Chapter
Structure of Atom

Topic-1: Different Atomic Models that Leads to Bohr Model

1 MCQs with One Correct Answer

1. According to Bohr's model, the highest kinetic energy is associated with the electron in the **[Adv. 2024]**
   (a) First orbit of H atom (b) First orbit of He^+
   (c) Second orbit of He^+ (d) Second orbit of Li^{2+}
2. The kinetic energy of an electron in the second Bohr orbit of a hydrogen atom is [a_0 is Bohr radius] : **[2012]**
   (a) $\frac{h^2}{4\pi^2 ma_0^2}$ (b) $\frac{h^2}{16\pi^2 ma_0^2}$
   (c) $\frac{h^2}{32\pi^2 ma_0^2}$ (d) $\frac{h^2}{64\pi^2 ma_0^2}$
3. Given that the abundances of isotopes ^{54}Fe, ^{56}Fe and ^{57}Fe are 5%, 90% and 5%, respectively, the atomic mass of Fe is **[2009S]**
   (a) 55.85 (b) 55.95 (c) 55.75 (d) 56.05
4. The radius of which of the following orbit is same as that of the first Bohr's orbit of hydrogen atom? **[2004S]**
   (a) $He^+ (n=2)$ (b) $Li^{2+} (n=2)$
   (c) $Li^{2+} (n=3)$ (d) $Be^{3+} (n=2)$
5. Rurtherford's experiment, which established the nuclear model of the atom, used a beam of **[2002S]**
   (a) β -particles, which impinged on a metal foil and got absorbed
   (b) γ -rays, which impinged on a metal foil and ejected electrons
   (c) helium atoms, which impinged on a metal foil and got scattered
   (d) helium nuclei, which impinged on a metal foil and got scattered
6. Which of the following does not characterise X-rays? **[1992 - 1 Mark]**
   (a) The radiation can ionise gases
   (b) It causes ZnS to fluorescence
   (c) Deflected by electric and magnetic fields
   (d) Have wavelengths shorter than ultraviolet rays
7. The wavelength of a spectral line for an electronic transition is inversely related to : **[1988 - 1 Mark]**
   (a) the number of electrons undergoing the transition
   (b) the nuclear charge of the atom
   (c) the difference in the energy of the energy levels involved in the transition
   (d) the velocity of the electron undergoing the transition.
8. The triad of nuclei that is isotonic is **[1988 - 1 Mark]**
   (a) $^{14}_{6}C$, $^{15}_{7}N$, $^{17}_{9}F$ (b) $^{12}_{6}C$, $^{14}_{7}N$, $^{19}_{9}F$
   (c) $^{14}_{6}C$, $^{14}_{7}N$, $^{17}_{9}F$ (d) $^{14}_{6}C$, $^{14}_{7}N$, $^{19}_{9}F$
9. The ratio of the energy of a photon of 2000 Å wavelength radiation to that of 4000 Å radiation is : **[1986 - 1 Mark]**
   (a) 1/4 (b) 4 (c) 1/2 (d) 2
10. Rutherford's alpha particle scattering experiment eventually led to the conclusion that : **[1986 - 1 Mark]**
    (a) mass and energy are related
    (b) electrons occupy space around the nucleus
    (c) neutrons are buried deep in the nucleus
    (d) the point of impact with matter can be precisely determined.
11. Electromagnetic radiation with maximum wavelength is : **[1985 - 1 Mark]**
    (a) ultraviolet (b) radiowave
    (c) X-ray (d) infrared
12. The radius of an atomic nucleus is of the order of : **[1985 - 1 Mark]**
    (a) 10^{-10} cm (b) 10^{-13} cm (c) 10^{-15} cm (d) 10^{-8} cm
13. Bohr model can explain : **[1985 - 1 Mark]**
    (a) the spectrum of hydrogen atom only
    (b) spectrum of an atom or ion containing one electron only
    (c) the spectrum of hydrogen molecule
    (d) the solar spectrum
14. Which electronic level would allow the hydrogen atom to absorb a photon but not to emit a photon? **[1984 - 1 Mark]**
    (a) 3s (b) 2p (c) 2s (d) 1s
15. The increasing order (lowest first) for the values of e/m (charge/mass) for electron (e), proton (p), neutron (n) and alpha particle (α) is : **[1984 - 1 Mark]**
    (a) e, p, n, α (b) n, p, e, α
    (c) n, p, α, e (d) n, α, p, e
16. Rutherford's scattering experiment is related to the size of the **[1983 - 1 Mark]**
    (a) nucleus (b) atom (c) electron (d) neutron

17. Rutherford's experiment on scattering of α-particles showed for the first time that the atom has **[1981 - 1 Mark]**
(a) electrons (b) protons
(c) nucleus (d) neutrons

18. The number of neutrons in dipositive zinc ion with mass number 70 is **[1979]**
(a) 34 (b) 36 (c) 38 (d) 40

2 Integer Value Answer

19. For He^+, a transition takes place from the orbit of radius 105.8 pm to the orbit of radius 26.45 pm.
The wavelength (in nm) of the emitted photon during the transition is ___. **[Adv. 2023]**
[**Use:** Bohr radius, a = 52.9 pm; Rydberg constant, $R_H = 2.2 \times 10^{-18}$ J; Planck's constant, $h = 6.6 \times 10^{-34}$ J s; Speed of light, $c = 3 \times 10^8$ m s^{-1}]

20. The work function (ϕ) of some metals is listed below. The number of metals which will show photoelectric effect when light of 300 nm wavelength falls on the metal is **[2011]**

Metal	Li	Na	K	Mg	Cu	Ag	Fe	Pt	W
ϕ (eV)	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

3 Numeric / New Stem Based Questions

21. Wavelength of high energy transition of H–atoms is 91.2nm. Calculate the corresponding wavelength of He atoms. **[2003 - 2 Marks]**

22. Calculate the wave number for the shortest wavelength transition in the Balmer series of atomic hydrogen. **[1996 - 1 Mark]**

23. According to Bohr's theory, the electronic energy of hydrogen atom in the n^{th} Bohr's orbit is given by $E_n = \frac{-21.76 \times 10^{-19}}{n^2}$ J. Calculate the longest wavelength of light that will be needed to remove an electron from the third Bohr orbit of the He^+ ion. **[1990 - 3 Marks]**

24. Calculate the wavelength in Angstrom of the photon that is emitted when an electron in the Bohr orbit, $n = 2$ returns to the orbit, $n = 1$ in the hydrogen atom. The ionization potential of the ground state hydrogen atom is 2.17×10^{-11} erg per atom. **[1982 - 4 Marks]**

25. The energy of the electron in the second and the third Bohr's orbits of the hydrogen atom is -5.42×10^{-12} erg and -2.41×10^{-12} erg respectively. Calculate the wavelength of the emitted radiation when the electron drops from the third to the second orbit. **[1981 - 3 Marks]**

4 Fill in the Blanks

26. The light radiations with discrete quantities of energy are called .... **[1993 - 1 Mark]**

27. Elements of the same mass number but of different atomic numbers are known as .... **[1983 - 1 Mark]**

28. Isotopes of an element differ in the number of .... in their nuclei. **[1982 - 1 Mark]**

29. The mass of a hydrogen atom is .... kg. **[1982 - 1 Mark]**

5 True / False

30. In a given electric field, β-particles are deflected more than α-particles in spite of α-particles having larger charge. **[1993 - 1 Mark]**

31. Gamma rays are electromagnetic radiations of wavelengths of 10^{-6} cm to 10^{-5} cm. **[1983 - 1 Mark]**

6 MCQs with One or More than One Correct Answer

32. The energy of an electron in the first Bohr orbit of H atom is –13.6 eV. The possible energy value(s) of the excited state(s) for electrons in Bohr orbits of hydrogen is (are) **[1998 - 2 Marks]**
(a) –3.4 eV (b) –4.2 eV (c) –6.8 eV (d) –1.5 eV

