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CHEMISTRY

Volume 1 & 2

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UNIT-2: QUANTUM MECHANICAL MODEL OF ATOM

EVALUATE YOURSELF

1. Calculate the de-Brogile wavelength of an electron that has been accelerated from rest through a potential difference of 1 ke V.

Accelerated potential = 1 keV

The kinetic energy of electron = The energy due to accelerating potential

$$\frac{1}{2}mV^2 = eV$$

$$mV^2 = 2eV$$

Multiply by 'm'

$$m^2V^2 = 2meV$$

$$mV = \sqrt{2meV} \quad \ldots (1)$$

De-broglie wavelength $\lambda = \frac{h}{mV}$ ... (2)

Substitute equation (1) in (2)

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$\lambda = \frac{6.626\times10^{-34}\,JS}{\sqrt{2\times9.1\times10^{-31}\times1keV}}$$

$$= \frac{6.626\times10^{-34}\,JS}{\sqrt{2\times9.1\times10^{-31}kg\times1\times10^{33}\times1.6\times10^{-19}kgJ}}$$

$$\lambda = 3.88 \times 10^{-11}\ m.$$

2. Calculate the uncertainty in the position of an electron, if the uncertainty in its velocity is 5.7×10^5 ms^{-1}. ***(JUNE 19)***

$\Delta V = 5.7 \times 10^5\ ms^{-1}$ $\quad m = 9.1 \times 10^{-3}$ kg $\quad \Delta x = ?$

$$\frac{h}{4\pi} = \frac{6.626\times10^{-24}}{4\times3.14} kgm^2s^{-1}$$

$$\frac{h}{4\pi} = 5.28\times10^{-35}\ kg\ m^2\ s^{-1}$$

log	value
5.28	0.7226 (-)
51.87	1.7149
	$\bar{1}$.0077

Antilog($\bar{1}$.0077) = 1.017×10^{-1}

Heisenberg's uncertainty principle $\Delta x.\ m\Delta V \geq \frac{h}{4\pi}$

$$\Delta x \geq \frac{h}{4\pi\times m\Delta V}$$

$$\geq \frac{5.28\times10^{-35}\,kgm^2s^{-1}}{9.1\times10^{-3}kg\times5.7\times10^5ms^{-1}} \geq \frac{5.28\times10^{-35}}{51.87\times10^{-26}}$$

$$\Delta x \geq 1.017 \times 10^{-10}m$$

3. How many orbitals are possible in the 4th energy level?

(n = 4) n = 4 $\quad$ *l* = 0, 1, 2, 3

Number of possible orbitals = $n^2 = 4^2 = 16$

4. Calculate the total of angular nodes and radial nodes present in 3d and 4f orbitals. ***(SEP 20)***

Orbital	**n**	***l***	**Radial Node $n - l - 1$**	**Angular node *l***	**Total node $n - 1$**
3d	3	2	0	2	2
4f	4	3	0	3	3

5. Energy of an electron in hydrogen atom in ground state is -13.6 eV. What is the energy of the electron in the second excited state?

$$E_n = \frac{-13.6}{n^2} \text{eV / atom}$$

Second excited state n = 3; $E_3 = \frac{-13.6}{9}$ eV = -1.51 eV/atom

6. How many unpaired electrons are present in the ground state Fe^{3+} (z = 26), Mn^{2+} (z = 25) and argon (z = 18)?

Electronic configuration Fe^{3+}

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$

$3d^5$

↑	↑	↑	↑	↑

5 unpaired electrons

Electronic configuration of Mn^{2+}

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$

$3d^5$

↑	↑	↑	↑	↑

5 unpaired electrons

Electronic configuration of Ar

$1s^2 2s^2 2p^6 3s^2 3p^6$ (No unpaired electrons)

7. Explain the meaning of the symbol $4f^2$. Write all the four quantum numbers for these electrons.

$4f^2$

n = 4; l = 3, m_l = –3, –2, –1, 0, +1, +2, +3

-3	-2	-1	0	+1	+2	+3
↑	↑					

All the four quantum number for the two electrons are

n = 4	Electron	n	l	m_l	m_s
	$1e^-$	4	3	-3	+1/2
	$2e^-$	4	3	-2	+1/2

8. Which has the stable electronic configuration? Ni^{2+} or Fe^{3+}.

Electronic configuration of Ni^{2+} : $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^8$

Electronic configuration of Fe^{3+} : $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$

Fe^{3+} has stable $3d^5$ half filled configuration.

EVALUATION

Choose the Best Answer

1. Electronic configuration of species M^{2+} is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ and its atomic weight is 56. The number of neutrons in the nucleus of species M is

(a) 26 (b) 22 (c) 30 (d) 24

Ans: (c) 30

Solution: $M^{2+} = 1s^2\ 2s^2\ 2P^6\ 3s^2\ 3p^6\ 3d^6$ $M = 1s^2\ 2s^2\ 2P^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$

Number of neutrons = Mass Number – Atomic Number

= 56 – 26 = 30

2. The energy of light of wavelength 45 nm is

(a) 6.67×10^{15} J (b) 6.67×10^{11} J (c) 4.42×10^{-18} J (d) 4.42×10^{-15} J

Ans: (c) 4.42×10^{-18} J

Solution: $E = h\upsilon = h\frac{c}{\lambda} = \frac{6.626\times10^{-34}\,Js\times3\times10^{8}\,ms^{-1}}{45\times10^{-9}\,m} = 4.42 \times 10^{-18}$ J

