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ANSWER BOOK

Rutherford scattering and the nuclear atom

Nuclear physics · Year 13

AQA 3.8.1.1, 3.8.1.2 · CIE 11.1.1, 11.1.7 · OCR A 6.4.1(a), 6.4.1(c), 6.4.3(b)(i), 6.4.3(b)(ii)

18 questions · 54 marks

NAVY EDITION

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SECTION A · Warm-up

A1 Most alpha particles passed through the thin gold foil with little or no deflection (1); a small fraction were deflected through large angles, with a very few deflected back through more than 90° (1). [2]

A2 The atom is mostly empty space, since most particles pass straight through (1); the positive charge and nearly all the mass are concentrated in a very small central nucleus, which repels the few particles that pass close to it (1). [2]

A3 Ionising radiation that is always present, from sources other than the source under investigation (1). Any two origins: radon gas from the ground, rocks and building materials, cosmic rays, radioactive traces in food, medical procedures (1). [2]

A4 An alpha particle is a helium nucleus: two protons and two neutrons (1). Gamma radiation is a high-frequency electromagnetic wave (a photon) (1). [2]

A5 Alpha: a sheet of paper (or a few cm of air) (1). Beta: a few mm of aluminium (1). Gamma: several cm of lead reduces the intensity (1). [3]

SECTION B · Standard

B1 Stopped by paper: alpha (1). Stopped by aluminium but not paper: beta (1). Only reduced by lead: gamma (1). [3]

B2 $I \propto 1/r^2$, so $I = 800 \times (1.0/2.0)^2$ (1) [2]
$I = 200$ units (1)

B3 $I = 1600 \times (0.50/2.0)^2 = 1600 \times 1/16$ (1) [2]
$I = 100$ counts per second (1)

B4 The atom is mostly empty space (1); the nucleus occupies only a tiny fraction of the atom's volume (1); most alpha particles pass far from any nucleus, experience very little electrostatic repulsion, and so are barely deflected (1). [3]

B5 With the positive charge spread through the whole atom, the electric field acting on an alpha particle would everywhere be weak (1); each alpha particle would therefore be deflected only through a very small angle (1); deflection through more than 90° needs a very strong repulsive force, which requires the positive charge (and most of the mass) to be concentrated in a very small volume, not spread out (1). [3]

B6 The count rate must fall by a factor of 3600/400 = 9 (1) [3]
$I \propto 1/x^2$, so the distance must increase by a factor of $\sqrt{9}$ = 3 (1)
x = 3 × 150 mm = 0.45 m (1)

B7 Alpha particles are absorbed by a few centimetres of air (or by the detector casing, or by the dead outer layer of skin), so from outside the body the radiation cannot reach living tissue (1). If the material were swallowed, alpha particles would be emitted directly into living tissue (1); alpha is the most strongly ionising radiation, so all of its energy would be absorbed in a very small volume of tissue, causing serious damage (1). [3]

SECTION C · Stretch

C1 Corrected count rate at 0.10 m = 520 - 20 = 500 counts per second (1) [4]
At 0.20 m: 500 × $(0.10/0.20)^2$ (1)
= 125 counts per second (1)
Measured rate = 125 + 20 = 145 counts per second (1)

C2 A large deflection occurs when an alpha particle passes very close to a nucleus (1); the concentrated positive charge exerts a strong electrostatic repulsion on the (positive) alpha particle (1); particles heading almost directly at a nucleus approach closest and are deflected most, some through more than 90° (1). [3]

C3 Alpha: most strongly ionising, least penetrating, stopped by paper (1). Beta: moderate ionising and penetrating power, stopped by a few mm of aluminium (1). Gamma: least ionising, most penetrating, only reduced by thick lead (1). [3]

C4 Alpha (W) is absorbed completely by even very thin foil, so the count rate would be near zero whatever the thickness (1). Gamma (Z) passes through thin foil almost unaffected, so the count rate would barely respond to a change in thickness (1). A beta source is suitable because its absorption changes measurably over thicknesses of about 0.1 mm (1). X is chosen rather than Y: its long half-life means the activity is effectively constant, so a change in count rate indicates a change in thickness rather than decay of the source (1). [4]

C5 Doubling the distance reduces the corrected (source-only) count rate to one quarter (1) [4]
So 340 - B = 4 × (100 - B) (1)
340 - B = 400 - 4B, so 3B = 60 and B = 20 counts per second (1)
Check: the corrected rates are 320 and 80 counts per second, a factor of 4 apart as the law requires (1)

C6 With the source locked away, measure the background count rate over a long period (1). Place the source a measured distance x from a Geiger-Müller tube, using a metre rule, and record the count rate; repeat for a range of distances, counting for long enough (or repeating) to reduce the random uncertainty of the counts (1). Subtract the background count rate from every reading to give the corrected count rate C (1). The rule measures from the outside of the casings, but the source sits inside its holder and the tube's sensitive volume lies behind its window, so the true separation is $x + x_0$ for some unknown constant offset x_0 (1). With $C = k/(x + x_0)^2$, $1/\sqrt{C} = (x + x_0)/\sqrt{k}$, so plot $1/\sqrt{C}$ against x: a straight line confirms the inverse-square law, it need not pass through the origin, and its intercept divided by its gradient gives the offset x_0 (1). Precautions: handle the source with long tongs, stand well back, keep the exposure time short, and return the source to its lead-lined store immediately after use (1). [6]