Unit 3 · Atomic Structure

ANSWER KEY · FOR TEACHERS

Full marks 33

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. Pauli's exclusion principle → **e.** no two electrons in an atom have the same set of four quantum numbers
2. Hund's rule → **j.** degenerate orbitals are filled singly, with parallel spins, before any pair up
3. Aufbau principle → **i.** orbitals are filled in increasing order of their energies
4. uncertainty principle → **b.** the position and the momentum of a particle can't both be known exactly
5. de Broglie's equation → **c.** $\lambda = h/mv$
6. orbital → **d.** the region round the nucleus where an electron is most likely to be found
7. degenerate orbitals → **a.** orbitals of the same energy
8. node → **f.** a surface on which the probability of finding the electron is zero

Each carries 0.5 mark. K · 4

2 Label the diagram

1. lead box
2. alpha particles
3. gold foil
4. microscope

Each carries 0.5 mark. K · 2

3 Multiple choice

i. **b.** 5 K · 1

For d, l = 2, so m = −2, −1, 0, +1, +2: 2l + 1 = **5** orbitals (holding 10 electrons).

ii. **c.** 18 K · 1

A shell holds $2n^2$ electrons: $2 \times 3^2 = \mathbf{18}$. (It has 9 orbitals, n^2, with two electrons in each.)

iii. **b.** n = 2, l = 2, m = 0, s = +½ U · 1

l can only be 0 to n − 1. For n = 2, l is 0 or 1, so l = 2 (a 2d orbital) is impossible.

iv. **b.** Fe^{3+} A · 1

Fe is [Ar] $4s^2\ 3d^6$. A transition metal loses its 4s electrons first, so Fe^{2+} is [Ar] $3d^6$ and Fe^{3+} is [Ar] $\mathbf{3d^5}$. Cr^{3+} is [Ar] $3d^3$ and Cu^{2+} [Ar] $3d^9$.

v. **b.** n = 4 → n = 2 A · 1

Jumps that end on n = 2 make the Balmer series, the visible lines. Jumps to n = 1 (Lyman) are ultraviolet; jumps to n = 3 (Paschen) are infrared.

4 Short answers

a. MARKING SCHEME U · 2

- ✓ 4s and 3d are close in energy.
- ✓ A completely filled d^{10} subshell is extra stable (symmetry, exchange energy), so an electron moves from 4s to 3d.

b. MARKING SCHEME A · 2

- ✓ n = 3 and l = 0 (3s).
- ✓ m = 0 and s = +½ (or −½).

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c. MARKING SCHEME A · 3

- ✓ S: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$, 2 unpaired.
- ✓ S^{2-}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$, 0 unpaired.
- ✓ S^{2-} is diamagnetic.

5 Long answer

ANSWER A · 4

Aufbau principle: electrons fill the atomic orbitals in increasing order of their energies.
(n + l) rule: the orbital with the lower value of n + l has the lower energy; when two have the same n + l, the one with the lower n is lower.
n + l: 5p = 6, 6s = 6, 4f = 7, 5d = 7. So **5p < 6s < 4f < 5d**.
Mn: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^5$, or [Ar] $4s^2\ 3d^5$. The five 3d electrons are one in each 3d orbital (Hund's rule): **5 unpaired electrons**.

MARKING SCHEME

- ✓ The Aufbau principle stated.
- ✓ The (n + l) rule, with the lower n first for equal n + l.
- ✓ 5p < 6s < 4f < 5d.
- ✓ Mn [Ar] $4s^2\ 3d^5$, 5 unpaired.

6 Numerical problems

a. ANSWER A · 4

i. The jump ends on n = 2: the **Balmer series**.

ii. $\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = 1.097 \times 10^7 \times \frac{3}{16} = 2.057 \times 10^6\ \text{m}^{-1}$, so $\lambda = 4.86 \times 10^{-7}\ \text{m} = \mathbf{486\ nm}$.

iii. $\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8}{4.86 \times 10^{-7}} = \mathbf{6.17 \times 10^{14}\ Hz}$.

iv. $E = h\nu = 6.626 \times 10^{-34} \times 6.17 \times 10^{14} = \mathbf{4.09 \times 10^{-19}\ J}$.

MARKING SCHEME

- ✓ Balmer series.
- ✓ λ = 486 nm from Rydberg's formula.
- ✓ $\nu = 6.17 \times 10^{14}$ Hz.
- ✓ E = 4.09×10^{-19} J.

b. ANSWER A · 4

i. $\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.5 \times 10^6} = 4.85 \times 10^{-10}\ \text{m} = \mathbf{0.485\ nm}$, about the size of an atom.

ii. $\Delta x \cdot m\Delta v \geq \frac{h}{4\pi}$, so $\Delta x \geq \frac{6.626 \times 10^{-34}}{4\pi \times 9.11 \times 10^{-31} \times 1.0 \times 10^4} = \mathbf{5.8 \times 10^{-9}\ m}$ (5.8 nm).

MARKING SCHEME

- ✓ λ = h/mv set up.
- ✓ $\lambda = 4.85 \times 10^{-10}$ m.
- ✓ $\Delta x \cdot \Delta p \geq h/4\pi$ with $\Delta p = m\Delta v$.
- ✓ $\Delta x = 5.8 \times 10^{-9}$ m.

7 Think

ANSWER HA · 3

An electron has no definite path. By the **uncertainty principle**, its position and momentum can't both be known exactly, so it can't move in a fixed orbit at a fixed distance.
Quantum mechanics gives only the **probability** of finding the electron at each place (ψ^2): an electron in n = 2 is in an orbital, a region where it is likely to be, and it can be found nearer to or farther from the nucleus. Bohr's radius is at best a most likely or typical distance, not a path.

MARKING SCHEME

- ✓ The uncertainty principle: no exact position and momentum together, so no fixed orbit.
- ✓ Only a probability of finding the electron (an orbital, ψ^2).
- ✓ It can be found at many distances; Bohr's radius is not a path.

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8 Activity: Lines or a rainbow?

(not marked)

WHAT STUDENTS SHOULD FIND

The filament bulb gives a **continuous spectrum**, a smooth band of colors with no gaps, and so does a white LED (broad, with no gaps). An orange sodium streetlight shows almost only a **yellow-orange line**; a tube light shows a band with a few brighter lines in it, from the gas inside. Separate bright lines mean light given out by atoms of a gas, each line one jump of an electron between energy levels: a **line spectrum**.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	8	3	19	3	**33**

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