3. The energies E_1 and E_2 of two radiations are 25 eV and 50 eV respectively. The relation between their wavelengths i.e. λ_1 and λ_2 will be

(a) $\frac{\lambda_1}{\lambda_2} = 1$ (b) $\lambda_1 = 2\lambda_2$ (c) $\lambda_1 = \sqrt{25\times50}\lambda_2$ (d) $2\lambda_1 = \lambda_2$

Ans: (b) $\lambda_1 = 2\lambda_2$

Solution: $\frac{E_1}{E_2} = \frac{25eV}{50eV} = \frac{1}{2}$; $\frac{hc}{\lambda_1} / \frac{hc}{\lambda_2} = \frac{1}{2}$; $\frac{hc}{\lambda_1} \times \frac{\lambda_2}{hc} = \frac{1}{2}$; $2\lambda_2 = 1\lambda_1$

4. Splitting of spectral lines in an electric field is called ***(MAR 19, MAY 22)***

(a) Zeeman effect (b) Shielding effect (c) Compton effect (d) Stark effect

Ans: (d) Stark effect

5. Based on equation $E = -2.178 \times 10^{-18}\ J \left(\frac{z^2}{n^2}\right)$, certain conclusions are written. Which of them is not correct? ***(NEET)***

(a) Equation can be used to calculate the change in energy when the electron changes orbit

(b) For n = 1, the electron has a more negative energy than it does for n = 6, which means that the electron is more loosely bound in the smallest allowed orbit

(c) The negative sign in equation simply means that the energy of electron bound to the nucleus is lower than it would be if the electrons were at the infinite distance from the nucleus

(d) Larger the values of n, the larger is the orbit radius

Ans: (b) For n = 1, the electron has a more negative energy than it does for n = 6, which means that the electron is more loosely bound in the smallest allowed orbit

6. According to the Bohr Theory, which of the following transitions in the hydrogen atom will give rise to the least energetic photon?

(a) n = 6 to n = 1 (b) n = 5 to n = 4 (c) n = 5 to n = 3 (d) n = 6 to n = 5

Ans: (d) n = 6 to n = 5

Solution: n = 6 to n = 5

$E_6 = \frac{-13.6}{6^2}$; $E_5 = \frac{-13.6}{5^2}$

$$E_6 - E_5 = \left(\frac{-13.6}{6^2}\right) - \left(\frac{-13.6}{5^2}\right) = \frac{-13.6}{36} + \frac{13.6}{25} = 0.166 \text{ eV atom}^{-1}$$

$$E_5 - E_4 = \left(\frac{-13.6}{5^2}\right) - \left(\frac{-13.6}{4^2}\right) = \frac{-13.6}{25} + \frac{13.6}{16} = 0.306 \text{ eV atom}^{-1}$$

7. **Assertion :** The spectrum of He^+ is expected to be similar to that of hydrogen.

Reason : He^+ is also one electron system.

(a) If both assertion and reason are true and reason is the correct explanation of assertion

(b) If both assertion and reason are true but reason is not the correct explanation of assertion

(c) If assertion is true but reason is false (d) If both assertion and reason are false

Ans: (a) If both assertion and reason are true and reason is the correct explanation of assertion

8. Which of the following pairs of d-orbitals will have electron density along the axes? ***(NEET Phase-II)***

(a) d_{z^2}, d_{xz} (b) d_{xz}, d_{yz} (c) $d_{z^2}, d_{x^2-y^2}$ (d) $d_{xy}, d_{x^2-y^2}$

Ans: (c) $d_{z^2}, d_{x^2-y^2}$

9. Two electrons occupying the same orbital are distinguished by ***(JULY 23)***

(a) azimuthal quantum number (b) spin quantum number

(c) magnetic quantum number (d) orbital quantum number

Ans: (b) spin quantum number

10. The electronic configuration of Eu (Atomic No. 63) Gd (Atomic No. 64) and Tb (Atomic No. 65) are ***(NEET Phase II)***

(a) [Xe] $4f^6 5d^1 6s^2$, [Xe] $4f^7 5d^1 6s^2$ and [Xe] $4f^8 5d^1 6s^2$

(b) [Xe] $4f^7$ $6s^2$, [Xe] $4f^7$ $5d^1$ $6s^2$ and [Xe] $4f^9$ $6s^2$
(c) [Xe] $4f^7$ $6s^2$, [Xe] $4f^8$ $6s^2$ and [Xe] $4f^8$ $5d^1$ $6s^2$
(d) [Xe] $4f^6$ $5d^1$ $6s^2$, [Xe] $4f^7$ $5d^1$ $6s^2$ and [Xe] $4f^9$ $6s^2$

Ans: (b) [Xe] $4f^7$ $6s^2$, [Xe] $4f^7$ $5d^1$ $6s^2$ and [Xe] $4f^9$ $6s^2$

11. The maximum number of electrons in a sub shell is given by the expression *(MARCH 24)*
(a) $2n^2$ (b) $2l + 1$ (c) $4l + 2$ (d) none of these

Ans: (c) $4l + 2$

Solution: $2(2l + 1) = 4l + 2$

12. For d-electron, the orbital angular momentum is
(a) $\frac{\sqrt{2}h}{2\pi}$ (b) $\frac{\sqrt{2h}}{2\pi}$ (c) $\frac{\sqrt{2\times 4}h}{2\pi}$ (d) $\frac{\sqrt{6}h}{2\pi}$

