

Answers to examination-style questions

Answers	Marks	Examiner's tips
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- 1 (a) • The (magnitude of the) charge on the nuclei was $Z e$ but the mass was an integer greater than $Z \times m_p$
- Rutherford thought that a nucleus with atomic number Z and mass number A would have Z protons and $A - Z$ neutrons.
- He used the neutron-proton model to explain why the mass number of any nucleus heavier than the ${}^1_1\text{H}$ is greater than its atomic number.
- Rutherford had devised and proved the nuclear model of the atom.

any 2

- (b) If $R = kE^n$, a graph of $\ln R$ on the y -axis against $\ln E$ on the x -axis should give a straight line...
with a gradient equal to n .

1

1

See table:

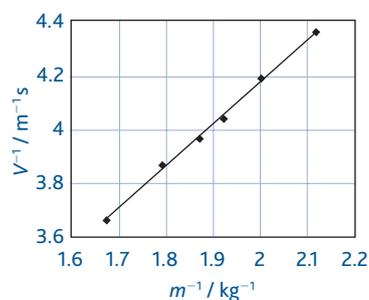
2

R/mm	39	48	53	57	66	78
E/MeV	5.3	6.0	6.5	6.8	7.4	8.3
$\ln R$	3.66	3.87	3.97	4.04	4.19	4.36
$\ln E$	1.67	1.79	1.87	1.92	2.00	2.12

Correct values to 2 or more sig figs for:

- $\ln R$
- $\ln E$

6



Marks awarded for:

- correctly labelled scales
- suitable scales
- all points plotted correctly
- best fit line
- correct calculation of gradient

$$\text{Gradient} = \frac{4.36 - 3.66}{2.12 - 1.67} = 1.55$$

i.e. $n = 1.55$

- n in the range = 1.5 to 1.6

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<p>2 (a) <i>Relevant points include the following.</i></p> <p>(i) The metal should be thin so that:</p> <ul style="list-style-type: none"> • the α particles can penetrate the foil (or will not be absorbed by it). • the α particles must only be scattered once. <p>(ii) The beam of alpha particles should be narrow:</p> <ul style="list-style-type: none"> • to define a precise location where the scattering takes place • so that the scattering angle can be determined accurately. <p>(b) Some α particles are scattered through very large angles ($> 90^\circ$, or back towards the source). This can only occur if an α particle collides with a particle of much greater mass than its own mass.</p> <p>(c) Top α particle: path showing upwards deflection by at least 10°.</p> <p>Middle α particle: path showing very close approach to nucleus and return along the same path.</p> <p>Bottom α particle: path is a smooth curve showing a downwards deflection that is greater than the deflection of the top α particle.</p>	<p>any 3</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Questions about Rutherford scattering are usually directed at the conclusions of the experiment, but in this part you are asked whether you understand some of the reasons behind the experimental design. It is particularly important to appreciate that the experiment assumes that an α particle will have <i>just one encounter</i> with a nucleus as it passes through the foil.</p> <p>It is well known that the majority of the α particles experience no deflection (or 'go straight through'). This would be expected even if the atom had a more uniform distribution of mass, as in Thomson's model. The definite evidence for a massive nucleus comes from the large angle deflections and back scattering.</p> <p>The question indicates that all three particles are deflected by at least 10°. Repulsion between the positive nucleus and the positive α particle causes an upwards deflection. Remember that the force becomes greater as the separation decreases, so this is a <i>smooth curve</i>.</p> <p>This α particle makes a 'head on' approach and is scattered through 180°. It must be shown to approach the nucleus more closely than either of the other α particles.</p> <p>The bottom α particle approaches the nucleus more closely than the top one, and therefore experiences a larger deflection. Its path will curve more sharply.</p> <p>An α particle is a helium nucleus ${}^4_2\text{H}$; emission removes 2 protons and 2 neutrons from a nucleus. Emission of a γ ray photon removes only energy; no change takes place in either Z or A.</p>
<p>3 (a) Proton number Z is reduced by 2. Nucleon number A is reduced by 4.</p>	<p>1</p> <p>1</p>	<p>An α particle is a helium nucleus ${}^4_2\text{H}$; emission removes 2 protons and 2 neutrons from a nucleus. Emission of a γ ray photon removes only energy; no change takes place in either Z or A.</p>

