

Exercise walk-through

20.2

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

International Baccalaureate · IB Diploma · Physics · HL

Atomic Spectra · 3.1

Reasoning

An emitted photon corresponds to a transition to a lower energy level. Absorption requires a compatible energy difference. Rutherford scattering supported a small dense nucleus, but that experiment alone did not establish the complete quantum model. Read a labelled energy-level diagram before calculating. Keep joules and electronvolts distinct and use the given constants. Compare attributed spectra at a common wavelength scale and avoid looking at unsafe light sources.

The gap sets photon energy

- 1 **Set the model** An electron drops from -1.5 eV to -3.4 eV .
- 2 **Calculate** Photon energy $= 1.9\text{ eV} = 3.04 \times 10^{-19}\text{ J}$; frequency $E/h \approx 4.6 \times 10^{14}\text{ Hz}$.

Decision

The photon has positive energy despite negative bound-state levels. Other allowed energy gaps produce other spectral lines.

A hydrogen transition

- 1 Set the model** Use the Bohr model $E_n = -13.6/n^2$ eV. Consider the transition from $n = 2$ to $n = 1$.
- 2 Calculate** Energy released $= 13.6(1 - 1/4) = 10.2$ eV. Wavelength $hc/E \approx 122$ nm.

Decision

This is ultraviolet. The Bohr model predicts hydrogen energies but its literal orbit picture is not a complete quantum description.

Exercises 2.1·2.3

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 ${}^A_ZX$. [2]

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

Exercises 2.1·2.3

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

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 Write the meaning of each symbol in nuclear notation ${}^A_ZX$. [2]

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

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

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.

Exercises 2.4·3.1

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]

3.1 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 $-3.4 \rightarrow -1.5$ eV transition, and the energy (in eV) of the photon that ionizes the atom from the -1.5 eV level. [4]

Exercises 2.4-3.1

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

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

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

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 $-3.4 \rightarrow -1.5 \text{ eV}$ transition, and the energy (in eV) of the photon that ionizes the atom from the -1.5 eV level. [4]

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

Exercises 3.2-3.4

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

Exercises 3.2-3.4

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]

3.2 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 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]

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

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

Exercise 3.5

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 $3 \rightarrow 2$ transition ($hc = 1.99 \times 10^{-25} \text{ J m}$), and state the assumption about angular momentum that produces these levels. [5]

Exercise 3.5

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 $3 \rightarrow 2$ transition ($hc = 1.99 \times 10^{-25} \text{ J m}$), and state the assumption about angular momentum that produces these levels. [5]

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