Ans: (d) $\frac{\sqrt{6}h}{2\pi}$

Solution: Orbital angular momentum $= \sqrt{l(l+1)}\frac{h}{2\pi} = \sqrt{2(2+1)}\frac{h}{2\pi} = \sqrt{6}\frac{h}{2\pi}$

13. What is the maximum numbers of electrons that can be associated with the following set of quantum numbers? n = 3, l = 1 and m = -1.
(a) 4 (b) 6 (c) 2 (d) = 10

Ans: (c) 2

14. **Assertion :** Number of radial and angular nodes for 3p orbital are 1, 1 respectively.
Reason : Number of radial and angular nodes depends only on principal quantum number.
(a) both assertion and reason are true and reason is the correct explanation of assertion
(b) both assertion and reason are true but reason is not the correct explanation of assertion
(c) assertion is true but reason is false (d) both assertion and reason are false

Ans: (c) Assertion is true but reason is false

15. The total number of orbitals associated with the principal quantum number n = 3 is *(JUL 22, MAR 23)*
(a) 9 (b) 8 (c) 5 (d) 7

Ans: (a) 9

Solution: Number of orbitals $= n^2 = 3^2 = 9$ orbitals

16. If n = 6, the correct sequence for filling of electrons will be,
(a) ns → (n – 2) f → (n – 1) d → np (b) ns → (n – 1) d → (n – 2) f → np
(c) ns → (n – 2) f → np → (n – 1) d (d) none of these are correct

Ans: (a) ns → (n – 2) f → (n – 1) d → np

17. Consider the following sets of quantum numbers:

	n	l	m	s
i)	3	0	0	$+\frac{1}{2}$
ii)	2	2	1	$-\frac{1}{2}$
iii)	4	3	-2	$+\frac{1}{2}$
iv)	1	0	-1	$+\frac{1}{2}$
v)	3	4	3	$-\frac{1}{2}$

Which of the following sets of quantum number is not possible?
(a) (i), (ii), (iii) and (iv) (b) (ii), (iv) and (v) (c) (i) and (iii) (d) (ii), (iii) and (iv)

Ans: (b) (ii), (iv) and (v)

18. How many electrons in an atom with atomic number 105 can have (n + *l*) = 8?
(a) 30 (b) 17 (c) 15 (d) unpredictable

Ans: (b) 17

Solution: Electronic configuration [Rn] $5f^{14}\,6d^{3}.7s^{2}$

Orbital	(n + *l*)	Number of electrons
5f	5 + 3 = 8	14
6d	6 + 2 = 8	3
7s	7 + 0 = 7	2 (Not to be counted)
Number of electrons		14 + 3 = 17

19. Electron density in the yz plane of $3d_{x^2-y^2}$ orbital is
(a) zero (b) 0.50 (c) 0.75 (d) 0.90

Ans: (a) zero

20. If uncertainty in position and momentum are equal, then minimum uncertainty in velocity is
(a) $\frac{1}{m}\sqrt{\frac{h}{\pi}}$ (b) $\sqrt{\frac{h}{\pi}}$ (c) $\frac{1}{2m}\sqrt{\frac{h}{\pi}}$ (d) $\frac{h}{4\pi}$

Ans: (c) $\frac{1}{2m}\sqrt{\frac{h}{\pi}}$

Solution:

$\Delta x.\,\Delta p \geq \frac{h}{4\pi}$	$\Delta v^2 \geq \frac{h}{4\pi m^2}$
$\Delta p.\,\Delta p \geq \frac{h}{4\pi}$	$(\Delta v) \geq \sqrt{\frac{h}{4\pi m^2}}$; $\Delta v \geq \frac{1}{2m}\sqrt{\frac{h}{\pi}}$
$\Delta p^2 \geq \frac{h}{4\pi}$; $m^2(\Delta v^2) \geq \frac{h}{4\pi}$	

21. A macroscopic particle of mass 100 g and moving at a velocity of 100 cm s^{-1} will have a de Broglie wavelength of
(a) 6.6×10^{-29} cm (b) 6.6×10^{-30} cm (c) 6.6×10^{-31} cm (d) 6.6×10^{-32} cm

Ans: (c) 6.6×10^{-31} cm

Solution: m = 100g = 100×10^{-3} kg V = 100 cms^{-1} = 100×10^{-2} ms^{-1}

$$\lambda = \frac{h}{mV} = \frac{6.626\times10^{-34}\,Js^{-1}}{100\times10^{-3}\,kg\times100\times10^{-2}\,ms^{-1}} = 6.626 \times 10^{-33}\ ms^{-1} = 6.626 \times 10^{-31}\ cms^{-1}$$

22. The ratio of de Broglie wavelengths of a deuterium atom to that of an α-particle, when the velocity of the former is five times greater than that of later, is
(a) 4 (b) 0.2 (c) 2.5 (d) 0.4

Ans: (d) 0.4

23. The energy of an electron in the 3rd orbit of hydrogen atom is –E. The energy of an electron in the first orbit will be ***(JUNE 19)***
(a) -3E (b) $\frac{-E}{3}$ (c) $\frac{-E}{9}$ (d) -9E