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(b) γ radiation is much more penetrating than α radiation.	1	Comparison is essential in your answer, because the question asks about the <i>relative</i> penetrating powers. Typically, α radiation is absorbed completely by paper but γ radiation requires thick lead to reduce its intensity.
(c) By the inverse square law $\frac{I_3}{I_1} = \frac{1.0^2}{3.0^2}$ $= \frac{1}{9}$ (or 0.11)	1 1	The working follows from the mathematical representation of the inverse square law for γ radiation: intensity $I = \frac{k}{x^2}$ where k is a constant and x is the distance from the source.
4 (a) (i) Origins of background radiation: cosmic rays; radioactive rocks (or ground, or building materials); nuclear weapons testing (or nuclear accidents); nuclear power industry; discharge of nuclear waste; radioactive gases in the air; medical waste.	2	You should be aware of some (if not all) of the possible sources of background radiation on such an extensive list. Any three you list would score 2 marks, but if you list just two you would only receive 1 mark.
(ii) Use of $A = A_0 e^{-\lambda t}$ gives $(84 - 3) = (110 - 3) e^{-\lambda \times 600}$ $\therefore e^{\lambda \times 600} = \frac{107}{81}$, and $\lambda = \frac{\ln\left(\frac{107}{81}\right)}{600}$ \therefore decay constant $\lambda = 4.64 \times 10^{-4} \text{ s}^{-1}$	1 1 1	The count rate is proportional to the activity A (which is $\frac{\Delta N}{\Delta t}$). Both measured count rates have to be corrected for background in this case. Solution of the exponential decay equation involves the use of logs, as in capacitor discharge theory (<i>A2 Physics A Unit 4</i>).
(iii) Use of $\frac{\Delta N}{\Delta t} = \lambda N$ gives initial number of nuclei $N = \frac{107}{4.64 \times 10^{-4}}$ $= 2.31 \times 10^5$	1 1	The question tells you to assume that all of the radiation emitted by the source is detected. (In practice this is very unlikely!) This means that initially there would be 107 emissions per second.
(b) α radiation is highly ionising, hence causes cancer/damages cells/kills cells/affects DNA. Outside the body it is less damaging, because it is absorbed by the skin (or is stopped by the skin, or causes a burning sensation). Inside the body it is more damaging, because it is able to produce ionisation in vital organs such as lungs.	1 1 1	Part (b) has one general mark for referring to the overall danger presented by α radiation, and two specific marks for discussing and explaining its effects when the source is outside and inside the body. Radioactive α -emitting gases pose a particular hazard if they are inhaled. By comparison, laboratory α -emitting sealed sources are practically harmless.

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<p>5 (a) The random nature of decay means:</p> <ul style="list-style-type: none"> • it is not possible to predict <i>which one</i> of the large number of unstable nuclei in a radioactive sample will decay • or to predict <i>when</i> it will decay. 	2	There are usually millions (at least) of radioactive nuclei in a given sample. The behaviour of the individual nuclei cannot be predicted, but the behaviour of the complete sample is predictable. It obeys an exponential decay law.
<p>(b) Graph drawn of activity/Bq against time/year to show:</p> <ul style="list-style-type: none"> • a curve of decreasing negative gradient starting at 5.5×10^5 Bq • correctly decaying activity values corresponding with value of half life (2.75×10^5 Bq at 2.6 years, 1.38×10^5 Bq at 5.2 years). 	2	Make sure that the axes of your graph are properly labelled. Both axes should start at the origin. To satisfy the question, the time axis must go up to 6 years. Exponential decay graphs are smooth curves which intersect the vertical axis at $t = 0$, but which never meet the time axis.
<p>(c) (i) $T_{1/2} = \frac{\ln 2}{\lambda}$ gives $\lambda = \frac{\ln 2}{2.6 \times 3.15 \times 10^7}$ decay constant $\lambda = 8.46 \times 10^{-9} \text{ s}^{-1}$</p>	1 1	Data tables about radioactive nuclides usually provide values of half lives. The decay constant is readily calculated from the half life.
<p>(ii) Use of $\frac{\Delta N}{\Delta t} = \lambda N$ gives initial number of nuclei $N = \frac{5.5 \times 10^5}{8.46 \times 10^{-9}} = 6.50 \times 10^{13}$</p>	1 1	The decay law, which is based on statistics, indicates that the probability of decay per unit time is constant for a given nuclide. This constant is the decay constant λ . It follows that the decay rate (or activity) is proportional to the number of active nuclei present.
<p>(iii) Use of $A = A_0 e^{-\lambda t}$ gives $0.75 \times 10^5 = 1.0 \times 10^5 e^{-\lambda t}$ $\therefore \text{time } t = \frac{\ln\left(\frac{1.0}{0.75}\right)}{\lambda} = \frac{\ln 1.33}{8.46 \times 10^{-9}} = 3.40 \times 10^7 \text{ s}$</p>	1 1	The time taken for the activity to halve is 2.6 years, so it is not surprising that the time taken for the activity to fall by 25% is just over 1 year. ($3.40 \times 10^7 \text{ s} = 1.08 \text{ year}$).
<p>6 (a) γ rays are very penetrating (or α or β rays would not be detected outside the body). γ rays are less ionising, hence less hazardous to patients (or α or β rays are more ionising and more hazardous).</p>	1 1	In this type of diagnosis the radioactive material is introduced <i>inside</i> the body but has to be detected <i>outside</i> the body. The radiation has to penetrate through thick human tissue, but should not subject the patient to profuse ionisation.
<p>(b) The background count rate is very much smaller than the measured count rate (background count rates are typically less than 1 counts s^{-1}). Random fluctuations in the measurements are greater than the background ground count rate.</p>	1 1	This part would be easily overlooked if you wanted to get on with the graph! Notice that 2 marks are available, so two aspects are required in your answer. Maybe the second point is only clear once you have plotted the graph.

