Class 12 Physics · Chapter 12: Atoms

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. Bohr's first postulate states that an electron in an atom [1]

(a) can revolve in certain stable orbits without emitting radiant energy

(b) radiates energy at the frequency of its revolution

(c) has an angular momentum that can take any value

(d) emits a photon whenever it is in an excited orbit

Answer: (a) The first postulate: the electron can revolve in certain stable orbits, the stationary states, each of definite total energy, without emitting radiant energy, contrary to electromagnetic theory. Option b is the classical expectation; option c contradicts the second postulate; emission happens only in a transition (third postulate), not while in an orbit.

2. Bohr's model can be applied directly to which one of the following? [1]

(a) A neutral helium atom

(b) A singly ionised lithium ion, Li^{+}

(c) A doubly ionised lithium ion, Li^{2+}

(d) A neutral lithium atom

Answer: (c) Bohr's model works for hydrogenic atoms: a nucleus of charge +Ze with a single electron. Lithium has three electrons, so Li^{2+} has one left. Neutral helium has two electrons, Li^{+} has two and neutral lithium three, so each has electron-electron interactions the model leaves out.

3. An α-particle aimed head-on at a nucleus comes momentarily to rest at a distance d from its centre. If the kinetic energy of the α-particle is doubled, the distance of closest approach becomes how many times d? [1]

(a) 2

(b) 0.5

(c) 0.25

(d) 1.41

Answer: (b) At the turning point $K = (1/4\pi\varepsilon_0)(2e)(Ze)/d$, so $d \propto 1/K$. Doubling K halves d: 0.5 d. 2 takes d proportional to K; 0.25 takes $d \propto 1/K^2$; 1.41 takes $d \propto \sqrt{K}$.

4. α-particles of the same kinetic energy are aimed head-on, in turn, at a gold nucleus (Z = 79) and a silver nucleus (Z = 47). The ratio of the distance of closest approach for gold to that for silver is about [1]

(a) 0.59

(b) 1.30

(c) 2.83

(d) 1.68

Answer: (d) $d = 2Ze^2/(4\pi\varepsilon_0 K)$, so at the same K, $d \propto Z$: $d(Au)/d(Ag) = 79/47 \approx 1.68$. 0.59 inverts the ratio; 1.30 takes $d \propto \sqrt{Z}$; 2.83 takes $d \propto Z^2$.

5. According to classical electromagnetic theory, an electron revolving round the nucleus in Rutherford's model [1]

(a) moves in a fixed orbit for ever, since the Coulomb force supplies the centripetal force

(b) radiates energy continuously and spirals into the nucleus

(c) radiates energy only when it jumps between orbits

(d) radiates no energy, since its speed is constant

Answer: (b) A charge moving in a circle is constantly accelerated, and an accelerated charge emits electromagnetic radiation. The electron's energy would fall continuously and it would spiral into the nucleus, so the atom could not be stable. Constant speed (d) does not mean zero acceleration; option c is Bohr's postulate, not classical theory.

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6. A line of wavelength 434 nm is observed in the emission spectrum of hydrogen. Taking $E_n = -13.6/n^2$ eV and hc = 1240 eV nm, find the energy of the photon and identify the transition that produces this line. To which series does it belong? [2]

$E = hc/\lambda = 1240/434 \approx 2.86$ eV. The levels are $E_2 = -3.40$ eV and $E_5 = -13.6/25 = -0.544$ eV, and $E_5 - E_2 = 2.86$ eV, so the transition is n = 5 to n = 2. A line ending on n = 2 belongs to the Balmer series (visible).

- photon energy 2.86 eV (1)
- matches $E_5 - E_2$: transition n = 5 to n = 2, Balmer series (1)

7. Give one observation of the α-particle scattering experiment that Thomson's model of the atom cannot explain, and the reason Rutherford's model of the atom is unstable. [2]

In Thomson's model the positive charge is spread uniformly through the atom, so the field it produces is far too small to turn an α-particle back; yet about 1 in 8000 α-particles is deflected by more than 90°. Rutherford's model is unstable because its orbiting electrons are accelerated and, by classical electromagnetic theory, radiate energy continuously, so they would spiral into the nucleus.

