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Atomic Structure — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · CHEMISTRY · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take the ground-state energy of hydrogen as −13.6 eV, the radius of its first Bohr orbit as 52.9 pm, hc = 1240 eV nm, h = 6.6 × 10^{-34} J s, electron mass = 9.1 × 10^{-31} kg and π = 3.14 unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Electromagnetic radiation · Photoelectric effect · Hydrogen spectrum · Bohr model · Dual nature of matter · Heisenberg's uncertainty principle · Atomic orbitals and ψ² · Quantum numbers · Shapes of orbitals · Aufbau principle · Hund's rule · Electronic configuration

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. The numbers of radial nodes and angular nodes of a 4d orbital are, respectively,

(1) 2 and 1

(2) 1 and 2

(3) 1 and 3

(4) 0 and 2

2. The maximum number of electrons in an atom that can have the quantum numbers n = 4 and $m_l = -1$ is

(1) 2

(2) 8

(3) 6

(4) 4

3. Which of the following gaseous ions has the same number of unpaired electrons as Cr^{3+}?

(1) Mn^{2+}

(2) Fe^{2+}

(3) Ni^{2+}

(4) V^{2+}

4. The ratio of the radius of the second Bohr orbit of He^{+} to that of the third Bohr orbit of Li^{2+} is

(1) 2 : 3

(2) 3 : 2

(3) 4 : 9

(4) 8 : 9

5. Electrons in a sample of hydrogen atoms are excited to the n = 6 level. As they return to the ground state, the largest number of different lines that can appear in the Balmer series is

(1) 5

(2) 15

(3) 4

(4) 3

6. The energy needed to excite a Li^{2+} ion from its ground state to its second excited state is about (ground-state energy of hydrogen −13.6 eV)

(1) 122.4 eV

(2) 91.8 eV

(3) 12.1 eV

(4) 108.8 eV

7. The de Broglie wavelength of the electron in the third Bohr orbit of a hydrogen atom is about (radius of the first Bohr orbit 52.9 pm)

(1) 0.33 nm

(2) 0.16 nm

(3) 1.0 nm

(4) 3.0 nm

8. The position of an electron is known to within 0.1 nm. The least uncertainty in its velocity is about ($h = 6.6 \times 10^{-34}$ J s, $m_e = 9.1 \times 10^{-31}$ kg)

(1) 5.8×10^5 m/s

(2) 1.2×10^6 m/s

(3) 7.3×10^6 m/s

(4) 5.8×10^4 m/s

9. Light of wavelength 250 nm ejects electrons from a metal surface with a maximum kinetic energy of 1.86 eV. The threshold wavelength of the metal is about (hc = 1240 eV nm)

(1) 667 nm

(2) 250 nm

(3) 400 nm

(4) 500 nm

10. Consider the following statements about the hydrogen atom.
(A) For the 1s orbital, ψ^2 is greatest at the nucleus.
(B) The 2s orbital has one radial node.
(C) The radial probability of finding a 1s electron is greatest at the nucleus.
(D) The wave function ψ of the 2s orbital changes sign at its node.
(E) The 2s orbital has one angular node.
Choose the correct answer from the options given below:

(1) (A), (B) and (D) only

(2) (A), (C) and (D) only

(3) (B), (D) and (E) only

(4) (A), (B), (C) and (D) only

11. Of the orbitals p_x, dxy, dyz, dzx, dx^2-y^2 and dz^2, how many have zero electron density everywhere along all three Cartesian axes?

(1) 2

(2) 4

(3) 5

(4) 3

12. Which pair of elements of the first transition series both have only one electron in the 4s orbital in the ground state?

(1) Cr and Mn

(2) Cr and Cu

(3) Cu and Zn

(4) V and Cr

13. Which of the following sets of quantum numbers (n, l, m_l, m_s) is NOT allowed?

(1) 3, 2, −2, +½

(2) 4, 0, 0, −½

(3) 5, 3, −3, +½

(4) 2, 2, 1, +½

14. In a many-electron atom, the order of increasing energy of the orbitals 6p, 5d, 4f and 6s (by the (n + l) rule) is

(1) 6s < 4f < 5d < 6p

(2) 4f < 6s < 5d < 6p

(3) 6s < 5d < 4f < 6p

(4) 4f < 5d < 6s < 6p

15. The wavelength of the first line of the Balmer series of hydrogen is 656 nm. The wavelength of the second line of the Lyman series of He^+ is

(1) 102.5 nm

(2) 25.6 nm

(3) 164 nm

(4) 51.3 nm

16. Assertion A: Bohr's model of the atom is not consistent with Heisenberg's uncertainty principle.
Reason R: In Bohr's model an electron moves in an orbit of definite radius with a definite speed, so its position and momentum are both known exactly at the same time.
In the light of the above statements, choose the correct answer from the options given below:

(1) A is true but R is false

(2) Both A and R are true but R is NOT the correct explanation of A

(3) Both A and R are true and R is the correct explanation of A

(4) A is false but R is true

17. The ionisation enthalpy of hydrogen atoms in the ground state is 1312 kJ/mol. The energy needed to excite one mole of hydrogen atoms from the ground state to the n = 3 level is about

(1) 984 kJ

(2) 146 kJ

(3) 1312 kJ

(4) 1166 kJ

18. The energy of one mole of photons of ultraviolet light of wavelength 300 nm is about (hc = 1240 eV nm, 1 eV = 1.6×10^{-19} J, $N_A = 6.02 \times 10^{23}$ mol^{-1})

(1) 4.1 kJ

(2) 398 kJ

(3) 40 kJ

(4) 199 kJ

19. Which of the following has the largest number of unpaired electrons in the ground state?

(1) Fe^{3+}

(2) Co^{2+}

(3) Mn

(4) Cr

20. For a many-electron atom, which electron, given by its (n, l) values, has the highest energy?

(1) n = 4, l = 1

(2) n = 3, l = 2

(3) n = 5, l = 0

(4) n = 4, l = 2

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. Electrons in a sample of hydrogen atoms are in the n = 6 level. The number of different spectral lines emitted as they return to the ground state that do NOT belong to the Lyman series is _____.

Answer: _____

22. The radius (in pm) of the second Bohr orbit of Li^{2+} is _____ (to the nearest integer; radius of the first Bohr orbit of hydrogen = 52.9 pm).

Answer: _____

23. The speed of the electron in the first Bohr orbit of hydrogen is 2.18×10^6 m/s. Its speed in the third Bohr orbit of He^+ is $x \times 10^4$ m/s. The value of x is _____ (to the nearest integer).

Answer: _____

24. The number of electrons in a ground-state zinc atom (Z = 30) for which n + l = 4 is _____.

Answer: _____

25. An electron has the same de Broglie wavelength as a photon of energy 6.2 keV. The kinetic energy of the electron (in eV) is _____ (to the nearest integer; hc = 1240 eV nm, h = 6.6×10^{-34} J s, $m_e = 9.1 \times 10^{-31}$ kg, 1 eV = 1.6×10^{-19} J).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(2)	(3)	(4)	(1)	(3)	(4)	(3)	(1)	(3)	(1)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(4)	(2)	(4)	(1)	(2)	(3)	(4)	(2)	(4)	(4)

Q21	Q22	Q23	Q24	Q25
10	71	145	8	37

WORKED SOLUTIONS

Q1. Answer (2). Angular nodes = l = 2. Radial nodes = n − l − 1 = 4 − 2 − 1 = 1.

Q2. Answer (3). For n = 4, l can be 0, 1, 2 or 3; $m_l = -1$ is possible for l = 1, 2 and 3, i.e. in three orbitals (4p, 4d, 4f). Each holds two electrons: 6.

Q3. Answer (4). Cr^{3+} is $3d^3$ (3 unpaired). V^{2+} is $3d^3$ (3); Mn^{2+} is $3d^5$ (5); Fe^{2+} is $3d^6$ (4); Ni^{2+} is $3d^8$ (2).

Q4. Answer (1). $r = 52.9\ n^2/Z$ pm. He^+, n = 2: 4/2 = 2; Li^{2+}, n = 3: 9/3 = 3. Ratio 2 : 3.

Q5. Answer (3). Balmer lines end on n = 2. From n = 6 they are 6 → 2, 5 → 2, 4 → 2 and 3 → 2: four lines. (In all, 6 × 5/2 = 15 lines are possible.)

Q6. Answer (4). $E_n = -13.6\ Z^2/n^2$ eV with Z = 3: $E_1 = -122.4$ eV and the second excited state (n = 3) has $E_3 = -13.6$ eV. ΔE = 122.4 − 13.6 = 108.8 eV. (91.8 eV would take it only to n = 2.)

Q7. Answer (3). Bohr's condition mvr = nh/2π means nλ = 2πr: a whole number of wavelengths fits round the orbit. $r_3 = 9 \times 52.9$ pm, so $\lambda = 2\pi \times 9 \times 52.9/3$ pm $= 6\pi \times 52.9 \approx 997$ pm ≈ 1.0 nm.

Q8. Answer (1). $\Delta x \cdot m\Delta v \geq h/4\pi$, so $\Delta v \geq 6.6 \times 10^{-34}/(4 \times 3.14 \times 9.1 \times 10^{-31} \times 10^{-1^{\circ}}) \approx 5.8 \times 10^5$ m/s, a sizeable fraction of the electron's speed in an atom.