Ans: (d) -9E

24. Time independent Schrodinger wave equation is
(a) $\hat{H}\psi = E\psi$ (b) $\tilde{N}^2\psi + \frac{8\pi^2 m}{h^2}(E + V)\psi = 0$
(c) $\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} + \frac{2m}{h^2}(E - V)\psi = 0$ (d) all of these

Ans: (a) $\hat{H}\psi = E\psi$

25. Which of the following does not represent the mathematical expression for the Heisenberg uncertainty principle?
(a) $\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$ (b) $\Delta x \cdot \Delta v \geq \frac{h}{4\pi m}$ (c) $\Delta E \cdot \Delta t \geq \frac{h}{4\pi}$ (d) $\Delta E \cdot \Delta x \geq \frac{h}{4\pi}$

Ans: (d) $\Delta E \cdot \Delta x \geq \frac{h}{4\pi}$

ADDITIONAL QUESTIONS

26. The orientation of an atomic orbital is governed by
(a) Magnetic quantum number (b) Principal quantum number
(c) Azimuthal quantum number (d) Spin quantum number

Ans: (a) Magnetic quantum number

27. Which of the following is not permissible arrangement of electrons in an atom?
(a) n = 5, ℓ = 3, m = 0 , s = +1/2 (b) n = 3, ℓ = 2, m = -2 , s = -1/2
(c) n = 3, ℓ = 2, m = -3, s = -1/2 (d) n = 4, ℓ = 0, m = 0, s = -1/2

Ans: (c) n = 3, ℓ = 2, m = -3, s = -1/2

28. The orbital angular momentum of a p-electron is given as

(a) $\sqrt{3}\frac{h}{2\pi}$ (b) $\frac{\sqrt{3}}{2}\frac{h}{\pi}$ (c) $\sqrt{6}\sqrt{\frac{h}{2\pi}}$ (d) $\frac{h}{\sqrt{2\pi}}$

Ans: (d) $\frac{h}{\sqrt{2\pi}}$

29. How many electrons can fit in the orbital for which n = 3 and l = 1?

(a) 2 (b) 6 (c) 10 (d) 14

Ans: (b) 6

30. The maximum number of electrons that can be accommodated in L orbit is. ***(SEP 20)***

(a) 8 (b) 2 (c) 4 (d) 6

Ans: (a) 8

EVALUATION (BOOK BACK)

2, 3 and 5 Mark Question and Answers

26. Which quantum number reveal information about the shape, energy, orientation and size of orbitals?

1.	Shape	Subsidiary quantum number
2.	Energy	Principal quantum number
3.	Orientation	Magnetic quantum number
4.	Size	Principal quantum number

27. How many orbitals are possible for n = 4? ***(MAY 22)***

Number of orbitals possible $= n^2 = 4^2 = 16$

16 orbitals possible for n = 4

28. How many radial nodes for 2s, 4p, 5d and 4f orbitals exhibit? How many angular nodes? ***(SEP 20)***

Orbital	n	l	Radial Nodes $n - l - 1$	Angular Nodes
2s	2	0	1	0
4p	4	1	2	1
5d	5	2	2	2
4f	4	3	0	3

[**Hint:** For 's' orbital, radial node = n – 1; For p, d & f orbital, radial node = n – l – 1]

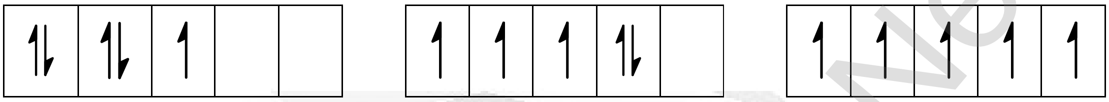
29. The stabilisation of a half filled d-orbital is more pronounced than that of the p-orbital. Why?

Total exchange energy for ‘d’ orbital = 10

Total exchange energy for ‘p’ orbital = 3

Half filled ‘d’ orbital has more exchange energy than that of ‘p’ orbital. So ‘d’ orbital is more stable.

30. Consider the following electronic arrangements for the d^5 configuration.



(a) (b) (c)

i) Which of these represents the ground state?

Figure (c) represents the ground state.

ii) Which configuration has the maximum exchange energy?

Figure (c) has the maximum exchange energy.

31. State and explain Pauli’s exclusion principle. ***(MAR 19, MAR 23)***

No two electrons in an atom can have the same set of values of all four quantum numbers.

32. Define orbital? What are the n and *l* values for $3p_x$ and $4d_{x^2-y^2}$ electron? ***(JUNE 19, JULY 23, MARCH 24)***

Orbital is a three dimensional space in which the probability of finding the electron is maximum.

Orbital	n	*l*
$3p_x$	3	1
$4d_{x^2-y^2}$	4	2

33. Explain briefly the time independent Schrodinger wave equation?

$\hat{H}\psi = E\psi$ ... (1)

$\hat{H}$ is called Hamiltonian operator

ψ is the wave function and is a function of position co-ordinates of the particle.