33. The sum of the number of neutrons and proton in the isotope of hydrogen is : **[1986 - 1 Mark]**
(a) 6 (b) 2 (c) 4 (d) 3

34. When alpha particles are sent through a thin metal foil, most of them go straight through the foil because : **[1984 - 1 Mark]**
(a) alpha particles are much heavier than electrons
(b) alpha particles are positively charged
(c) most part of the atom is empty space
(d) alpha particle move with high velocity

35. Many elements have non-integral atomic masses because: **[1984 - 1 Mark]**
(a) they have isotopes
(b) their isotopes have non-integral masses
(c) their isotopes have different masses
(d) the constitutents, neutrons, protons and electrons, combine to give fractional masses

36. An isotone of $^{76}_{32}Ge$ is : **[1984 - 1 Mark]**
(a) $^{77}_{32}Ge$ (b) $^{77}_{33}As$ (c) $^{77}_{34}Se$ (d) $^{78}_{34}Se$

7 Match the Following

37. Consider the Bohr's model of a one – electron atom where the electron moves around the nucleus. In the following List–I contains some quantities for the n^{th} orbit of the atom and List–II contains options showing how they depend on n **[Adv. 2019]**

List–I	List–II
(I) Radius of the n^{th} orbit	(P) $\propto n^{-2}$
(II) Angular momentum of the electron in the n^{th} orbit	(Q) $\propto n^{-1}$
(III) Kinetic energy of the electron in the n^{th} orbit	(R) $\propto n^0$
(IV) Potential energy of the electron in the n^{th} orbit	(S) $\propto n^1$
	(T) $\propto n^2$
	(U) $\propto n^{1/2}$

Which of the following options has the correct Combination considering List–I and List–II?
(a) (II), (R) (b) (II), (Q) (c) (I), (P) (d) (I), (T)

10 Subjective Problems

38. Calculate the energy required to excite one litre of hydrogen gas at 1 atm and 298 K to the first excited state of atomic hydrogen. The energy for the dissociation of H–H bond is 436 kJ mol^{-1}. **[2000 - 4 Marks]**

39. Consider the hydrogen atom to be a proton embedded in a cavity of radius a_0 (Bohr radius) whose charge is neutralised by the addition of an electron to the cavity in vacuum, infinitely slowly. Estimate the average total energy of an electron in its ground state in a hydrogen atom as the work done in the above neutralisation process. Also, if the magnitude of the average kinetic energy is half the magnitude of the average potential energy, find the average potential energy. **[1996 - 2 Marks]**

40. Iodine molecule dissociates into atoms after absorbing light of 4500Å. If one quantum of radiation is absorbed by each molecule, calculate the kinetic energy of iodine atoms. (Bond energy of I_2 = 240 kJ mol^{-1}) **[1995 - 2 Marks]**

41. Find out the number of waves made by a Bohr electron in one complete revolution in its 3rd orbit. **[1994 - 3 Marks]**

42. What transition in the hydrogen spectrum would have the same wavelength as the Balmer transition $n = 4$ to $n = 2$ of He^+ spectrum? **[1993 - 3 Marks]**

43. Estimate the difference in energy between 1st and 2nd Bohr orbit for a hydrogen atom. At what minimum atomic number, a transition from $n = 2$ to $n = 1$ energy level would result in the emission of X-rays with $\lambda = 3.0 \times 10^{-8}$m? Which hydrogen atom-like species does this atomic number correspond to ? **[1993 - 5 Marks]**

44. The electron energy in hydrogen atom is given by $E = (-21.7 \times 10^{-12})/n^2$ ergs. Calculate the energy required to remove an electron completely from the $n = 2$ orbit. What is the longest wavelength (in cm) of light that can be used to cause this transition? **[1984 - 3 Marks]**

45. Naturally occurring boron consists of two isotopes whose atomic weights are 10.01 and 11.01. The atomic weight of natural boron is 10.81. Calculate the percentage of each isotope in natural boron. **[1978]**

Topic-2: Advancement Towards Quantum Mechanical Model of Atom

1 MCQs with One Correct Answer

1. The wavelength associated with a golf ball weighing 200 g and moving at a speed of 5 m/h is of the order **[2001S]**
   (a) 10^{-10} m (b) 10^{-20} m (c) 10^{-30} m (d) 10^{-40} m

2. Which of the following relates to photons both as wave motion and as a stream of particles? **[1992 - 1 Mark]**
   (a) Inference (b) $E = mc^2$
   (c) Diffraction (d) $E = h\nu$

2 Integer Value Answer

3. Consider a helium (He) atom that absorbs a photon of wavelength 330 nm. The change in the velocity (in cm s^{-1}) of He atom after the photon absorption is ___.
   (Assume : Momentum is conserved when photon is absorbed. Use : Planck constant = 6.6×10^{-34} J s, Avogadro number = 6×10^{23} mol^{-1}, Molar mass of He = 4 g mol^{-1}) **[Adv. 2021]**

4. The atomic masses of 'He' and 'Ne' are 4 and 20 a.m.u., respectively. The value of the de Broglie wavelength of 'He' gas at —73 °C is "M" times that of the de Broglie wavelength of 'Ne' at 727 °C. 'M' is **[Adv. 2013]**

4 Fill in the Blanks

5. Wave functions of electrons in atoms and molecules are called............... **[1993 - 1 Mark]**

6. The uncertainty principle and the concept of wave nature of matter were proposed by .... and .... respectively. (Heisenberg, Schrodinger, Maxwell, de Broglie) **[1988 - 1 Mark]**

6 MCQs with One or More than One Correct Answer

7. Among the following, the correct statement(s) for electrons in an atom is(are) **[Adv. 2024]**
   (a) Uncertainty principle rules out the existence of definite paths for electrons.
   (b) The energy of an electron in 2s orbital of an atom is lower than the energy of an electron that is infinitely far away from the nucleus.
   (c) According to Bohr's model, the most negative energy value for an electron is given by $n = 1$, which corresponds to the most stable orbit.
   (d) According to Bohr's model, the magnitude of velocity of electrons increases with increase in values of n.

10 Subjective Problems

8. Find the velocity (ms^{-1}) of electron in first Bohr's orbit of radius a_0. Also find the de Broglie's wavelength (in m). Find the orbital angular momentum of 2p orbital of hydrogen atom in units of $h/2\pi$. **[2005 - 2 Marks]**

9. A ball of mass 100 g is moving with 100 ms^{-1}. Find its wavelength. **[2004 - 1 Mark]**

10. The Schrodinger wave equation for hydrogen atom is **[2004 - 2 Marks]**

$$\Psi_{2s} = \frac{1}{4\sqrt{2\pi}}\left(\frac{1}{a_0}\right)^{3/2}\left(2 - \frac{r_0}{a_0}\right)e^{-r_0/a_0}$$

Where a_0 is Bohr's radius. If the radial node in 2s be at r_0, then find r_0 in terms of a_0.

