, so $\lambda_X = \dfrac{\ln 2}{2T}$.
- Sample Y: initial activity A, half-life $3T$, so $\lambda_Y = \dfrac{\ln 2}{3T}$.

Solution 10

Set the two activities equal:

$$4A\,e^{-t\ln 2/2T} = A\,e^{-t\ln 2/3T}$$

- Divide by A, then bring the exponentials together: $4 = e^{t\ln 2\left(\frac{1}{2T}-\frac{1}{3T}\right)}$.
- The bracket is $\dfrac{3-2}{6T} = \dfrac{1}{6T}$, so $4 = e^{t\ln 2/6T}$.
- Take logs: $\ln 4 = \dfrac{t\ln 2}{6T}$, and $\ln 4 = 2\ln 2$.
- The $\ln 2$ cancels: $2 = \dfrac{t}{6T}$, so $t = 12T$.

Solution 10

Sense-check it without algebra. X starts four times as active but halves twice as often. In $12T$, X has run through $12T/2T = 6$ half-lives and Y through $12T/3T = 4$; the ratio of what is left is 4×2^{-6} against 1×2^{-4}, and both equal $A/16$.
The answer is wanted **in terms of** T, so leave it as $12T$ — substituting a number for T loses the mark.

Mark scheme

- correct substitution of A0 and λ into A0 exp (–λt) for sample X or sample Y **C1**
- 4A exp (–t ln 2 / 2T) = A exp (–t ln 2 / 3T) **C1**
- t = 12T **A1**

Solution 10

(c)

Mark scheme

- Any two points from:
- ▪ (radiation) emitted in all directions, not just in direction of detector
- ▪ some radiation absorbed by air / sample / window of detector
- ▪ some radiation may not register even though it reaches detector B2

Question 9

9702/43 J25 ▪ Q9 ▪ 10 marks

9 **(a)** Define activity of a radioactive sample.

Question 9

(b) Explain why the variation with time of the activity of a radioactive sample is exponential in nature.

Question 9

(c) A sample contains a single radioactive isotope that decays to form a stable isotope.

The sample has an activity of 180 Bq at time $t = 0$.
At a time 8.4 minutes later, the activity is 120 Bq.

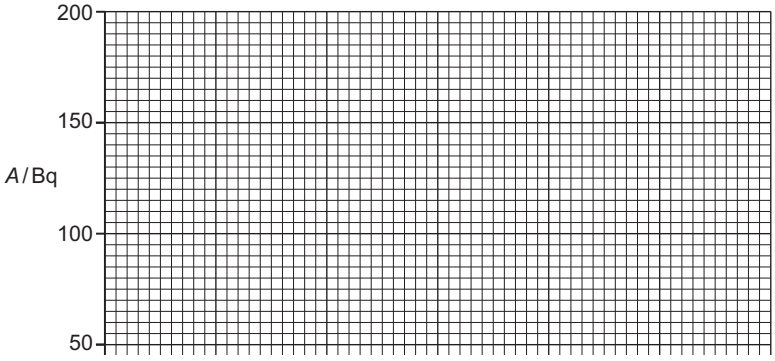
(i) Determine the decay constant, in min^{-1}, of the radioactive isotope.

Question 9

(ii) Use your answer in **(c)(i)** to determine the half-life, in min, of the radioactive isotope.

Question 9

(iii) On Fig. 9.1, sketch the variation of the activity A of the sample with t for values of t between $t = 0$ and $t = 24$ min.



Question 9

Question 9

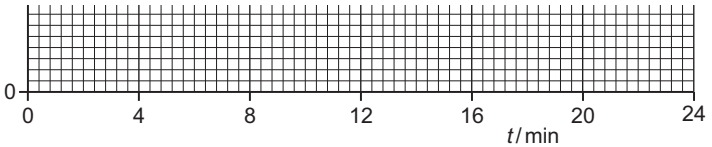


Fig. 9.1

[3]

[Total: 10]

Solution 9

(a)

Mark scheme

- number of nuclear disintegrations per unit time

Solution 9

(b)

Mark scheme

- activity is proportional to the number of undecayed nuclei
- activity = (−) rate of change of number of undecayed nuclei
- N is proportional to the rate of change of N (so exponential variation)

Solution 9

(c)(i) Worked steps

Activity decays exponentially, exactly as the number of undecayed nuclei does.

- $A = A_0 e^{-\lambda t}$, with $A_0 = 180$ at $t = 0$ and $A = 120$ at $t = 8.4$ min.
- $120 = 180\, e^{-8.4\lambda}$, so $e^{-8.4\lambda} = \dfrac{120}{180} = 0.667$.
- $-8.4\lambda = \ln 0.667 = -0.405$
- $\lambda = \dfrac{0.405}{8.4} = 0.048 \text{ min}^{-1}$

Solution 9

The unit follows the time: minutes in, so per minute out. The question asks for min^{-1}, so convert nothing.

Mark scheme

- $120 = 180 \exp(-\lambda \times 8.4)$
- $\lambda = 0.048$ min–1

Solution 9

(c)(ii) Worked steps

One relation connects the two, and it comes from putting $A = \frac{1}{2}A_0$ into the decay law.

- $t_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda} = \dfrac{0.693}{0.048}$
- $t_{\frac{1}{2}} = 14$ min

Solution 9

Use your own λ: this part is marked on the method, so a value carried forward correctly still earns it.

Mark scheme

- half-life $= \ln 2 \,/\, 0.048$
- $= 14$ min

Solution 9

(c)(iii) Worked steps

Draw the exponential the two previous answers describe. The mark scheme names three features:

1. **Starts at** $(0, 180)$ **with a negative gradient throughout** — the activity begins at A_0 and only falls.
2. **Passes through** $(8.4, 120)$ — the reading the question gave you.
3. **Gradient becomes less steep, passing through** $(14, 90)$ — one half-life has elapsed at 14 min, so the activity is exactly half of 180.

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The third condition is what makes the curve exponential rather than a straight line: the rate of decay is proportional to the activity, so as the activity falls the curve flattens.

Solution 9

Two more anchors, if you want them: at 28 min (two half-lives) the activity would be 45, and the curve must approach the time axis without reaching it inside the plotted range. A line that hits zero is the usual way to lose the last mark.

Mark scheme

- line with negative gradient throughout, starting at (0, 180)
- curve with negative gradient passing through (8.4, 120)
- curve with decreasing negative gradient, from $t = 0$ to $t = 24$ min, passing through (14, 90)
- 9702/43
- May/June 2025