Physics Factsheet

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A2 Questions Radioactivity

Radioactive decay lends itself to a broad range of assessment. In addition to practical investigations, problems can be set to test theory, calculations, graphical work, and health and environmental issues. Written answers in paragraph form can be demanded (although they still tend to be marked in terms of separate points made).

Some of the topics that can be assessed include:
1. Types and properties of decay products (including scattering theory and the nuclear atom – Rutherford).
2. The decay process (including sources of radiation [man-made and natural], equations of decay, N-Z graphs, decay chains, etc.).
3. Decay graphs (including ideas of activity, decay constant, half-life, background correction, etc.)
4. Maths based on $A=\lambda N$, $\lambda T_{½} = 0.693$, and equations of the form $A=A_0e^{-\lambda t}$.
5. The inverse square law for gamma radiation.
6. Environmental issues (safety/waste disposal/half-lives).
7 Medical uses and dangers (this topic has already been covered in some depth in Factsheets 77 and 82).

This Factsheet will deal almost exclusively with answering questions on these topics. There are four exam-style questions to illustrate various points and demonstrate the methods of solution required. Then there are a number of short questions for you to attempt – the solutions are supplied.

Exam-style question 1

1 (a) Discuss problems involved in safe storage of radioactive waste (3)
(b) Complete this table relating the range, ionising power, and dangers associated with decay products α, β, and γ.

Decay Product	Range in Air	Ionising Power	Danger to humans
α	Very small	(1)	(2)
β	(1)	Medium (1)	Most dangerous if taken into body in breathing or as food / drink. Less dangerous from external source.
γ	(1)		(2)

Exam-style question 1 solutions

1 (a) half-life very long (1)
possible leakage into environment / water supply (1)
geological instability causing disruption to security of storage (1)
radioactivity may degrade storage vessel (1)
-any three or these or other sensible points.

> ***Exam Hint:** Be prepared to write essay-type answers concerning safety and environmental issues. Remember, the number and quality of points you make are important – not the total number of words you write.*

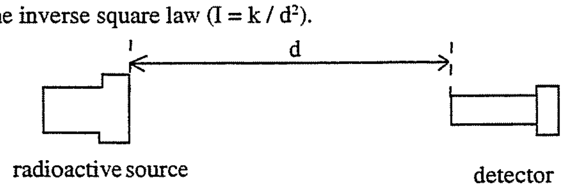
1(b)

Decay Product	Range in Air	Ionising Power	Danger to humans
α	Very small	Very large (1)	Most dangerous if taken into body in breathing or as food / drink. (1) Less dangerous from external source. (1)
β	Small (1)	Medium	Most dangerous if taken into body in breathing or as food / drink. Less dangerous from external source.
γ	Very large (1)	Very small (1)	Most travel straight through body (1) Equally dangerous externally or internally (1)

> ***Exam Hint:** Be clear about the link between range and ionising power for α, β, and γ decay, and the differences between these decay products.*

Exam-style question 2

2. An experiment is set up to confirm that gamma-ray intensity obeys the inverse square law ($I = k / d^2$).



(a) Why will this experiment not give the required result for α and β particles? (1)

(b) How can you ensure that alpha or beta particles from the source cannot reach the detector? (1)

(c) Should the source have a long or a short half-life? Explain your answer. (2)

(d) The count rate is taken over a range of values for distance **d**. Explain what correction must be made to the recorded count rate in investigations of this sort, and how the final corrected value is determined. (2)

(e) These values for corrected count rate (s^{-1}) at various distances are found. Show graphically that the results obey the inverse square law. (7)

d /m	count rate /s		
0.20	442		
0.40	112		
0.60	51		
0.80	28		
1.00	18		
1.20	12		

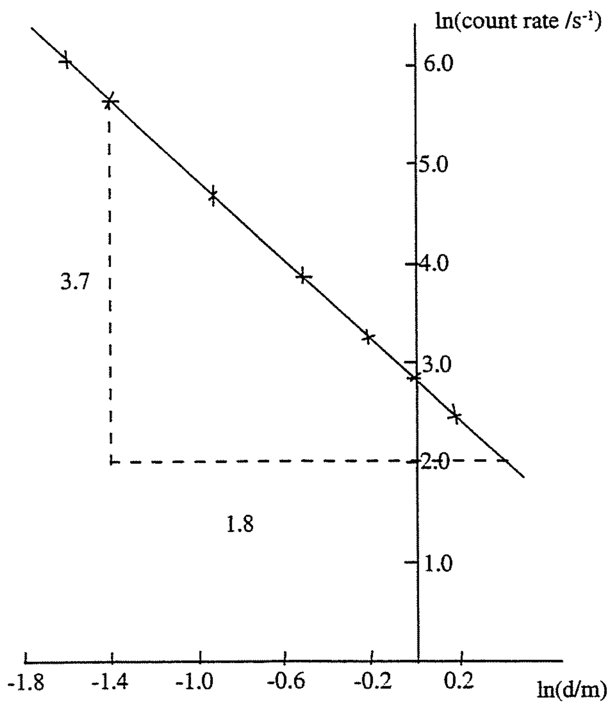
(The third and fourth columns are for your use.)