Topic-3: Quantum Mechanical Model of Atom

1 MCQs with One Correct Answer

1. The number of radial nodes of $3s$ and $2p$ orbitals are respectively **[2005S]**
   (a) 2, 0 (b) 0, 2 (c) 1, 2 (d) 2, 1

2. If the nitrogen atom has electronic configuration $1s^7$, it would have energy lower than that of the normal ground state configuration $1s^2 2s^2 2p^3$, because the electrons would be closer to the nucleus. Yet $1s^7$ is not observed because it violates. **[2002S]**
   (a) Heisenberg uncertainty principle
   (b) Hund's rule
   (c) Pauli exclusion principle
   (d) Bohr postulate of stationary orbits

3. The quantum numbers +1/2 and –1/2 for the electron spin represent **[2001S]**
   (a) rotation of the electron in clockwise and anticlockwise direction respectively
   (b) rotation of the electron in anticlockwise and clockwise direction respectively
   (c) magnetic moment of the electron pointing up and down respectively
   (d) two quantum mechanical spin states which have no classical analogue

4. The electronic configuration of an element is $1s^2$, $2s^2 2p^6$, $3s^2 3p^6 3d^5$, $4s^1$. This represents its **[2000S]**
   (a) excited state (b) ground state
   (c) cationic form (d) anionic form

5. The number of nodal planes in a p_x orbital is **[2000S]**
   (a) one (b) two (c) three (d) zero

6. The electrons, identified by quantum numbers n and l, (i) $n = 4, l = 1$, (ii) $n = 4, l = 0$, (iii) $n = 3, l = 2$, and (iv) $n = 3, l = 1$ can be placed in order of increasing energy, from the lowest to highest, as **[1999 - 2 Marks]**
   (a) (iv) < (ii) < (iii) < (i) (b) (ii) < (iv) < (i) < (iii)
   (c) (i) < (iii) < (ii) < (iv) (d) (iii) < (i) < (iv) < (ii)

7. For a d-electron, the orbital angular momentum is **[1997 - 1 Mark]**
   (a) $\sqrt{6}(h/2\pi)$ (b) $\sqrt{2}(h/2\pi)$
   (c) $(h/2\pi)$ (d) $2(h/2\pi)$

8. The orbital angular momentum of an electron in $2s$ orbital is: **[1996 - 1 Mark]**
   (a) $+\frac{1}{2}.\frac{h}{2\pi}$ (b) Zero (c) $\frac{h}{2\pi}$ (d) $\sqrt{2}.\frac{h}{2\pi}$

9. A $3p$ orbital has : **[1995S]**
   (a) two non spherical nodes
   (b) two spherical nodes
   (c) one spherical and one non spherical node
   (d) one spherical and two non spherical nodes

10. The correct set of quantum numbers for the unpaired electron of chlorine atom is : **[1989 - 1 Mark]**

	n	l	m
(a)	2	1	0
(b)	2	1	1
(c)	3	1	1
(d)	3	0	0

11. The correct ground state electronic configuration of chromium atom is : **[1989 - 1 Mark]**
    (a) [Ar] $3d^5 4s^1$ (b) [Ar] $3d^4 4s^2$
    (c) [Ar] $3d^6 4s^0$ (d) [Ar] $4d^5 4s^1$

12. The outermost electronic configuration of the most electronegative element is **[1988 - 1 Mark]**
    (a) $ns^2\ np^3$ (b) $ns^2\ np^4$ (c) $ns^2\ np^5$ (d) $ns^2\ np^6$

13. The orbital diagram in which the Aufbau principle is violated is : **[1988 - 1 Mark]**

	2s	2p		
(a)	↑↓	↑↓	↑	
(b)	↑	↑↓	↑	↑
(c)	↑↓	↑	↑	↑
(d)	↑↓	↑↓	↑	↑

14. Which one of the following sets of quantum numbers represents an impossible arrangement? **[1986 - 1 Mark]**

	n	l	m_l	m_s
(a)	3	2	–2	½
(b)	4	0	0	½
(c)	3	2	–3	½
(d)	5	3	0	–½

15. Correct set of four quantum numbers for the valence (outermost) electron of rubidium ($Z = 37$) is : **[1984 - 1 Mark]**
    (a) 5, 0, 0, +½ (b) 5, 1, 0, +½
    (c) 5, 1, 1, +½ (d) 6, 0, 0, +½

16. Any p-orbital can accommodate upto **[1983 - 1 Mark]**
    (a) four electrons
    (b) six electrons
    (c) two electrons with parallel spins
    (d) two electrons with opposite spins

17. The principal quantum number of an atom is related to the **[1983 - 1 Mark]**
    (a) size of the orbital
    (b) spin angular momentum
    (c) orbital angular momentum
    (d) orientation of the orbital in space

2 Integer Value Answer

18. Not considering the electronic spin, the degeneracy of the second excited state ($n = 3$) of H atom is 9, while the degeneracy of the second excited state of H^- is **[Adv. 2015]**

19. In an atom, the total number of electrons having quantum numbers $n = 4$, $|m_1| = 1$ and $m_s = -\frac{1}{2}$ is **[Adv. 2014]**

20. The maximum number of electrons that can have principal quantum number, $n = 3$, and spin quantum $m_s = -\frac{1}{2}$, is **[2011]**

3 Numeric / New Stem Based Questions

21. What is the maximum number of electrons that may be present in all the atomic orbitals with principal quantum number 3 and azimuthal quantum number 2? **[1985 - 2 Marks]**

4 Fill in the Blanks

22. The outermost electronic configuration of Cr is .... **[1994 - 1 Mark]**

23. The $2p_x$, $2p_y$ and $2p_z$ orbitals of atom have identical shapes but differ in their .... **[1993 - 1 Mark]**

24. When there are two electrons in the same orbital, they have .... spins. **[1982 - 1 Mark]**

5 True / False

25. The electron density in the XY plane in $3d_{x^2-y^2}$ orbital is zero. **[1986 - 1 Mark]**

26. The energy of the electron in the $3d$-orbital is less than that in the $4s$-orbital in the hydrogen atom. **[1983 - 1 Mark]**

27. The outer electronic configuration of the ground state chromium atom is $3d^4 4s^2$. **[1982 - 1 Mark]**

6 MCQs with One or More than One Correct Answer

28. The ground state energy of hydrogen atom is –13.6 eV. Consider an electronic state ψ of He^+ whose energy, azimuthal quantum number and magnetic quantum number are –3.4 eV, 2 and 0, respectively. Which of the following statement(s) is (are) true from the state ψ? **[Adv. 2019]**

(a) It is a $4d$ state
(b) It has 3 radial nodes
(c) It has 2 angular nodes
(d) The nuclear charge experienced by the electron in this state is less than $2e$, where e is the magnitude of the electronic charge

29. Ground state electronic configuration of nitrogen atom can be represented by **[1999 - 3 Marks]**

(a) ↑↓ ↑↓ ↑ ↑ ↑
(b) ↑↓ ↑↓ ↑ ↓ ↑
(c) ↑↓ ↑↓ ↑ ↓ ↓
(d) ↑↓ ↑↓ ↓ ↓ ↓

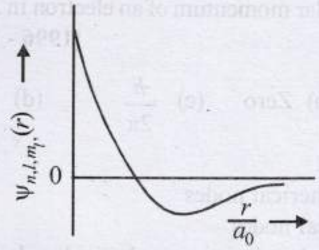
30. Which of the following satement(s) is (are) correct? **[1998 - 2 Marks]**

(a) The electronic configuration of Cr is [Ar] $3d^5 4s^1$. (Atomic Number of Cr = 24)
(b) The magnetic quantum number may have a negative value.
(c) In silver atom, 23 electrons have a spin of one type and 24 of the opposite type. (Atomic Number of Ag = 47)
(d) The oxidation state of nitrogen in HN_3 is – 3.

7 Match the Following

(Qs. 31-35) are based on the table, having 3 columns and 4 rows. Each question has four options (A), (B), (C) and (D). Only one of these four options is correct. By appropriately matching the information given in the three columns of the following table.