- uniform charge gives far too small a field, yet about 1 in 8000 α-particles is deflected by more than 90° (1)
- Rutherford: accelerated orbiting electron radiates and spirals into the nucleus (1)

8. Distinguish between the emission line spectrum and the absorption spectrum of a gas. Why can the line spectrum of a gas serve to identify it? [2]

An emission line spectrum is obtained when the gas, excited at low pressure (for example by an electric current), emits only certain wavelengths: bright lines on a dark background. An absorption spectrum is obtained when white light passes through the gas: dark lines appear at the same wavelengths as the emission lines. Each element has its own characteristic set of lines, so the spectrum acts as a fingerprint of the gas.

- emission: bright lines on dark background from excited gas; absorption: dark lines in white light passed through gas, at the same wavelengths (1)
- lines are characteristic of each element, so they identify the gas (1)

9. A sample of hydrogen gas has its atoms excited to the level n = 4. (a) How many different lines can the sample emit, and how many of them belong to each of the Lyman, Balmer and Paschen series? (b) Taking $E_n = -13.6/n^2$ eV and hc = 1240 eV nm, find the longest wavelength among these lines. [3]

(a) The number of lines is $n(n-1)/2 = 4 \times 3/2 = 6$. Lyman (ending on n = 1): 4→1, 3→1, 2→1, three lines. Balmer (ending on n = 2): 4→2, 3→2, two lines. Paschen (ending on n = 3): 4→3, one line. (b) The longest wavelength is the smallest energy gap, 4→3: $\Delta E = 13.6 \times (1/9 - 1/16) = 0.661$ eV, $\lambda = 1240/0.661 \approx 1876$ nm (infrared).

- six lines (1)
- Lyman 3, Balmer 2, Paschen 1 (1)
- longest wavelength from 4→3, about 1876 nm (1)

10. (a) Why, according to de Broglie, can an electron wave persist in a Bohr orbit only if the circumference holds a whole number of wavelengths? (b) The circumference of a Bohr orbit of hydrogen holds exactly three de Broglie wavelengths of the electron. Taking $a_0 = 0.53$ Å, find the radius of the orbit and the de Broglie wavelength of the electron. [3]

(a) As with waves on a string, only standing waves survive: a wave that does not fit a whole number of times round the orbit interferes with itself on going round, and its amplitude quickly drops to zero. So $2\pi r_n = n\lambda$. (b) Three wavelengths means n = 3, so $r_3 = 9a_0 = 4.77$ Å, and $\lambda = 2\pi r_3/3 = 2\pi \times 4.77/3 \approx 9.99$ Å, about 10 Å.

- only resonant standing waves persist; other waves cancel themselves (1)
- n = 3, r = 4.77 Å (1)
- λ ≈ 10 Å (1)

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11. Using Bohr's second postulate and the condition for a stable circular orbit, show that the radius of the nth orbit of the electron in a hydrogen atom is proportional to n^2. In which orbit is the radius 9 times the radius of the second orbit? [3]

For a stable orbit the Coulomb force gives the centripetal force: $(1/4\pi\varepsilon_0)e^2/r^2 = mv^2/r$, so $mv^2r = e^2/4\pi\varepsilon_0$. Bohr's postulate: $mvr = nh/2\pi$, so $v = nh/(2\pi mr)$. Substituting, $m(nh/2\pi mr)^2r = e^2/4\pi\varepsilon_0$, which gives $r_n = (n^2/m)(h/2\pi)^2(4\pi\varepsilon_0/e^2)$, proportional to n^2. So $r_n/r_2 = n^2/4 = 9$ gives $n^2 = 36$ and $n = 6$.

- force balance $(1/4\pi\varepsilon_0)e^2/r^2 = mv^2/r$ (1)
- uses $mvr = nh/2\pi$ to eliminate v, $r_n \propto n^2$ (1)
- n = 6 (1)

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