Q9. Answer (3). Photon energy = 1240/250 = 4.96 eV. Work function = 4.96 − 1.86 = 3.10 eV. $\lambda_0 = 1240/3.10 = 400$ nm.

Q10. Answer (1). $\psi_{1s} \propto e^{\wedge}(-r/a_0)$ is largest at r = 0 (A true), but the radial probability $4\pi r^2\psi^2$ is zero at r = 0 and peaks at $r = a_0$ (C false). $\psi_{2s} \propto (2 - r/a_0)e^{\wedge}(-r/2a_0)$ passes through zero and changes sign at $r = 2a_0$: one radial node (B, D true). An s orbital has l = 0 angular nodes (E false).

Q11. Answer (4). The angular parts go as x, xy, yz, zx, $x^2 - y^2$ and $3z^2 - r^2$. On every axis two of x, y, z are zero, so xy, yz and zx vanish there: the three d orbitals with lobes between the axes. p_x and $dx^2{-}y^2$ point along x, and dz^2 along z.

Q12. Answer (2). Cr is $[Ar]3d^5 4s^1$ (half-filled d) and Cu is $[Ar]3d^{1^{\circ}}4s^1$ (filled d), the two exceptions to the Aufbau order in the series; Mn ($3d^5 4s^2$), Zn ($3d^{1^{\circ}}4s^2$) and V ($3d^3 4s^2$) have two 4s electrons.

Q13. Answer (4). l can be at most n − 1, so n = 2 does not allow l = 2. The other sets satisfy $0 \leq l \leq n - 1$ and $-l \leq m_l \leq l$.

Q14. Answer (1). n + l: 6s = 6, 4f = 7, 5d = 7, 6p = 7. The lowest n + l fills first; for equal n + l the lower n comes first: 6s < 4f < 5d < 6p.

Q15. Answer (2). $1/\lambda = RZ^2(1/n_1^2 - 1/n_2^2)$. H, Balmer first line (3 → 2): R × 5/36. He^+, Lyman second line (3 → 1): 4R × 8/9 = 32R/9. λ = 656 × (5/36)/(32/9) = 656 × 5/128 = 25.6 nm. (102.5 nm is the second Lyman line of hydrogen itself.)

Q16. Answer (3). Bohr orbits fix r and v (hence momentum) together, which the uncertainty principle forbids; this is one of the limitations of the model. Both are true and R explains A.

Q17. Answer (4). $E_n = -1312/n^2$ kJ/mol. $E_3 - E_1 = 1312(1 - 1/9) = 1312 \times 8/9 \approx 1166$ kJ for one mole. (984 kJ is the energy to reach n = 2.)

Q18. Answer (2). One photon: 1240/300 = 4.13 eV = 6.61×10^{-19} J. One mole: $6.61 \times 10^{-19} \times 6.02 \times 10^{23} \approx 3.98 \times 10^5$ J = 398 kJ, more than the C–C bond enthalpy (about 348 kJ/mol), which is why UV light can break such bonds.

Q19. Answer (4). Cr is $3d^5 4s^1$: six unpaired electrons (half-filled 3d and 4s). Fe^{3+} ($3d^5$) and Mn ($3d^5 4s^2$) have five; Co^{2+} ($3d^7$) has three.

Q20. Answer (4). n + l: 4p = 5, 3d = 5, 5s = 5, 4d = 6. 4d has the largest n + l, so it is highest in energy.

Q21. Answer 10. Any pair of levels from 1 to 6 gives a line: $6 \times 5/2 = 15$ in all. The Lyman lines end on n = 1, one from each of n = 2 to 6: 5 lines. 15 − 5 = 10.

Q22. Answer 71. $r = 52.9\ n^2/Z = 52.9 \times 4/3 \approx 70.5$ pm, i.e. 71.

Q23. Answer 145. $v \propto Z/n$: $v = 2.18 \times 10^6 \times 2/3 \approx 1.453 \times 10^6$ m/s = 145×10^4 m/s.

Q24. Answer 8. Zn: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2$. n + l = 4 for 3p (3 + 1) and 4s (4 + 0): 6 + 2 = 8 electrons.

Q25. Answer 37. Photon: $\lambda = 1240/6200$ nm = 0.2 nm. Electron: $K = p^2/2m = h^2/(2m\lambda^2) = (6.6 \times 10^{-34})^2/(2 \times 9.1 \times 10^{-31} \times (2 \times 10^{-10})^2) = 5.98 \times 10^{-18}$ J ≈ 37.4 eV, i.e. 37. The photon carries far more energy than an electron of the same wavelength.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: Bohr orbits were found from the force and angular-momentum conditions in SI units, spectral lines and quantum-number sets were enumerated, configurations were built by the Aufbau order with its known exceptions, and the hydrogen 1s and 2s wave functions were evaluated numerically.