The wave function, ψ_{n,l,m_l} is a mathematical function whose value depends upon spherical polar coordinates (r, θ, ϕ) of the electron and characterized by the quantum numbers n, l and m_l. Here r is distance from nucleus, θ is colatitude and ϕ is azimuth. In the mathematical functions given in the table, Z is atomic number and a_0 is Bohr radius. **[Adv. 2017]**

Column-1	Column-2	Column-3
(I) 1s orbital	(i) $\psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_0}\right)}$	(P) 
(II) 2s orbital	(ii) One radial node	(Q) Probability density at nucleus $\propto \frac{1}{a_0^3}$

(III) $2p_z$ orbital	(iii) $\psi_{n,l,m_l} \propto \left(\frac{Z}{a_0}\right)^{\frac{5}{2}} re^{-\left(\frac{Zr}{2a_0}\right)} \cos\theta$	(R) Probability density is maximum at nucleus
(IV) $3d_{z^2}$ orbital	(iv) *xy*-plane is a nodal plane	(S) Energy needed to excite electron from $n = 2$ state to $n = 4$ state is $\frac{27}{32}$ times the energy needed to excite electron from $n = 2$ state to $n = 6$ state

31. For the given orbital in Column 1, the only CORRECT combination for any hydrogen-like species is
(a) (I) (ii) (S) (b) (IV) (iv) (R) (c) (II) (ii) (P) (d) (III) (iii) (P)

32. For hydrogen atom, the only CORRECT combination is
(a) (I) (i) (S) (b) (II) (i) (Q) (c) (I) (i) (P) (d) (I) (iv) (R)

33. For He^+ ion, the only INCORRECT combination is
(a) (I) (i) (R) (b) (II) (ii) (Q) (c) (I) (iii) (R) (d) (I) (i) (S)

34. Match the entries in Column I with the correctly related quantum number(s) in Column II. **[2008 - 6M]**

Column-I	Column-II
(A) Orbital angular momentum of the electron in a hydrogen-like atomic orbital	(p) Principal quantum number
(B) A hydrogen-like one-electron wave function obeying Pauli principle	(q) Azimuthal quantum number
(C) Shape, size and orientation of hydrogen- like atomic orbitals	(r) Magnetic quantum number
(D) Probability density of electron at the nucleus in hydrogen-like atom	(s) Electron spin quantum number

35. E_n = Total energy, K_n = Kinetic energy, V_n = Potential energy, r_n = Radius of n^{th} orbit Match the following :

Column-I	Column-II
(A) $V_n / K_n = ?$	(p) 0
(B) If radius of n^{th} orbit $\propto E_n^x$, $x = ?$	(q) –1
(C) Angular momentum in lowest orbital	(r) –2
(D) $\frac{1}{r_n} \propto Z^y$, $y = ?$	(s) 1

8 Comprehension/Passage Based Questions

The hydrogen-like species Li^{2+} is in a spherically symmetric state S_1 with one radial node. Upon absorbing light the ion undergoes transition to a state S_2. The state S_2 has one radial node and its energy is equal to the ground state energy of the hydrogen atom. **[2010]**

36. The state S_1 is :
(a) 1*s* (b) 2*s* (c) 2*p* (d) 3*s*

37. Energy of the state S_1 in units of the hydrogen atom ground state energy is :
(a) 0.75 (b) 1.50 (c) 2.25 (d) 4.50

38. The orbital angular momentum quantum number of the state S_2 is :
(a) 0 (b) 1 (c) 2 (d) 3

10 Subjective Problems

39. Give reasons why the ground state outermost electronic configuration of silicon is : **[1985 - 2 Marks]**

3*s* [↑↓] 3*p* [↑][↑][ ] and not 3*s* [↑↓] 3*p* [↑][↓][ ]

Answer Key

Topic-1 : Different Atomic Models that Leads to Bohr Model

1. (b) **2.** (c) **3.** (b) **4.** (d) **5.** (d) **6.** (c) **7.** (c) **8.** (a) **9.** (d) **10.** (b)
11. (b) **12.** (b) **13.** (b) **14.** (d) **15.** (d) **16.** (a) **17.** (c) **18.** (d) **19.** (30) **20.** (4)
21. (22.8) **22.** (27419) **23.** (2055) **24.** (1220) **25.** (660) **26.** (photons) **27.** (isobars)
28. (neutrons) **29.** (1.66×10^{-27}kg) **30.** True **31.** False **32.** (a, d) **33.** (b, d) **34.** (a, c) **35.** (a, c)
36. (b, d) **37.** (d)

Topic-2 : Advancement Towards Quantum Mechanical Model of Atom

1. (a) **2.** (d) **3.** (30) **4.** (5) **5.** (orbitals) **6.** (Heisenberg, de-Broglie) **7.** (a, b, c)

Topic-3 : Quantum Mechanical Model of Atom

1. (a) **2.** (c) **3.** (d) **4.** (b) **5.** (a) **6.** (a) **7.** (a) **8.** (b) **9.** (c) **10.** (c)
11. (a) **12.** (c) **13.** (b) **14.** (c) **15.** (a) **16.** (d) **17.** (a) **18.** (3) **19.** (6) **20.** (9)
21. (10) **22.** ($4s^1, 3d^5$) **23.** (orientation in space) **24.** (antiparallel; or opposite)
25. (False) **26.** (True) **27.** (False) **28.** (a, c) **29.** (a, d) **30.** (a, b, c) **31.** (c) **32.** (a) **33.** (c)
34. (A) - (q); (B) - (p, q, r, s); (C) - (p, q, r); (D) - (p, q, r) **35.** (A) - (r); (B) - (q); (C) - (p); (D) - (s) **36.** (b)
37. (c) **38.** (b)

Hints & Solutions

Topic-1: Different Atomic Models that Leads to Bohr Model

1. (b) K.E. of electron in n^{th} Bohr's orbit is given by :

$$K.E. = 13.6\frac{Z^2}{n^2} \text{ eV/atom}$$

$$n = 1 \text{ (H-atom)} \rightarrow K.E. \propto \frac{1^2}{1^2} = 1$$

$$n = 1 \text{ (He}^+ \text{ ion)} \rightarrow K.E. \propto \frac{2^2}{1^2} = 4$$

$$n = 2 \text{ (He}^+ \text{ ion)} \rightarrow K.E. \propto \frac{2^2}{2^2} = 1$$

$$n = 2 \text{ (Li}^{2+} \text{ ion)} \rightarrow K.E. \propto \frac{3^2}{2^2} = \frac{9}{4}$$

Thus, K.E. is highest for first orbit of He^+.

2. (c) As per Bohr's postulate,

$$mvr = \frac{nh}{2\pi} \quad \text{So, } v = \frac{nh}{2\pi mr}$$

$$KE = \frac{1}{2}mv^2 \quad \text{So, } KE = \frac{1}{2}m\left(\frac{nh}{2\pi mr}\right)^2$$

Since, $r = \frac{a_o \times n^2}{z}$

So, for 2[nd] Bohr orbit

$$r = \frac{a_o \times 2^2}{1} = 4a_o$$

$$KE = \frac{1}{2}m\left(\frac{2^2 h^2}{4\pi^2 m^2 \times (4a_o)^2}\right) = \frac{h^2}{32\pi^2 m a_o^2}$$

3. (b) Average atomic mass of Fe

$$= \frac{(54 \times 5) + (56 \times 90) + (57 \times 5)}{100} = 55.95$$

4. (d) $r_n = 0.529\frac{n^2}{Z}$ Å

For hydrogen, $n = 1$ and $Z = 1$; $\therefore$ $r_H = 0.529$

For Be^{3+}, $n = 2$ and $Z = 4$;

$$\therefore r_{Be^{3+}} = \frac{0.529 \times 2^2}{4} = 0.529$$

5. (d) Rutherford's experiment was actually α-particle scattering experiment. α-Particle is doubly positively charged helium ion, i.e., He - nucleus.

6. (c) **X-rays** can ionise gases and cannot get deflected by electric and magnetic fields, wavelength of these rays is 150 to 0.1Å. Thus, the wavelength of X-rays is shorter than that of U.V. rays.

7. (c) Difference in the energy of the energy levels involved in the transition.

8. (a) Isotones have same number of neutrons. All atoms in triad (a) have same number of neutrons (i.e., $A - Z = 8$).

