InkPhysics

ANSWER BOOK

Nuclear radius and density

Nuclear physics · Year 13

AQA 3.8.1.5 · OCR A 6.4.1(c), 6.4.1(f), 6.4.1(g)

18 questions · 49 marks

NAVY EDITION

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SECTION A · Warm-up

A1 $R = R_0A^{1/3}$, where A is the nucleon number (1); $R_0 \approx 1.2 \times 10^{-15}$ m (1.2 fm) (1). [2]

A2 $R = R_0A^{1/3} = 1.2 \times 10^{-15} \times 64^{1/3} = 1.2 \times 10^{-15} \times 4$ (1)
$R = 4.8 \times 10^{-15}$ m (1) [2]

A3 Volume $\propto R^3 \propto A$, and mass $\propto A$ (1); so the density (mass/volume) is approximately the same for all nuclei (1). [2]

A4 Atomic radius: about 1×10^{-10} m (1). Nuclear radius: a few femtometres, of order 10^{-15} m to 10^{-14} m (1). [2]

A5 Plot R against $A^{1/3}$ (1); the gradient of the line is the constant R_0, about 1.2 fm (1). [2]

SECTION B · Standard

B1 $R = R_0A^{1/3} = 1.2 \times 10^{-15} \times 27^{1/3} = 1.2 \times 10^{-15} \times 3$ (1)
$R = 3.6 \times 10^{-15}$ m (1) [2]

B2 $\rho = u/((4/3)\pi R_0^3)$ (1)
$= (1.66 \times 10^{-27})/((4/3)\pi \times (1.2 \times 10^{-15})^3)$ (1)
$\rho = 2.29 \times 10^{17}$ kg m^{-3} (1) [3]

B3 $R_{125}/R_8 = (125/8)^{1/3}$ (1)
ratio = 2.5 (1) [2]

B4 Constant density means each nucleon occupies about the same volume in every nucleus (1); this is what is expected if nucleons are in contact, packed like touching spheres (1); if nucleons were spread out, larger nuclei could have lower densities, which is not observed (1). [3]

B5 $A = (R/R_0)^3 = (6.0/1.2)^3$ (1)
A = 125 (1) [2]

B6 fraction = $(R_{nucleus}/R_{atom})^3 = (7.0 \times 10^{-15}/(1.35 \times 10^{-10}))^3$ (1)
fraction = 1.4×10^{-13} (1)
The nucleus occupies a vanishingly small fraction of the atom's volume: the atom is almost entirely empty space, as Rutherford scattering showed (1) [3]

B7 At high energies the de Broglie wavelength of an electron is comparable to the diameter of a nucleus, so the nucleus produces a measurable diffraction pattern (1). Electrons are leptons, so they do not experience the strong nuclear force and probe the charge distribution alone (1). [2]

SECTION C · Stretch

C1 At closest approach all the kinetic energy has become electrostatic potential energy: $E_k = k(2e)(79e)/r$ (1) [4]
$E_k = 5.0 \times 10^6 \times 1.60 \times 10^{-19} = 8.0 \times 10^{-13}$ J (1)
$r = k \times 2 \times 79 \times e^2/E_k$ (1)
$r = 4.55 \times 10^{-14}$ m (1)

C2 $R = 1.2 \times 10^{-15} \times 12^{1/3} = 2.75 \times 10^{-15}$ m (1) [4]
mass $= 12 \times 1.66 \times 10^{-27} = 1.99 \times 10^{-26}$ kg (1)
$\rho = m/((4/3)\pi R^3) = 2.29 \times 10^{17}$ kg m^{-3} (1)
This is the same as the density of nuclear matter in general, as expected for constant nuclear density (1).

C3 High-energy electrons, with a de Broglie wavelength comparable to the nuclear diameter, are fired at a thin sample (1). The electrons diffract around the nuclei, giving an intensity pattern with minima (1). The angle of the first minimum depends on the nuclear diameter, so measuring it allows the radius to be calculated (1). [3]

C4 At closest approach all the kinetic energy has become electrostatic potential energy: $E_k = k(2e)(79e)/r$ (1) [4]
$E_k = 8.99 \times 10^9 \times 2 \times 79 \times (1.60 \times 10^{-19})^2/(4.0 \times 10^{-14})$ (1)
$E_k = 9.1 \times 10^{-13}$ J (1)
$E_k = 9.1 \times 10^{-13}/(1.60 \times 10^{-13}) = 5.7$ MeV (1)

C5 The alpha particle stops where all its kinetic energy has become electrostatic potential energy, which is before it reaches the nuclear surface (1); closest approach therefore gives only an upper limit, and the value depends on the alpha energy used rather than on the nucleus alone (1). Electron diffraction measures the nucleus itself: the angle of the first minimum of the diffraction pattern is set by the nuclear diameter (1). The electron diffraction value of 7.2×10^{-15} m is therefore the better estimate (1). [4]

C6 $V = m/\rho = (4.0 \times 10^{30})/(2.3 \times 10^{17}) = 1.7 \times 10^{13}$ m^3 (1) [3]
$V = (4/3)\pi R^3$, so $R = (3V/4\pi)^{1/3}$ (1)
$R = 1.6 \times 10^4$ m (about 16 km) (1)