E is the energy of the system.

$$\hat{H} = \left[\frac{-h^2}{8\pi^2 m}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)+V\right] \quad ... (2)$$

Substitute (2) in (1)

$$\left[\frac{-h^2}{8\pi^2 m}\left(\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}\right)+V\psi\right] = E\psi$$

Multiply by $\frac{-8\pi^2 m}{h^2}$ and rearranging

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}-\frac{8\pi^2 m}{h^2}V\psi = E\psi\left(\frac{-8\pi^2 m}{h^2}\right)$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}+\frac{8\pi^2 m}{h^2}E\psi-\frac{8\pi^2 m}{h^2}V\psi = 0$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}+\frac{8\pi^2 m}{h^2}(E-V)\psi = 0$$

The above equation is known as time independent Schrodinger wave equation.

34. Calculate the uncertainty in position of an electron, if Δv = 0.1% and $\upsilon = 2.2 \times 10^6$ ms^{-1}.

$$\Delta x \,.\, \Delta p \geq \frac{h}{4\pi}$$

Δx . $(m\Delta v) \geq 5.28 \times 10^{-35}$ kg m^2 s^{-1}

Given Δv = 0.1%; V = 2.2×10^6 ms^{-1}; M = 9.1×10^{-31} kg

$$\Delta V = \frac{0.1}{100}\times 2.2\times10^6\,\text{ms}^{-1}$$

$$\Delta x \geq \frac{5.28\times10^{-35}\times 100\,\text{kg m}^2\text{s}^{-1}}{9.1\times10^{-31}\,\text{kg}\times2.2\times10^3\,\text{ms}^{-1}\times0.1}$$

Uncertainty in position $\Delta x \geq 2.6 \times 10^{-8}$ m.

35. Determine the values of all the four quantum numbers of the 8th electron in O atom and 15th electron in Cl atom and the last electron in chromium.

Electron type	Quantum No.
The 8th electron of O-atom	n = 2; l = 1, m = either +1 or -1; s = $-\frac{1}{2}$
15th electron of 'Cl' atom	n = 3; l = 1; m = either +1 or -1; s = $+\frac{1}{2}$
Last electron of 'Cr' atom	n = 3, l = 2, m = +2; s = $+\frac{1}{2}$

36. The quantum mechanical treatment of the hydrogen atom gives the energy value: $E_n = \frac{-13.6}{n^2}$ eV atom^{-1}

i) Use this expression to find ΔE between n = 3 and m = 4

ii) Calculate the wavelength corresponding to the above transition

i) $E_n = \frac{13.6}{n^2}$ eV atom^{-1} $n=3 \Rightarrow E_3 = \frac{-13.6}{3^2} = \frac{-13.6}{9} = -1.51$ eV atom^{-1} $n=4 \Rightarrow E_4 = \frac{-13.6}{4^2} = \frac{-13.6}{16} = -0.85$ eV atom^{-1} $\Delta E = (E_4 - E_3) = (-0.85) - (-1.51)$ $= -0.85 + 1.51$ $= +0.66$ eV atom^{-1}	ii) 1 eV = 1.6×10^{-19} J $\Delta E = 0.66 \times 1.66 \times 10^{-19}$ J $\Delta E = 1.06 \times 10^{-19}$ J $h\nu = 1.06 \times 10^{-19}$ J 1.06×10^{-19} J $= h.\frac{c}{\lambda}$ $\therefore \lambda = \frac{hc}{1.06 \times 10^{-19} J} = \frac{6.626 \times 10^{-34} JS \times 3 \times 10^{8} ms^{-1}}{1.06 \times 10^{-19} J}$ $\lambda = 1.875 \times 10^{-6}$ m

37. How fast must a 54 g tennis ball travel in order to have a de Broglie wavelength that is equal to that of a photon of green light 5400 Å?

m = 54 g = 54×10^{-3} kg ; λ = 5400 Å = 5400×10^{-10} m ; V = ?

$\lambda = \frac{h}{mV}$; $V = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34} JS}{54 \times 10^{-3} kg \times 5400 \times 10^{-10} m}$

Velocity of the ball V = 2.27×10^{-26} m s^{-1}

38. For each of the following, give the sub level designation, the allowable m values and the number of orbitals

i) n = 4, *l* = 2 ii) n = 5, *l* = 3 iii) n = 7, *l* = 0

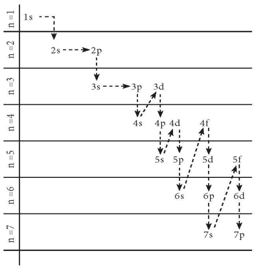
Sub level designation	Allowable 'm' values	Number of orbitals
i) n = 4; *l* = 2	m = –2, –1, 0, +1, +2	5
ii) n = 5; *l* = 3	m = –3, –2, –1, 0, +1, +2, +3	7
iii) n = 7; *l* = 0	m = 0	1

39. Give the electronic configuration of Mn^{2+} and Cr^{3+}. ***(JUL 22)***

$Mn^{2+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$ $Cr^{3+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3$

40. Describe the Aufbau principle.

In the ground state of atoms, the orbitals are filled in the order of their increasing energies.



41. An atom of an element contains 35 electrons and 45 neutrons. Deduce

i) The number of protons ii) The electronic configuration for the element

iii) All the four quantum numbers for the last electron

i) The number of protons = 35

ii) The electronic configuration for the element - $[Ar]\ 4s^2\ 3d^{10}\ 4p^5$

iii) All the four quantum number for the last electron - n = 4; l = 1; m = 0; s = $-\frac{1}{2}$

42. Show that the circumference of the Bohr orbit for the hydrogen atom is an integral multiple of the de Broglie wavelength associated with the electron revolving around the nucleus.