9. (d) $E = \frac{hc}{\lambda}$; $\lambda_1 = 2000$ Å; $\lambda_2 = 4000$ Å;

$$\text{so } \frac{E_1}{E_2} = \frac{\lambda_2}{\lambda_1} = \frac{4000}{2000} = 2$$

10. (b) Electrons in an atom occupy the extra nuclear region.

11. (b) The following is the increasing order of wavelength or decreasing order of energy of electromagnetic radiations :

cosmic rays
γ-rays
X-rays
UV-rays
Visible
Infra-red radiation
Micro waves
Radio waves

(↓ Increasing λ, Decreasing ν)

Among given choices, radiowaves have maximum wavelength.

12. (b) The radius of nucleus is of the order of 1.5×10^{-13} to 6.5×10^{-13} cm or 1.5 to 6.5 Fermi (1 Fermi = 10^{-13} cm)

13. (b) Bohr model can explain spectrum of atoms/ions containing one electron only.

14. (d) Energy is emitted when electron falls from higher energy level to lower energy level and energy is absorbed when electron moves from lower level to higher level. 1*s* is the lowest energy level of electron in an atom. $\therefore$ An electron in 1*s* level of hydrogen can absorb energy but cannot emit energy.

15. **(d)** $\frac{e}{m}$ for neutron $= \frac{0}{1} = 0$; α-particle $= \frac{2}{4} = 0.5$;

proton $= \frac{1}{1} = 1$; electron $= \frac{1}{1/1837} = 1837$

16. **(a)** According to Rutherford's experiment. "The central part consisting of whole of the positive charge and most of the mass, called nucleus, is extremely small in size compared to the size of the atom."

17. **(c)** Rutherford's scattering experiment led to the discovery of nucleus.

18. **(d)** No. of neutrons = Mass number – Atomic number $= 70 - 30 = 40$.

19. **(30)** For single electron system, $r_n = 52.9 \times \frac{n^2}{Z}$ pm

$105.8 = \frac{52.9 \times n_1^2}{2} \therefore n_1^2 = 4 \Rightarrow n_1 = 2$

$26.45 = \frac{52.9 \times n_2^2}{2} \therefore n_2 = 1$

So, transition is from 2 to 1.

Now $\frac{hc}{\lambda} = R_H Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

$\lambda = 30 \times 10^{-9}$ m = 30 nm

20. **(4)** Energy associated with incident photon $= \frac{hc}{\lambda}$

$$E = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9}} \text{J}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9} \times 1.6 \times 10^{-19}} \text{eV} = 4.16 \text{eV}$$

Photoelectric effect can take place only when $E_{photon} > \phi$

Thus, number of metals showing photoelectric effect will be 4 (*i.e.* Li, Na, K and Mg).

21. **(22.8)** For maximum energy, $n_1 = 1$ and $n_2 = \infty$

$$\frac{1}{\lambda} = R_H Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

Since R_H is a constant and transition remains the same

$\frac{1}{\lambda} \propto Z^2$; $\frac{\lambda_{He}}{\lambda_H} = \frac{Z_H^2}{Z_{He}^2} = \frac{1}{4}$

Hence, $\lambda_{He} = \frac{1}{4} \times 91.2 =$ **22.8 nm**

22. **(27419)** The shortest wavelength transition in the Balmer series corresponds to the transition

$n = 2 \rightarrow n = \infty$. Hence, $n_1 = 2, n_2 = \infty$

$$\bar{v} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = (109677 \text{cm}^{-1}) \left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$$

$= \mathbf{27419.25\ cm^{-1}}$

23. **(2055)** E_n of H $= \frac{-21.76 \times 10^{-19}}{n^2}$ J

$\therefore E_n$ of $He^+ = \frac{-21.76 \times 10^{-19}}{n^2} \times Z^2$ J

$\therefore E_3$ of $He^+ = \frac{-21.76 \times 10^{-19} \times 4}{9}$ J

Hence, energy equivalent to E_3 must be supplied to remove the electron from 3rd orbit of He^+. Wavelength corresponding to this energy can be determined by applying the relation.

$$E = \frac{hc}{\lambda} \quad \text{or } \lambda = \frac{hc}{E} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8 \times 9}{21.76 \times 10^{-19} \times 4}$$

$= 2055 \times 10^{-10}$ m = **2055 Å**

24. **(1220)** (i) Energy of n^{th} orbit $= E_n = \frac{E_1}{n^2}$

(ii) Difference in energy $= E_1 - E_2 = h\nu = \frac{hc}{\lambda}$

or $\lambda = \frac{hc}{E_1 - E_2}$

Given $E_1 = 2.17 \times 10^{-11}$

$\therefore$ Energy of second orbit $= E_2 = \frac{2.17 \times 10^{-11}}{2^2}$

$= 0.5425 \times 10^{-11}$ erg

$\Delta E = E_1 - E_2 = 2.17 \times 10^{-11} - 0.5425 \times 10^{-11}$

$= 1.6275 \times 10^{-11}$ erg

$$\lambda = \frac{6.62 \times 10^{-27} \times 3 \times 10^{10}}{1.6275 \times 10^{-11}} = 12.20 \times 10^{-6} \text{cm} = \mathbf{1220\ Å}$$

25. **(660)** $\Delta E = E_3 - E_2 = h\nu = \frac{hc}{\lambda}$ or $\lambda = \frac{hc}{E_3 - E_2}$

Given $E_2 = -5.42 \times 10^{-12}$ erg, $E_3 = -2.41 \times 10^{-12}$ erg

$$\therefore \lambda = \frac{6.626 \times 10^{-27} \times 3 \times 10^{10}}{-2.41 \times 10^{-12} - (-5.42 \times 10^{-12})}$$

$$= \frac{19.878 \times 10^{-17}}{3.01 \times 10^{-12}} = 6.604 \times 10^{-5} \text{cm} = \mathbf{660\ nm}$$

26. **photons**

27. **isobars**

28. **neutrons**

29. **1.66×10^{-27} kg**

Mass of hydrogen atom

$$= \frac{\text{Atomic mass of hydrogen}}{\text{Avogadro number}} = \frac{1.008}{6.02 \times 10^{23}}$$

$= 0.166 \times 10^{-23}$ g $= 1.66 \times 10^{-27}$ kg

30. **True :** β-particles are deflected more than α-particles because they have very-very large *e/m* value as compared to α-particles due to the fact that electrons are much lighter than He^{2+} species.

31. **False :** Gamma rays are electromagnetic radiations of wavelengths 10^{-9} cm to 10^{-10} cm.

32. **(a, d)** The energy of an electron on Bohr orbits of hydrogen atoms is given by the expression

$$E_n = -\frac{\text{Constant}}{n^2}$$

Where *n* takes only integral values. For the first Bohr orbit, $n = 1$ and it is given that $E_1 = -13.6$ eV

Hence $E_n = -\frac{13.6\text{eV}}{n^2}$ of the given values of energy, only -3.4 eV and -1.5 eV can be obtained by substituting $n = 2$ and 3 respectively in the above expression.

33. **(b, d)** In tritium (the isotope of hydrogen) nucleus there is one proton and 2 neutrons. $\therefore n + p = 3$. In deuterium nucleus there is one proton and one neutron $\therefore n + p = 2$.

34. **(a, c)** α-particles pass through because most part of the atom is empty.

35. **(a, c)** Because they have isotopes with different masses. The average atomic mass is the weighted mean of their presence in nature; e.g., Cl^{35} and Cl^{37} are present in ratio 3 : 1 in nature.

So $A = \frac{35 \times 3 + 37 \times 1}{4} = 35.5$

36. **(b, d)** $^{77}_{33}$As and $^{78}_{34}$Se have same number of neutrons $(= A - Z)$ as $^{76}_{32}$Ge.

