

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Most alpha particles passed straight through: the atom is mostly empty space; a few deflected through large angles or bounced back: almost all positive charge and mass concentrate in a tiny dense nucleus.

2.2 A = nucleon number (protons + neutrons); Z = proton number, and X the chemical symbol of the element.

2.3 Electrons occupy discrete energy levels, so only specific energy gaps exist; each line is a photon of one exact frequency, $f = \Delta E/h$ – a continuum would need a continuous range of allowed energies.

2.4 Starlight passed through a spectrometer shows absorption lines that match an element's known pattern – the element's presence in the star's atmosphere.

2.5 $r_{min} = 2kZe^2/KE = (2 \times 9.0 \times 10^9 \times 79 \times (1.6 \times 10^{-19})^2)/(6.4 \times 10^{-13}) = 3.6 \times 10^{-26}/6.4 \times 10^{-13} = 5.7 \times 10^{-14}$ m.

3.1 $\Delta E = 1.9$ eV = 3.0×10^{-19} J; $f = E/h = (3.0 \times 10^{-19})/(6.6 \times 10^{-34}) = 4.6 \times 10^{14}$ Hz; ionization from -1.5 eV needs the electron lifted to zero: 1.5 eV.

3.2 Straight through: the atom's mass and positive charge are not spread out – the space between nuclei is empty; bounce back: a head-on encounter with a concentrated positive charge whose electrostatic repulsion reverses the alpha – so nearly all the mass sits in that tiny nucleus.

3.3 Absorption lines arise when atoms absorb exactly the photon energies of their upward transitions – the same gaps that produce emission lines; matching the star's dark-line pattern against element X's laboratory fingerprint identifies X's presence, because no other element shares the same set of level spacings.

3.4 Proton number $Z = 92$; nucleon number $A = 235$; neutrons = $A - Z = 143$.

3.5 $E_3 = -13.6/9 = -1.5$ eV; $\Delta E = E_3 - E_2 = -1.5 - (-3.4) = 1.9$ eV; $\lambda = hc/\Delta E = (1.99 \times 10^{-25})/(3.0 \times 10^{-19}) = 6.6 \times 10^{-7}$ m – the red H-alpha line; the levels follow from quantized angular momentum $mvr = nh/2\pi$.