Circumference of the orbit = $n\lambda$ for Hydrogen atom n = 1 Circumference of the orbit in hydrogen atom = λ	$2\pi r = \lambda$ $2\pi r = \frac{h}{mV}\ (\because \lambda = \frac{h}{mV})$ $mVr = \frac{h}{2\pi}$

So, the circumference of the Bohr orbit for the hydrogen atom is an integral multiple of the de Broglie wavelength associated with the electron revolving around the nucleus.

43. Calculate the energy required for the process.

$He^{+}_{(g)} \longrightarrow He^{2+}_{(g)} + e^{-}$

The ionisation energy for the H atom in its ground state is –13.6 eV atom^{-1}.

$He^{+} \longrightarrow He^{2+} + e^{-}$ $E_n = \frac{-13.6z^2}{n^2}$ $E_1 = \frac{-13.6(2)^2}{(1)^2} = -56.4$	$E_\alpha = \frac{-13.6(2)^2}{(\alpha)^2} = 0$ Required energy for the given process $E_\alpha - E_1 = 0 - (-56.4) = 56.4$ eV

44. An ion with mass number 37 possesses unit negative charge. If the ion contains 11.1% more neutrons than electrons. Find the symbol of the ion.

	Atom	Uni-negative ion
Number of electrons	x – 1	x
Number of protons	x – 1	x – 1
Number of neutrons	y	y

Given that y $= x + 11.1\%$ of $x = \left(x + \frac{11.1}{100}x\right) = x + 0.111\,x$

Number of neutrons y = 1.111x

Mass number = 37

Number of protons + Number of neutrons = 37

(x – 1) + 1.111x = 37 x + 1.111x = 38 2.111x = 38	$x = \frac{38}{2.11}$ x = 18.009 ; x = 18

Atomic number = x – 1 = 18 – 1 = 17

Mass number = 37

Symbol of the ion = $^{37}_{17}Cl^{-}$

45. The Li^{2+} ion is a hydrogen like ion that can be described by the Bohr model. Calculate the Bohr radius of the third orbit and calculate the energy of an electron in 4th orbit.

$V_n = \frac{(0.529)n^2}{z}$ Å ; $E_n = \frac{-13.6 \times z^2}{n^2}$ eV atom^{-1} ; for Li^{2+}, Z = 3

Bohr radius for the third orbit (r_3) $= \frac{(0.529)(3)^2}{3} = 0.529 \times 3 = 1.587$ Å

Energy of the electron in the fourth orbit $E_4 = \frac{-13.6(3)^2}{(4)^2} = -7.65$ eV atom^{-1}

46. Protons can be accelerated in particle accelerators. Calculate the wavelength (in Å) of such accelerated proton moving at 2.85×10^8 ms^{-1} (the mass of proton is 1.673×10^{-27} kg).

$V = 2.85 \times 10^8$ ms^{-1} ; $m_p = 1.673 \times 10^{-27}$ kg

$\lambda = \frac{h}{mV} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\text{s}^{-1}}{1.673 \times 10^{-27}\ \text{kg} \times 2.85 \times 10^8\ \text{ms}^{-1}}$

$\lambda = 1.389 \times 10^{-15}$ m

$\lambda = 1.389 \times 10^{-5}$ Å

log	value
160	2.2041 (+)
38.88	1.5897
	3.7938

47. What is the de Broglie wavelength (in cm) of a 160 g cricket ball travelling at 140 km hr^{-1}?

$m = 160\ g = 160 \times 10^{-3}\ kg$

$V = 140\ km\ hr^{-1} = \frac{140\times10^{-3}}{60\times60}\ ms^{-1}$

$V = 38.88\ ms^{-1}$ $\lambda = \frac{h}{mV} = \frac{6.626\times10^{-34}\ kgm^2s^{-1}}{160\times10^{-3}\ kg\times38.88ms^{-1}}$

$= 1.065 \times 10^{-34}\ m$

log	value
6.626	0.8213(-)
	3.7938
	$\bar{3}$.0275

Antilog($\bar{3}$.0275) = 1.065×10^{-3}

48. Suppose that the uncertainty in determining the position of an electron in an orbit is 0.6 Å. What is the uncertainty in its momentum?

$\Delta x = 0.6\ Å = 0.6 \times 10^{-10}\ m$; $\Delta p = ?$

$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$; $\Delta x \cdot \Delta p \geq 5.28 \times 10^{-35}\ kg\ m^2\ s^{-1}$

$(0.6 \times 10^{-10})\ \Delta p \geq 5.28 \times 10^{-35}$

$\Delta p \geq \frac{5.28\times10^{-35}\ kgm^2s^{-1}}{0.6\times10^{-10}\ m}$

$\Delta p \geq 8.8 \times 10^{-25}\ kg\ ms^{-1}$

log	value
5.28	0.7226 (-)
0.6	$\bar{1}$.7782
	0.9444

Antilog(0.9444) = 8.798

49. Show that if the measurement of the uncertainty in the location of the particle is equal to its de Broglie wavelength, the minimum uncertainty in its velocity (ΔV) is equal to its velocity (V).