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<p>(c) Graph drawn of count rate/counts s^{-1} against time/hour to show:</p> <ul style="list-style-type: none"> • correct plotting of points on labelled axes, with count rate on vertical axis • a smooth curve of decreasing negative gradient that intersects the count rate axis but does not meet the time axis. 	2	The results shown in the table are from an actual experiment, so the points themselves do not lie on a perfectly smooth curve. However, the line you draw should be a smooth curve to represent average behaviour. <i>Your line must not simply join the points.</i>
<p>(d) One half life value calculated from best-fit line.</p> <p>Two or more half life values calculated and averaged.</p> <p>Half-life = 13 ± 1 hour</p>	1 1 1	One value is insufficient. For full marks you must take at least two values and average them. A more accurate analysis (not required here) would use a graph of $\ln(\text{count rate})$ against t : the gradient of this linear graph is $-\lambda$, and $T_{1/2} = \ln \frac{2}{\lambda}$.
<p>(e) Relevant points include the following points.</p> <ul style="list-style-type: none"> • The activity is high (so only a small sample is needed). • The radioisotope decays quickly. • There is less risk to the patient. • The medical test is of short duration. 	any 2	Because $T_{1/2} \propto \frac{1}{\lambda}$, it follows that a radioisotope of short half-life will have a large value of λ , and therefore a high activity when it is introduced into the patient. The sample used is small and it soon decays to a negligible activity.
<p>7 (a) (i) Positron (or positive electron, or beta plus) (Electron) neutrino</p>	1 1	The hint that two answers are needed is that the question asks for <i>particles</i> and offers 2 marks. Because you are required to state <i>names</i> , it is safer to write beta plus than β^+ . Note that the neon-21 is the daughter nucleus; it is not <i>emitted</i> .
<p>(ii) 11 neutrons</p>	1	Number of neutrons in nucleus $= A - Z = 21 - 10$.
<p>(b) (i) After one half life from $t = 0$ number of active nuclei $N = 2.5 \times 10^{11}$... and activity = 0.75×10^{10} Bq Activity $A = \frac{\Delta N}{\Delta t} = -\lambda N$ gives Decay constant $\lambda = \frac{0.75 \times 10^{10}}{2.5 \times 10^{11}}$ $= 3.0 \times 10^{-2} \text{ s}^{-1}$</p>	1 1 1	After one half life the number of active nuclei remaining is $\frac{1}{2}$ of 5×10^{11} and the activity is $\frac{1}{2}$ of 1.5×10^{10} Bq.
<p>(ii) Number of particles decaying per second = $\frac{2.6 \times 10^{-3}}{5.7 \times 10^{-13}} = 4.56 \times 10^9$ $\frac{\Delta N}{\Delta t} = -\lambda N$ gives $N = \frac{4.56 \times 10^9}{3.0 \times 10^{-2}}$ \therefore number of radioactive atoms in sample $N = 1.52 \times 10^{11}$</p>	1 1 1	The answer given here follows the directions given in the question, but you may notice that $T_{1/2}$ is about 23 s, from which $\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{23} = 3.0 \times 10^{-2} \text{ s}^{-1}$.
		The decay of one nucleus produces 5.7×10^{-13} J, but the source in this example is producing 2.6 m J per second. The number of decays per second is $\left(\frac{\text{energy emitted per second}}{\text{energy emitted per decay}} \right)$.

