

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

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_

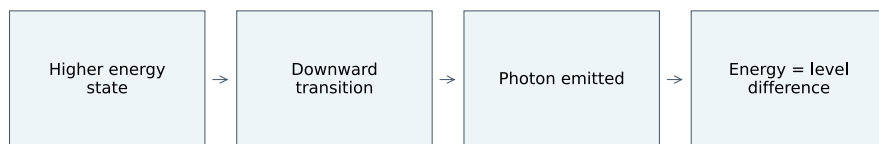
Total: 30 marks

**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  ${}^A_ZX$ , 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  $R = R_0A^{1/3}$  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)

$$E = hf \quad {}^A_ZX \quad R = R_0A^{1/3} \quad E_n = -\frac{13.6}{n^2} \text{ eV} \quad mvr = \frac{nh}{2\pi}$$

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  $E = 1.9$  eV  $= 3.0 \times 10^{-19}$  J, so  $f = E/h = (3.0 \times 10^{-19})/(6.6 \times 10^{-34}) = 4.6 \times 10^{14}$  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]

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

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

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

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

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### 3 Exam-style questions

**3.1** An atom has energy levels at  $-1.5\text{ eV}$ ,  $-3.4\text{ eV}$  and  $-13.6\text{ eV}$ . 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  $-1.5\text{ eV}$  level. [4]

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**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]

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**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]

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**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]

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**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]

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## Solutions

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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  $mvr = nh/2\pi$ .