Exam-style question 2 solutions

2. (a) some (if not all) particles absorbed by air (1)
   (b) metal filter (sheet) in front of source to absorb them (1)
   (c) long half-life (1)
   to ensure constant (ignoring randomness of decay) activity of source (1)
   (d) correct for background radiation (1)
   measure background and subtract from recorded values (1)
   (e) count rate = k/d^2 , ln(count rate) = ln k – 2 ln d (1)
   the logarithmic graph should be a straight line with gradient –2 (1)

d /m	count rate /s	ln (d /m)	ln count rate /s
0.20	442	-1.61	6.09
0.40	112	-0.92	4.72
0.60	51	-0.51	3.93
0.80	28	-0.22	3.33
1.00	18	0.00	2.89
1.20	12	0.18	2.48

(2 marks for table)



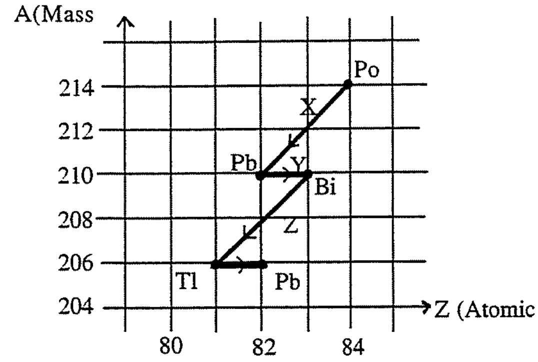
(2 marks for graph)

Gradient = -3.7 / 1.8 = -2.1 (1)

Alternatively, the marks could be gained by calculating the values for d^2, and plotting count rate against 1 / d^2, and obtaining a straight line through the origin.

Exam-style question 3

This is a small section of the Uranium-238 decay chain:



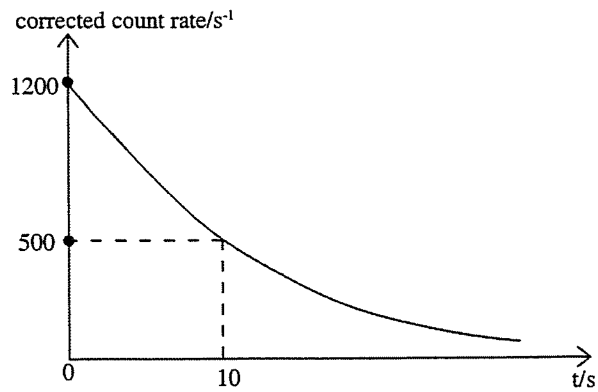
(a) Identify the decay products in sections X, Y, and Z of the chain. (1)
(b) Could the decay from Po-214 to Pb-206 be accomplished in less than four steps? (1)
(c) What information does this chart give us about gamma ray emission? Explain your answer.(2)
(d) Why would the reverse process (decay from Pb to Po) be impossible? (1)

Exam-style question 3 solutions

(a) X = α, Y = β, Z=α (1)
(b) No. (but there could be other pathways possible) (1)
(c) No information about γ rays. (1) They don't appear in the chart, as they don't result in a change in nuclear charge or mass. (1)
(d) Each decay process results in the loss of mass and/or energy from the nucleus. The reverse process would mean mass and/or energy would have to be gained in each step. (1)

Exam-style question 4

The sketch graph shows the corrected count rate measured for the decay of a radioactive sample (the sample-detector distance is constant):



(a) At time t=0s, what factors will affect the count-rate measured? (3)
(b) If the count-rate is 1200s^{-1} at t=0s, and is 500s^{-1} after 10s, find the decay constant for the radioactive isotope. (2)
(c) What is the half-life of this isotope? (1)
(d) If the measured count-rate is only 1% of the activity of the sample, find the number of atoms of this radioisotope present after 10s. (2)