37. **(d)** $r \propto \frac{n^2}{Z}$ or $r = 0.529 \times \frac{n^2}{Z}$; (I), (T)

$|L| \propto n$ or $mvr = \frac{nh}{2\pi}$; (II), (S)

38. Determination of number of moles of hydrogen gas,

$$n = \frac{PV}{RT} = \frac{1 \times 1}{0.082 \times 298} = 0.0409$$

The concerned reaction is $H_2 \longrightarrow 2H$; $\Delta H = 436$ kJ mol^{-1}

Energy required to bring 0.0409 moles of hydrogen gas to atomic state $= 436 \times 0.0409 =$ **17.83 kJ**

Calculation of total number of hydrogen atoms in 0.0409 mole of H_2 gas.

1 mole of H_2 gas has 6.02×10^{23} molecules

0.0409 mole of H_2 gas $= \frac{6.02 \times 10^{23}}{1} \times 0.0409$ molecules

Since, 1 molecule of H_2 gas has 2 hydrogen atoms

$6.02 \times 10^{23} \times 0.0409$ molecules of H_2 gas

$= 2 \times 6.02 \times 10^{23} \times 0.0409 = 4.92 \times 10^{22}$ atoms of hydrogen

Since, energy required to excite an electron from the ground state to the next excited state is given by

$$E = 13.6\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)\text{eV}$$

$$= 13.6 \times \left(\frac{1}{1} - \frac{1}{4}\right) = 13.6 \times \frac{3}{4} = 10.2\text{eV} = 1.632 \times 10^{-21}\text{ kJ}$$

Therefore, energy required to excite 4.92×10^{22} electrons $= 1.632 \times 10^{-21} \times 4.92 \times 10^{22}$ kJ $= 8.03 \times 10 = 80.3$ kJ

Therefore, total energy required $= 17.83 + 80.3 =$ **98.17 kJ**

39. Work done while bringing an electron infinitely slowly from infinity to proton of radius a_0 is given as follows

$$W = -\frac{e^2}{4\pi\varepsilon_0 . a_0}$$

This work done is equal to the total energy of an electron in its ground state in the hydrogen atom. At this stage, the electron is not moving and do not possess any K.E., so this total energy is equal to the potential energy.

$$\text{T.E.} = \text{P. E} + \text{K. E.} = \text{P. E.} = -\frac{e^2}{4\pi\varepsilon_0 . a_0} \quad ...(1)$$

In order the electron to be captured by proton to form a ground state hydrogen atom it should also attain

$$\text{K.E.} = \frac{e^2}{8\pi\varepsilon_0 a_0}$$

(It is given that magnitude of K.E. is half the magnitude of P.E. Note that P.E. is –ve and K.E is +ve)

$$\therefore \text{ T.E} = \text{P. E.} + \text{K. E.} = -\frac{e^2}{4\pi\varepsilon_0 a_0} + \frac{e^2}{8\pi\varepsilon_0 a_0}$$

or $\text{T.E.} = -\frac{e^2}{8\pi\varepsilon_0 a_0}$

$$\text{P.E.} = 2 \times \text{T.E.} = 2 \times \frac{-e^2}{8\pi \epsilon_0 a_0} \text{ or P.E.} = \frac{-e^2}{4\pi \epsilon_0 a_0}$$

40. Bond energy of $I_2 = 240$ kJ mol^{-1} $= 240 \times 10^3$ J mol^{-1}

$$= \frac{240 \times 10^3}{6.023 \times 10^{23}}\text{ J molecule}^{-1} = 3.984 \times 10^{-19}\text{ J molecule}^{-1}$$

Energy absorbed $= \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\text{ Js}\times3\times10^{8}\text{ ms}^{-1}}{4500\times10^{-10}\text{ m}}$

$= 4.417\times10^{-19}\text{ J}$

Kinetic energy = Absorbed energy – Bond energy

$\therefore$ Kinetic energy $= 4.417\times10^{-19} - 3.984\times10^{-19}$ J

$= 4.33\times10^{-20}$ J

$\therefore$ Kinetic energy of each atom of iodine

$= \frac{4.33\times10^{-20}}{2} = \mathbf{2.165\times10^{-20}\ J}$

41. Number of waves $= \frac{n(n-1)}{2}$

where n = Principal quantum number or number of orbit

Number of waves $= \frac{3(3-1)}{2} = \frac{3\times2}{2} = 3$

42. For He^+ ion, we have

$$\frac{1}{\lambda} = Z^2R_H\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$$

$$= (2)^2R_H\left[\frac{1}{(2)^2}-\frac{1}{(4)^2}\right] = R_H\frac{3}{4} \quad \text{...(i)}$$

Now for hydrogen atom $\frac{1}{\lambda} = R_H\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$ ...(ii)

Equating equations (i) and (ii), we get

$$\frac{1}{n_1^2}-\frac{1}{n_2^2} = \frac{3}{4}$$

Obviously, $n_1 = 1$ and $n_2 = 2$

Hence, the transition $\boldsymbol{n = 2}$ to $\boldsymbol{n = 1}$ in hydrogen atom will have the same wavelength as the transition, $n = 4$ to $n = 2$ in He^+ species.

43. $\Delta E = RhcZ^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$

Here, $R = 1.0967\times10^7\text{ m}^{-1}$

$h = 6.626\times10^{-34}$ J sec, $c = 3\times10^8$ m/sec

$n_1 = 1, n_2 = 2$ and for H-atom, $Z = 1$

$$E_2 - E_1 = 1.0967\times10^7\times6.626\times10^{-34}\times3\times10^8\left(\frac{1}{1}-\frac{1}{4}\right)$$

$$\Delta E = 1.0967\times6.626\times3\times\frac{3}{4}\times10^{-19}\text{ J} = 16.3512\times10^{-19}\text{ J}$$

$$= \frac{16.3512\times10^{-19}}{1.6\times10^{-19}}\text{ eV} = \mathbf{10.22\ eV}$$

$$\Delta E = \frac{hc}{\lambda} = RhcZ^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$$

$$\frac{1}{\lambda} = RZ^2\left(\frac{1}{1}-\frac{1}{4}\right) = RZ^2\times\frac{3}{4}$$

Given, $\lambda = 3\times10^{-8}$ m

$$\therefore \frac{1}{3\times10^{-8}} = 1.0967\times Z^2\times\frac{3}{4}\times10^7$$

$$\therefore Z^2 = \frac{10^8\times4}{3\times3\times1.0967\times10^7} = \frac{40}{9\times1.0967} \approx 4 \quad \therefore \mathbf{Z = 2}$$

So, it corresponds to He^+ which has 1 electron like hydrogen.

44. To calculate the energy required to remove electron from atom, $n = \infty$ is to be taken.

Energy of an electron in the n^{th} orbit of hydrogen is given by

$$E = -21.7\times10^{-12}\times\frac{1}{n^2}\text{ ergs}$$

$$\therefore \Delta E = -21.7\times10^{-12}\left(\frac{1}{2^2}-\frac{1}{\infty^2}\right)$$

$$= -21.7\times10^{-12}\left(\frac{1}{4}-0\right) = -21.7\times10^{-12}\times\frac{1}{4}$$

$$= \mathbf{-5.42\times10^{-12}\ ergs}$$

Now we know that $\Delta E = h\nu$

$$\therefore \quad \Delta E = \frac{hc}{\lambda}\left(\because \nu = \frac{c}{\lambda}\right) \quad \text{or} \quad \lambda = \frac{hc}{\Delta E}$$

Substituting the values, $\lambda = \frac{6.627\times10^{-27}\times3\times10^{10}}{5.42\times10^{-12}}$

$= \mathbf{3.67\times10^{-5}\ cm}$

45. Let the % of isotope with At. wt. 10.01 = x

$\therefore$ % of isotope with At. wt. 11.01 = $(100 - x)$

At. wt. of boron $= \frac{x\times10.01+(100-x)\times11.01}{100}$

$\Rightarrow 10.81 = \frac{x\times10.01+(100-x)\times11.01}{100} \quad \therefore x = 20$

Hence, % of isotope with At. wt. 10.01 = 20%

$\therefore$ % of isotope with At. wt. 11.01 = 100 – 20 = **80%**.