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<p>8 (a) Radius of U-238 nucleus $R = r_0 A^{1/2}$ $= 1.3 \times 10^{-15} \times 238^{1/2}$ $= 8.06 \times 10^{-15} \text{ m}$</p>	1 1	<p>You simply have to recognise that $A = 238$ for this nucleus, and then substitute into $R = r_0 A^{1/2}$</p>
<p>(b) Inverse square law gives $\frac{I_1}{I_2} = \frac{x_2^2}{x_1^2}$ $\therefore \frac{I_1}{I_2} = \frac{C}{0.10 C} = \frac{10}{1} = \left(\frac{x_2}{0.030}\right)^2$ from which $x_2 = 9.49 \times 10^{-2} \text{ m}$</p>	1 1	<p>γ radiation spreads out equally in all directions from a point source. This leads to an inverse square relationship between the intensity of radiation and the distance from the source. Doubling the distance reduces the intensity to $\frac{1}{4}$, etc.</p>
<p>(c) Use of $A = A_0 e^{-\lambda t}$ gives $0.85 = 1.0 e^{-\lambda \times 52}$ from which $e^{\lambda \times 52} = \frac{1.0}{0.85}$, and $\lambda = \frac{\ln(1.0/0.85)}{52}$ \therefore decay constant $\lambda = 3.13 \times 10^{-3} \text{ s}^{-1}$</p>	1 1 1	<p>The count rate falls to 85% of its initial value in 52s, so the initial intensity I_0 can be regarded as 1.0 and the intensity after 52s as 0.85. As usual, you have to be familiar with the use of logs to solve an exponential equation.</p>
<p>(d) <i>Relevant points include the following points.</i></p> <ul style="list-style-type: none"> • Technetium 99-m emits only γ radiation ... • hence radiation may be detected outside the body (or it is a weak ioniser and causes little damage). • It has a short half life and will not remain active in the body for long after use. • Its half life is long enough for it to remain active during diagnosis. • When needed it may be prepared on site. • It has a toxicity that can be tolerated by the body. 	any 3	<p>When using a radioisotope for medical diagnosis, the half-life of the chosen source should be comparable to the time required to carry out the investigation. This minimises the radiation dose received by the patient. The half life of $^{99}\text{Tc}_m$ is 6 hours. The fact that it is a pure γ-emitter with a relevant half-life makes it an ideal source for this purpose. Yet its relatively short half-life means that it has to be prepared at the place where it will be used.</p>
<p>9 (a) <i>Graph drawn of electron intensity against angle of diffraction θ to show:</i></p> <ul style="list-style-type: none"> • electron intensity decreases as θ increases • a non-zero first minimum, with a subsequent increase and then a further decrease in electron intensity. 	2	<p>The general shape of this electron diffraction curve should be well known and part (a) should therefore lead to two easy marks. Note that the first minimum is not a zero of intensity (unlike its optical equivalent for diffraction at a single slit).</p>

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<p>(b) (i) Last column of table completed with correct values: <i>either</i> $A^{1/2}$: 5.93, 4.93, 3.83, 3.04, 2.29 <i>or</i> $R^3/10^{-45}\text{m}^3$: 295, 165, 82.3, 40.4, 18.8 Graph axes both labelled with quantity and unit (e.g. $A^{1/2}$, $R/10^{-15}\text{m}$ <i>or</i> A, $R^3/10^{-45}\text{m}^3$), and choice of large scales which cause the graph to occupy more than half of the area of the graph paper. All points plotted correctly and suitable linear best-fit line drawn.</p>	<p>1</p> <p>1</p> <p>1</p>	<p>The relationship $R \propto A^{1/2}$ was arrived at originally by plotting a graph of $\log R$ against $\log A$ using experimental data. Its gradient should be $\frac{1}{2}$. To confirm that $R = r_0 A^{1/2}$ (where r_0 is constant), you either need to show that $R \propto A^{1/2}$ or that $R^3 \propto A$. The former graph is preferable, because it gives a more even distribution of points. However, to show direct proportion by either method the graph obtained needs to be a straight line <i>that passes through the origin</i>. Your scaling of the graph must allow for axis values that start at (0,0).</p>
<p>(ii) Gradient of straight line = r_0 (on graph of R against $A^{1/2}$) or = r_0^3 (on graph of R^3 against A) gives $r_0 = (1.1 \pm 0.1) \times 10^{-15}\text{m}$</p>	<p>1</p> <p>1</p>	<p>Since $R = r_0 A^{1/2}$, a graph of R against $A^{1/2}$ should have a gradient of r_0. The graph to test $R^3 = r_0^3 A$ should have a gradient of r_0^3.</p>
<p>(c) <i>Relevant points include the following points.</i></p> <ul style="list-style-type: none"> • Electrons are not subject to the strong nuclear force. • With α particles the closest distance of approach is measured, rather than R. • Electrons cause far less recoil. • Electrons give greater resolution. • High energy electrons are easier to produce. 	<p>any 3</p>	<p>The fact that electrons do not experience the strong force (unlike α particles) means that electron scattering experiments are easier to interpret than α particle scattering experiments.</p>

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).