Given $\Delta x = \lambda$; $\Delta V = ?$

$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$

$\lambda \cdot (m\Delta V) \geq \frac{h}{4\pi}$

$\Delta V \geq \frac{h}{4\pi(m\lambda)}$

$\Delta V \geq \frac{h}{4\pi m\times\left(\frac{h}{mV}\right)}$ $\quad (\because \lambda = \frac{h}{mV})$

$\Delta V \geq \frac{h\times mV}{4\pi mh}$

$\Delta V \geq \frac{V}{4\pi}$

$\therefore$ Minimum uncertainty in velocity = $\frac{V}{4\pi}$

50. What is the de Broglie wavelength of an electron, which is accelerated from the rest, through a potential difference of 100 V?

Potential difference $= 100V$

$= 100 \times 1.6 \times 10^{-19}\ J$

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{6.626\times10^{-34}\,Kgm^2s^{-1}}{\sqrt{2\times9.1\times10^{-31}kg\times100\times1.6\times10^{-19}J}}$$

$\lambda = 1.22 \times 10^{-10}$ m = 1.22 Å

51. Identify the missing quantum numbers and the sub energy level.

n	*l*	m	Sub energy level
?	?	0	4d
3	1	0	?
?	?	?	5p
?	?	-2	3d

n	*l*	m	Sub energy level
4	2	0	4d
3	1	0	3p
5	1	anyone value -1, 0, +1	5p
3	2	-2	3d

ADDITIONAL QUESTIONS

2 and 3 Mark Question and Answers

52. Explain Heisenbergs uncertainty principle. ***(SEP 20, JUL 22, MAR 23)***

It is impossible to accurately determine both the position and momentum of a microscopic particle simultaneously.

$\Delta x.\ \Delta P \geq h/4\pi$

Δx = uncertainty in position of particle

Δp = uncertainty in momentum of particle.

53. Define orbital.

Orbital is a three dimensional space in which the probability of finding the electron is maximum.

54. Define Aufbau principle.

In the ground state of the atoms, the orbitals are filled in the order of their increasing energies

55. Define Pauli Exclusion Principle.

No two electrons in an atom can have the same set of value of all four quantum numbers.

56. Define Hunds rule.

The electron pairing in the degenerate orbitals does not take place until all the available orbitals contains one electron each.

57. Define exchange energy. ***(SEP 21)***

If two or more electrons with the same spins are present in degenerate orbitals, there is a possibility for exchanging their positions.

During exchange process, the energy is released called as exchange energy.

58. Explain J.J. Thomson Atomic model.

Atoms consist of negatively charged particles called electrons.

Atom is a positively charged sphere in which the electrons are embedded like the seeds in the watermelon.

59. Calculate the orbital angular momentum for d and f orbital. ***(JUNE 19)***

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

For 'd' orbital; $l = 2$

Orbital angular momentum = $\sqrt{2(2+1)}\,\frac{h}{2\pi} = \frac{\sqrt{6}h}{2\pi}$

For 'f' orbital, $l = 3$

orbital angular momentum = $\sqrt{3(3+1)}\,\frac{h}{2\pi} = 2\sqrt{3}\times\frac{h}{2\pi} = \frac{\sqrt{3}h}{\pi}$

60. In degenerate orbitals, why do the completely filled and half filled configuration are more stable than the partially filled configuration? ***(SEP 20)***

(i) More number of exchanges of electrons are possible only in case of half filled configurations.

(ii) Half filled and completely filled subshells become more stable because of symmetrical distribution of electron in orbital.

So, completely filled and half filled configuration are more stable than the partially filled configuration.

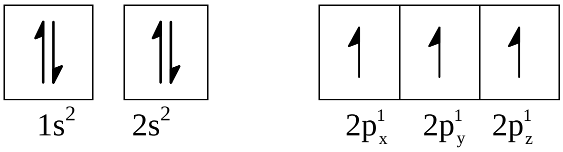
61. Calculate the maximum number of electrons that can be accommodated in L shell. ***(MAY 22)***

Maximum number of electron in L shell = $2n^2 = 2\times2^2 = 2\times4 = 8$ electrons

62. Write the electronic configuration and orbital diagram for nitrogen. ***(MAY 22)***

Electronic configuration for nitrogen = $1s^2\,2s^2\,2p^3$

Orbital diagram for nitrogen



Five Mark Question and Answers

63. Explain Rutherford experiment and Bohr model of an atom.

Rutherford bombarded a thin gold foil with a stream of fast moving α-particles passed through the foil.

(i) Most of the α-particles passed through the foil.

(ii) Some of them were deflected through a small angle

(iii) Very few α-particles were reflected back by 180°

Bohr atomic model: An atom consists of tiny positively charged nucleus and the electron are moving around the nucleus with high speed.

64. Explain Bohr model of atom.

1) The energies of electrons are quantised.
2) The electron is revolving around the nucleus in a certain fixed circular path called stationary orbit.
3) The angular momentum of electron equal to integral multiple of h/2π

$$mvr = \frac{nh}{2\pi}$$

n = 1, 2, 3, etc.

4) An electron revolves in orbit, it doesn't lose its energy.
However, when an electron jumps from higher energy state (E_2) to a lower energy state (E_1), the excess energy released as radiation.

$$h\upsilon = E_2 - E_1$$

$$\upsilon = \frac{E_2 - E_1}{h}$$

65. Write the limitations of Bohr's atom model.

1. Bohr's atom model is applicable to one electron species such as hydrogen, Li^{2+} and not applicable to multi electron atoms.
2. This theory cannot explain splitting of spectral lines in magnetic field (Zee man effect) or electric field (stark effect).
3. This theory does not explain the electron revolve in fixed orbit in which the angular momentum of the electron is equal to $nh/2\pi$.