Topic-2: Advancement Towards Quantum Mechanical Model of Atom

1. **(a)** According to de-Broglie's equation

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Given, $h = 6.6 \times 10^{-34}$ Js, $m = 200 \times 10^{-3}$ kg

$$v = \frac{5}{60 \times 60} \text{m/s} \quad \lambda = \frac{6.6 \times 10^{-34}}{200 \times 10^{-3} \times 5/(60 \times 60)}$$

$= 2.38 \times 10^{-10}$ m

2. **(d)** As packet of energy equal to $h\nu$; as wave having frequency ν.

3. **(30)** $p = \frac{h}{\lambda} \Rightarrow \frac{6.6 \times 10^{-34} \text{kgm}^2/\text{s}^2}{330 \times 10^{-9} \text{m}}$

$$= \frac{4 \times 10^{-3} \text{kg mol}^{-1}}{6 \times 10^{23} \text{mol}^{-1}} \times v \ (p = m \times v)$$

$v = 0.3$ m/s $= 30$ cm/s

4. **(5)** Since,

$$\lambda = \frac{h}{mV} = \frac{h}{\sqrt{2MK.E}} \ (\text{since K.E.} \propto T) \Rightarrow \lambda \propto \frac{1}{\sqrt{MT}}$$

For two gases,

$$\frac{\lambda_{He}}{\lambda_{Ne}} = \sqrt{\frac{M_{Ne}T_{Ne}}{M_{He}T_{He}}} = \sqrt{\frac{20}{4} \times \frac{1000}{200}} = 5$$

5. orbitals

6. Heisenberg, de-Broglie

7. **(a, b, c)**

(a) Uncertainty principle rules out existence of definite paths or trajectories of electron and other similar particles.

So, option (a) is correct.

(b) Shell or orbit more near to nucleus has less energy than far away.

So, option (b) is also correct.

(c) $E = -13.6 \frac{Z^2}{n^2}$ eV/atom

So, $n = 1$ has most negative energy.

So, option (c) is also correct.

(d) $V_e = V_0 \times \frac{Z}{n}$

When n increase velocity decreases.

So, option (d) is incorrect.

8. For hydrogen atom, $Z = 1, n = 1$

$$v = 2.18 \times 10^6 \times \frac{Z}{n} \text{ms}^{-1} = 2.18 \times 10^6 \text{ms}^{-1}$$

de Broglie wavelength,

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{9.1 \times 10^{-31} \times 2.18 \times 10^6}$$

$= \mathbf{3.34 \times 10^{-10}}$ **m** $= 3.3$ Å

For $2p$, $l = 1$

$\therefore$ Orbital angular momentum $= \sqrt{l(l+1)}\frac{h}{2\pi} = \sqrt{2}\frac{h}{2\pi}$

9. $\lambda = \frac{h}{mu} = \frac{6.627 \times 10^{-34}}{0.1 \times 100}$

or $\lambda = \mathbf{6.627 \times 10^{-35}}$ **m** $= \mathbf{6.627 \times 10^{-25}}$ **Å**

10. ψ_{2s}^2 = probability of finding electron within $2s$ sphere

$\psi_{2s}^2 = 0$ (at node)

($\because$ probability of finding an electron is zero at node)

$$\therefore 0 = \frac{1}{32\pi}\left(\frac{1}{a_0}\right)^3 \left(2 - \frac{r_0}{a_0}\right)^2 e^{-\frac{2r_0}{a_0}}$$

(Squaring the given value of ψ_{2s})

or $\left[2 - \frac{r_0}{a_0}\right] = 0$; $\therefore 2 = \frac{r_0}{a_0}$; $\mathbf{2a_0 = r_0}$

Topic-3: Quantum Mechanical Model of Atom

1. **(a)** Number of radial nodes $= (n - l - 1)$

For $3s$: $n = 3, l = 0$ (Number of radial node $= 2$)

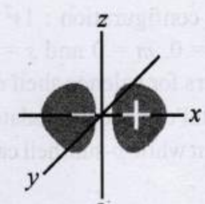
For $2p$: $n = 2, l = 1$ (Number of radial node $= 0$)

2. **(c)** Only two e^- can exist in the same orbital.

3. **(d)** The quantum numbers $+1/2$ and $-1/2$ for the electron spin can represent any one among clockwise or anticlockwise spin direction. But if one value represents clockwise spin then the other value will represent anticlockwise spin.

4. **(b)** $3d^5 4s^1$ system is more stable than $3d^4 4s^2$, hence former is the ground state configuration.

5. **(a)** p_x orbital being dumbell shaped, have number of nodal planes = 1, in yz plane. The electron density is only along x-axis (xy and zx planes), thus, in yz-plane, there will be zero electron density.



$2p_x$

6. **(a)** The two guiding rules to arrange the various orbitals in the increasing energy are:

(i) Energy of an orbital increases with increase in the value of $n + l$.

(ii) Of orbitals having the same value of $n + l$, the orbital with lower value of n has lower energy.

Thus, for the given orbitals, we have

(i) $n+l=4+1=5$ (ii) $n+l=4+0=4$
(iii) $n+l=3+2=5$ (iv) $n+l=3+1=4$
Hence, the order of increasing energy is
(iv) < (ii) < (iii) < (i)

7. **(a)** The expression for orbital angular momentum is

$$\text{Angular momentum} = \sqrt{l(l+1)}\left(\frac{h}{2\pi}\right)$$

For d orbital, $l=2$.

$$\text{Hence, } L = \sqrt{2(2+1)}\left(\frac{h}{2\pi}\right) = \sqrt{6}\left(\frac{h}{2\pi}\right)$$

8. **(b)** Orbital angular momentum $(mvr) = \frac{h}{2\pi}\sqrt{l(l+1)}$

For 2s orbital, l (azimuthal quantum number) = 0
∴ Orbital angular momentum = 0.

9. **(c)** Total nodes = $n-l$
No. of radial nodes = $n-l-1$
No. of angular nodes = l
For 3p sub-shell, $n=3$, $l=1$
∴ No. of radial nodes = $n-l-1 = 3-1-1 = 1$
∴ No. of angular nodes = $l = 1$

10. **(c)** Electronic configuration of chlorine is [Ne] $3s^2, 3p^5$
∴ Unpaired electron is found in 3p sub-shell.
∴ $n=3$, $l=1$, $m=1$

11. **(a)** Exactly half filled orbitals are more stable than nearly half filled orbitals.

Cr (At. no. 24) has configuration [Ar] $3d^5, 4s^1$.

12. **(c)** Configuration ns^2, np^5 means it requires only one electron to attain nearest noble gas configuration. So, it will be most electronegative element among given choices.

13. **(b)** According to Aufbau principle, the orbital of lower energy (2s) should be fully filled before the filling of orbital of higher energy starts.

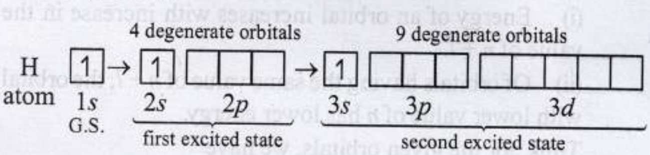
14. **(c)** If $l=2$, $m \neq -3$, m will vary from -2 to $+2$. *i.e.* possible values of m are $-2, -1, 0, +1$ and $+2$.

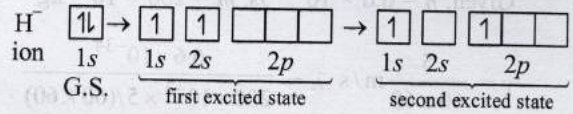
15. **(a)** Rb has the configuration : $1s^2\ 2s^2p^6\ 3s^2p^6d^{10}\ 4s^2p^6\ 5s^1$; so $n=5$, $l=0$, $m=0$ and $s=+½$ is correct set of quantum numbers for valence shell electron of Rb.