Exam-style question 4 solutions:

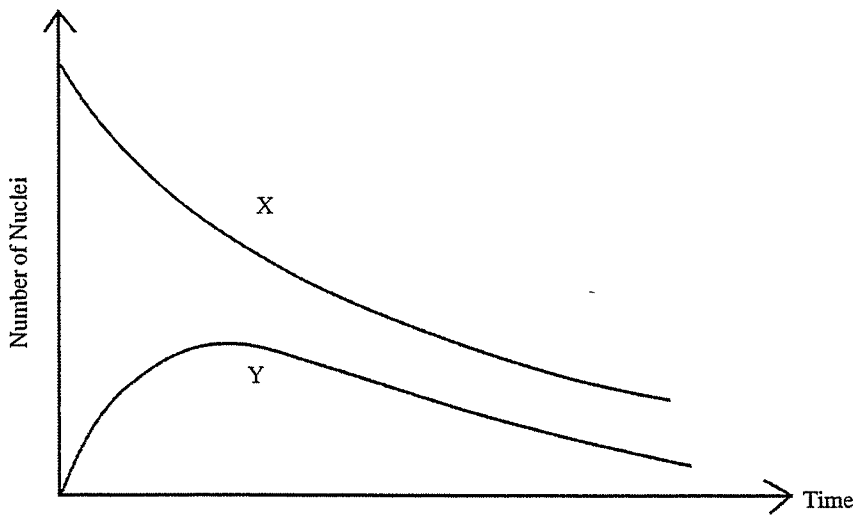
(a) the decay constant (or half-life) of the radioactive isotope
the number of atoms **of this radioisotope** present
the distance **d**
the type or size of the detector
the type of decay product (α, β, or γ)
-any 3 of these points, or sensible alternatives
(b) count rate ∝ activity
$A = A_0 e^{-\lambda t}$, $500 / 1200 = e^{-10\lambda}$, $\lambda = 0.088\ s^{-1}$. (2)
(c) $T_{½} = 0.693 / \lambda = 7.9$ s (1)
(d) $A = 500 \times 100 = 5.0 \times 10^4$ (1)
$A = \lambda N$, $N = A / \lambda = 50\,000 / 0.088 = 5.7 \times 10^5$ atoms. (1)

Practice Questions

1. What is the SI base unit for the rate of radioactive decay?
2. At a certain stage in a radioactive decay practical, the count rate was found to be 84Bq. If the average background measured was 254 counts in 2 minutes, find the corrected count rate (to the nearest whole number).
3. The following count rates were measured over successive 10s intervals in a beta decay practical. The source-detector distance was fixed, and the source half-life was 26 years.
   162, 188, 163, 152, 183, 171, 159, 173

   (a) Find the average count rate in Bq.
   (b) Find the maximum percentage error in these results.
   (c) What factors were responsible for the variation in readings.
4. Explain in words why the decay constant, λ, is inversely proportional to the half-life, $T_{½}$.
5. (a) The half-life of a source is 22 years. Find the decay constant, λ.
   (b) The decay constant for a radioisotope is $1.4 \times 10^{-4}\ s^{-1}$. Find the half life, $T_{½}$.
6. Complete the following decay equation:

   $${}^{y}_{x}A \longrightarrow {}^{y-8}_{x-3}B + \ ? \ + \ ? \ + \gamma$$
7. Here is a sketch graph of simultaneous decay from radioisotopes X and Y:



Explain what is happening.

Answers

1. $Bq = s^{-1}$
2. $254 / (2 \times 60) = 2.1$, $84 - 2 = 82Bq$
3. (a) 169 in 10s = 16.9Bq
   (b) (188-169) / 169 = 0.112 = 11.2%.
   (c) randomness of decay from source and **randomness** of background (not just "background").
4. The decay constant is the probability of decay for each unstable nucleus in the next second. The higher the probability of decay, the shorter time for half of the nuclei to decay.
5. (a) $\lambda = 0.693 / T_{½} = 0.693 / (22 \times 365 \times 24 \times 3600) = 9.99 \times 10^{-10} s^{-1}$.
   (b) $T_{½} = 0.693 / \lambda = 0.693 / 1.4 \times 10^{-4} = 4950s = 1.38$ hours.
6. Insert diagram 6.

   $${}^{y}_{x}A \longrightarrow {}^{y-8}_{x-3}B + 2\,{}^{4}_{2}\alpha + {}^{0}_{-1}\beta + \gamma$$

Acknowledgements:
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