66. Derive De-broglie equation. ***(MAR 19)***

According Planck's quantum hypothesis

$E = h\nu$ ... (1)

According to Einstein's mass – energy relations

$E = mc^2$ ... (2)

Comparing 1 and 2

$mc^2 = h\nu$

$mc^2 = hc/\lambda$ $\left(\because \nu = \frac{c}{\lambda}\right)$

$$\lambda = \frac{h}{mc}$$

The above equation represents the wave length of photons

For a particle of matter with mass 'm' and velocity 'v', the above equation can be written as

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

The above equation is known as De-broglie equation.

This equation is valid for the particle travels at speed much less than speed of light.

67. Explain main features of the quantum mechanical model of atom.

1) The energy of electrons in atoms is quantised.
2) The existence of quantised electronic energy levels is a direct results of the wave like properties of electrons.
3) According to Heisenberg uncertainty principle, the exact position and momentum of an electron cannot be determined with absolute accuracy.
4) Orbital is a three dimensional space in which the probability of finding the electron is maximum.
5) The solution of Schrodinger wave equation for the allowed energies of an atom gives the wave function p, which represents atomic orbital.
6) The probability of finding the electron in a small volume around a point (x, y, z) is always positive.

68. Explain quantum number in detail.

The electron in an atom can be characterised by a set of four quantum numbers.

1) Principle quantum number (n): ***(SEP 21, MAR 23, JULY 23, MARCH 24)***

This quantum number represents the energy level in which electron revolves around the nucleus.

n value	Shell
1	K
2	L
3	M
4	N

It is denoted by 'n'. n = 1, 2, 3, ...
The maximum number of electrons accommodated in a given shell is $2n^2$.

Energy of electron $E_n = \frac{(-1312.8)}{n^2} kJ.mol^{-1}$

The distance of electron from nucleus $r_n = \frac{(0.529)n^2}{z} A^\circ$

ℓ Value	Subshells
0	s
1	p
2	d
3	f
4	g

2) Azimuthal quantum Number (*l*)
It can take values from zero to (n – 1)
The maximum number of electrons that can be accommodated in a given subshels is 2(2*l* + 1)

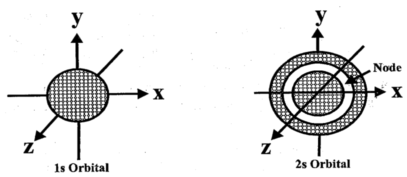
Orbital angular momentum = $\sqrt{l(l+1)} \cdot \frac{h}{2\pi}$

3) Magnetic quantum number (m_l): ***(JUL 22)***
It takes integral values from $-\ell$ to $+\ell$ including zero.
Different values of 'm' for a given $'\ell'$ value, represent different orientation of orbital in space.
It gives the direction of orbitals

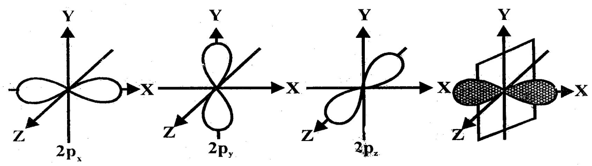
4) Spin quantum number (s):
It represents spin of the electron. The electron spins about its own axis either in a clockwise direction (or) anticlock wise direction.
The values of m_s is equal to + ½ and – ½.

69. Explain the shape of orbitals.

1) s-Orbital: For s-orbital *l* = 0, m = 0
The shape of 's' orbital is spherical. It is directionless.



2) p-Orbital: For p-orbital *l* = 1, m = -1, 0, +1.
The three different values of 'm' indicate that three different orientation possible for 'p' orbitals. These are designated as P_x, P_y and P_z.
'2p' orbital has one nodal plane.



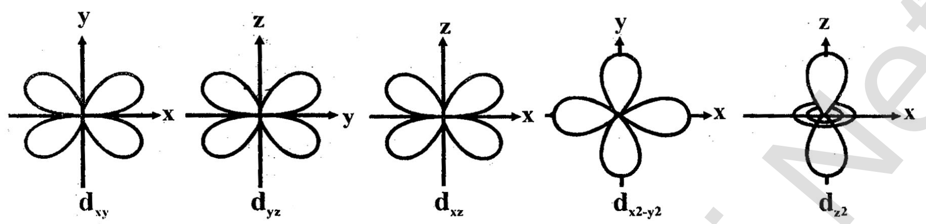
Nodal plane: **yz** **xz** **xy**

'd' orbitals:

For 'd' orbital l = 2, m = - 2, -1, 0, +1, +2. Shape of 'd' orbital is 'clover leaf'

For five 'm' value, five 'd' orbitals namely $3d_{xy}$, $3d_{xz}$, $3d_{yz}$, $3d_{x^2-y^2}$ and $3d_{z^2}$ are present.

'3d' orbitals contain two nodal planes.



f-Orbital: l = 3, m = -3, -2, -1, 0, +1, +2, +3

It has 7 orbital namely

$f_{y(3x^2-y^2)}, f_{z(x^2-y^2)}, f_{yz^2}, f_{z^3}, f_{xz^2}, f_{xyz}, f_{x(x^2-3y^2)}$

It has 3 nodal planes.