16. **(d)** One p-orbital can accommodate up to two electrons with opposite spin while p-subshell can accommodate upto six electrons.

17. **(a)** The principal quantum number (n) is related to the size of the orbital ($n = 1, 2, 3$.....)

18. **(3)** In one electron system, all orbitals of a shell are degenerate.





In case of many electron system, different orbitals of a shell are non-degenerate. Hence, in the second excited state, only three p-orbitals (2p) are degenerate.

19. **(6)** $|m_l| = 1$ means m_l can be $+1$ and -1.

For $n=4$, the total number of possible orbitals are :

4s	4p			4d					4f						
0	−1	0	+1	−2	−1	0	+1	+2	−3	−2	−1	0	+1	+2	+3

Thus, total number of orbitals having $|m_l| = 1$ is 6.
The number of electrons with $s = -1/2$ is 6.

20. **(9)**
Maximum number of orbitals when $n=3$ is $n^2 = 3^2 = 9$

∴ Number of electrons with $m_s = -\frac{1}{2}$ will be 9.

21. **(10)** For $n=3$ and $l=2$ (*i.e.*, 3d orbital), the values of m varies from -2 to $+2$, *i.e.* $-2, -1, 0, +1, +2$ and for each 'm' there are 2 values of 's', *i.e.* $+½$ and $-½$.
∴ Maximum no. of electrons in all the five d-orbitals is 10.

22. **$4s^1, 3d^5$;**
The electronic configuration of Cr is : $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$.
∴ Outermost electronic configuration is $3d^5, 4s^1$.

23. **orientation in space**

24. **antiparallel; or opposite**

25. **False :** The orbital $3d_{x^2-y^2}$ lie along X and Y axis where electron density is maximum.

26. **True :** In case of hydrogen (single electron system), energy of electron depends only on the principal quantum number. Thus, 4s is in higher energy level than 3d.

27. **False :** The outer electronic configuration of the ground state chromium atom is $3d^5 4s^1$, as half filled orbitals are more stable than nearly half filled orbitals.

28. **(a, c)** Given, azimuthal quantum no. (l) = 2 (d-subshell)
Magnetic quantum no.(m) = 0(zero), which is for d_{z^2} orbital.

$$E = -13.6\frac{z^2}{n^2} = -13.6 \times \frac{2^2}{n^2} = -3.4$$

$$13.6 \times \frac{2^2}{n^2} = 3.4$$

$n^2 = 4^2 \Rightarrow n = 4$
Radial node = $n-l-1 = 4-2-1 = 1$
Angular node = $l = 2$
Wave function corresponds to $\psi_{4,2,0}$. It represents $4d_{z^2}$-orbital which has only one radial node and two angular nodes. It experiences nuclear charge of 2e units.

29. **(a, d)** According to Hund's rule pairing of electrons starts only when each of the orbital in a sub shell has one electron each of parallel spin.

$\therefore$ (a) and (d) are correct ground state electronic configurations of nitrogen atom in ground state.

30. **(a, b, c)**

(a) $_{24}Cr = 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^5, 4s^1 = [Ar]\,3d^5, 4s^1$

(b) For magnetic quantum number (m), negative values are possible.

For s - subshell, $l = 0$, hence $m = 0$

for p - subshell, $l = 1$, hence $m = -1, 0, +1$

(c) $_{47}Ag = 1s^2, 2s^2\,2p^6, 3s^2 3p^6 3d^{10}, 4s^2\,4p^6\,4d^{10}, 5s^1$

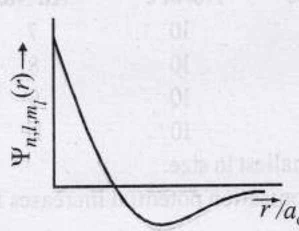
Hence, 23 electrons have a spin of one type and 24 of the opposite type.

(d) Oxidation state of N in HN_3 is $-1/3$.

31. **(c)** No. of radial nodes $= n - l - 1$, For $2s$ orbital, $n = 2, l = 0$

$\therefore$ No. of radial nodes $= 2 - 0 - 1 = 1$

The plotted graph is correct for $2s$-orbital, as wave function changes its sign at node.



32. **(a)** E.C. of H : $1s^1$; for $1s$ orbital

$$\psi_{n,l,m} \propto \left(\frac{Z}{a_0}\right)^{3/2} e^{-(Zr/a_0)}$$

For s-orbital, θ and ϕ cannot be a part of wave function expression. Hence, this is correct.

For $1s$ orbital of hydrogen like species: $E \propto -\frac{1}{n^2}$

Then, $E_4 - E_2 = \left(\frac{1}{2}\right)^2 - \left(\frac{1}{4}\right)^2 = \frac{3}{16}$

$E_6 - E_2 = \left(\frac{1}{2}\right)^2 - \left(\frac{1}{6}\right)^2 = \frac{8}{36}$

$\therefore (E_4 - E_2) = \frac{27}{32} \times (E_6 - E_2)$

33. **(c)** In the wave function (ψ) expression for $1s$-orbital of He^+, there should be no angular part (θ).

34. **(A) - (q); (B) - (p, q, r, s); (C) - (p, q, r); (D) - (p, q, r)**

(A) Orbital angular momentum $L = \sqrt{l(l+1)}\frac{h}{2\pi}$, i.e., L depends on azimuthal quantum number only.

(B) To describe a hydrogen like one-electron wave function, three quantum numbers n, l and m are required. Further, to obey Pauli principle, fourth quantum number s is also required.

(C) To define size, shape and orientation of atomic orbitals, n, l and m are required respectively.

(D) Probability density (ψ^2) of an electron can be determined from the value of n, l and m.

35. **(A) - (r); (B) - (q); (C) - (p); (D) - (s)**

(A) $\frac{V_n}{K_n} = \frac{-Kze^2/r}{Kze^2/2r} = -2$; where $K = \frac{1}{4\pi\varepsilon_0}$

(B) $r_n = \frac{n^2 h^2 \varepsilon_0}{\pi m Z e^2}, E_n = \frac{me^4}{8\varepsilon_0^2 h^2 n^2}$

$\Rightarrow E_n \propto \frac{1}{n^2} \propto \frac{1}{r_n} \Rightarrow r_n \propto \frac{1}{E_n}$

$\Rightarrow r_n \propto (E_n)^{-1} \Rightarrow x = -1$

(C) Angular momentum of electron in lowest ($1s$) orbital

$= \sqrt{l(l+1)}\frac{h}{2\pi} = \sqrt{0(0+1)}\frac{h}{2\pi} = 0;$

(D) $r_n = \frac{a_0 n^2}{Z} \Rightarrow \frac{1}{r_n} \propto Z^1 \Rightarrow y = 1$

For 36-38 The spherically symmetric state S_1 of Li^{2+} with one radial node is $2s$. Upon absorbing light, the ion gets excited to state S_2, which also has one radial node. The energy of electron in S_2 is same as that of H-atom in its ground state.

$\therefore E_n = \frac{Z^2}{n^2} E_1$ where E_1 is the energy of H-atom in the ground state $= \frac{(3)^2 E_1}{n^2}$ for Li^{2+}

$E_n = E_1 \Rightarrow n = 3$

$\therefore$ State S_2 of Li^{2+} having one radial node is $3p$.

Orbital angular momentum quantum number of $3p$ is 1.

Energy of state $S_1 = \frac{(3)^2}{(2)^2} E_1 = 2.25 E_1$

36. **(b)** **37.** **(c)** **38.** **(b)**

39. Ground state electronic configuration of Si

↑↓		↑	↑	
$3s$		$3p_x$	$3p_y$	$3p_z$

In a subshell, single e⁻ occupied orbitals must have parallel spins.