20.2 Structure of the atom (full E.1, HL)

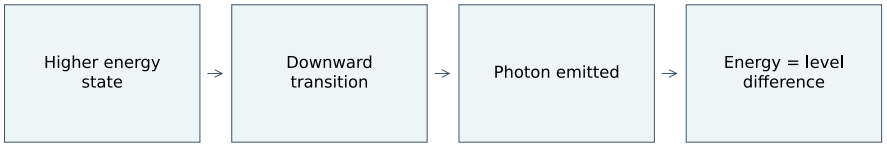
Name: _____ Class: _____ Date: _____ **Total: 30 marks**

KEY WORDS nucleon number • proton number • emission spectrum • Bohr model • distance of closest approach

Objective

Practise the full guide E.1 toolkit including AHL: the Geiger–Marsden–Rutherford experiment and the discovery of the nucleus, nuclear notation ${}^{A}_{Z}X$, emission and absorption spectra as evidence for discrete energy levels, photon emission and absorption in transitions with $E = hf$, and spectra as fingerprints of chemical composition; at higher level also $R = R_0 A^{1/3}$ with nuclear density, the distance of closest approach, and the Bohr levels $E_n = -13.6/n^2$ eV with $mvr = nh/2\pi$. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The E.1 rule set (HL)**

$$E = hf \qquad {}^{A}_{Z}X \qquad R = R_0 A^{1/3} \qquad E_n = -\frac{13.6}{n^2}\ \text{eV} \qquad mvr = \frac{nh}{2\pi}$$

Alpha scattering: most particles pass through (empty atom), few deflect far (tiny dense positive nucleus). Spectral lines correspond one-to-one with transitions between discrete levels; the set of lines identifies the element.

■ **Worked example: reading a line**

Levels at -1.5 eV and -3.4 eV: a downward jump emits $E = 1.9\ \text{eV} = 3.0\times10^{-19}$ J, so $f = E/h = (3.0\times10^{-19})/(6.6\times10^{-34}) = 4.6\times10^{14}$ Hz. The atom absorbs exactly this frequency climbing up – emission and absorption lines match. Two habits: convert eV to joules before using $E = hf$, and remember each line is one gap, not one level.

2 Practice

2.1 State what the Geiger–Marsden–Rutherford experiment revealed about the structure of the atom, citing two observations. [3]

2.2 Write the meaning of each symbol in nuclear notation ${}^{A}_{Z}X$. [2]

2.3 Why do emission and absorption spectra consist of sharp lines rather than continuous bands? [2]

2.4 State one use of spectral analysis that identifies chemical composition at astronomical distances. [1]

2.5 A 4.0 MeV alpha particle heads straight at a gold nucleus ($Z = 79$). Calculate its distance of closest approach. [3]

3 Exam-style questions

3.1 An atom has energy levels at -1.5 eV, -3.4 eV and -13.6 eV. Calculate the frequency of the photon emitted in the $-3.4 \to -1.5$ eV transition, and the energy (in eV) of the photon that ionizes the atom from the -1.5 eV level. [4]

3.2 Explain why almost all alpha particles passed straight through the gold foil while about 1 in 8000 bounced back, and what each observation implies. [4]

3.3 A gas of element X shows absorption lines at exactly the same frequencies as its emission lines. Explain how this identifies X in the atmosphere of a distant star. [3]

3.4 The nuclide $^{235}_{92}U$ is used in reactors. State its proton number, nucleon number, and the number of neutrons in its nucleus. [3]

3.5 In the Bohr model of hydrogen, calculate the energy of the $n = 3$ level, the energy and wavelength of the photon emitted in the $3 \to 2$ transition ($hc = 1.99 \times 10^{-25}$ J m), and state the assumption about angular momentum that produces these levels. [5]

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 $= 3.0 \times 10^{-19}$ 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 $mvr = nh/2\pi$.