PHYSICAL CHEMISTRY

ATOMIC STRUCTURE

1. 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 ______. **[JEE(Advanced) 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}]

2. 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}]

[JEE(Advanced) 2021]

3. 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 for the state Ψ ? **[JEE(Advanced) 2019]**

(A) It has 2 angular nodes

(B) It has 3 radial nodes

(C) It is a 4d state

(D) The nuclear charge experienced by the electron in this state is less than 2e, where e is the magnitude of the electronic charge.

4. **Answer the following by appropriately matching the lists based on the information given in the paragraph.**

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. **[JEE(Advanced) 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) (I), (P) (C) (I), (T) (D) (II), (Q)

5. Answer the following by appropriately matching the lists based on the information given in the paragraph.

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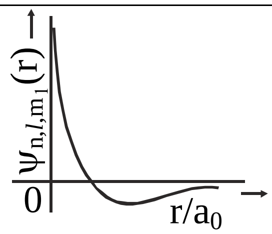
(IV) Potential energy of the electron in the n^{th} orbit	(S) $\propto n^{1}$
	(T) $\propto n^{2}$
	(U) $\propto n^{1/2}$

Which of the following options has the correct combination considering List-I and List-II ?

(A) (III), (S)
(B) (IV), (Q)
(C) (IV), (U)
(D) (III), (P)

Answer Q.6, Q.7 and Q.8 by appropriately matching the information given in the three columns of the following table.

The wave function ψ_{n,l,m_1} 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_1. 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 a_0 is Bohr radius. **[JEE(Advanced) 2017]**

Column-1	Column-2	Column-3
(I) 1s orbital	(i) $\psi_{n,l,m_1} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_e}\right)}$	(P) 
(II) 2s orbital	(ii) One radial node	(Q Probability density at nucleus $\propto \frac{1}{a_0^3}$
(III) $2p_z$ orbital	(iii) $\psi_{n,l,m_1} \propto \left(\frac{Z}{a_0}\right)^{\frac{5}{2}} re^{-\left(\frac{Zr}{2a_0}\right)} \cos\theta$	(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

6. For the given orbital in column 1, the only **CORRECT** combination for any hydrogen - like species is :

(A) (IV) (iv) (R) (B) (II) (ii) (P)

(C) (III) (iii) (P) (D) (I) (ii) (S)

7. For He^+ ion, the only **INCORRECT** combination is

(A) (II) (ii) (Q) (B) (I) (i) (S)

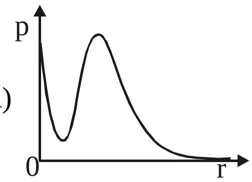
(C) (I) (i) (R) (D) (I) (iii) (R)

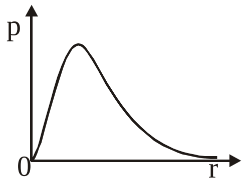
8. For hydrogen atom, the only **CORRECT** combination is

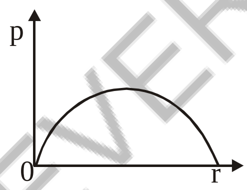
(A) (I) (iv) (R) (B) (I) (i) (P)

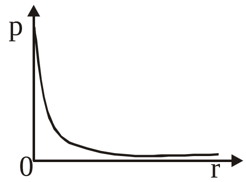
(C) (II) (i) (Q) (D) (I) (i) (S)

9. P is the probability of finding the 1s electron of hydrogen atom in a spherical shell of infinitesimal thickness, dr, at a distance r from the nucleus. The volume of this shell is $4\pi r^2 dr$. The qualitative sketch of the dependence of P on r is - **[JEE(Advanced) 2016]**

(A)


(B)


(C)


(D)


SOLUTIONS

1. Ans. (30)

Sol. For single electron system

$$r = 52.9 \times \frac{n^2}{Z} \text{ pm}$$

Given Z = 2 for He^+

$r_2 = 105.8$ pm

So $105.8 = 52.9 \times \frac{n_2^2}{2}$

$n_2 = 2$

$r_1 = 26.45$

So $26.45 = 52.9 \times \frac{n_1^2}{2}$

$n_1 = 1$

So transition is from 2 to 1.

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

So $\lambda = 30 \times 10^{-9}$ m = 30 nanometer.

Here 'R_H' is given in terms of energy value.

2. Ans. (30)

Sol. $\lambda = \frac{h}{p} \Rightarrow p = \frac{6.6\times10^{-34}}{330\times10^{-9}} = \frac{4\times10^{-3}}{6\times10^{23}}\times v$ $(p = m \times v)$

v = 0.3 m/s = 30 cm/s

3. Ans. (A, C)

Sol. # $-3.4 = \frac{-13.6\times4}{n^2} \quad \Rightarrow \quad n = 4$

$\ell = 2$

m = 0

Angular nodes = ℓ = 2

Radial nodes = $(n - \ell - 1) = 1$

$n\ell$ = 4d state

4. Ans. (C)

5. Ans. (D)

Solution for Q. No. 4 and Q. No. 5

Sol. $r = 0.529 \times \frac{n^2}{z} \quad \Rightarrow r \propto n^2 \quad \Rightarrow$ (I) (T)

$mvr = \frac{nh}{2\pi} \quad \Rightarrow (mvr) \propto n \quad \Rightarrow$ (II) (S)

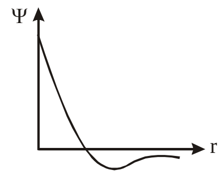
$KE = +13.6 \times \frac{z^2}{n^2} \quad \Rightarrow KE \propto n^{-2} \quad \Rightarrow$ (III) (P)

$PE = -2 \times 13.6 \times \frac{z^2}{n^2} \quad \Rightarrow PE \propto n^{-2} \quad \Rightarrow$ (IV) (P)

6. Ans. (B)

Sol. (A) (IV) (iv) (R) $\Rightarrow$ incorrect, because, d_{z^2} has no nodal plane.

(B) (II) (ii) (P) $\Rightarrow$ correct, because 2s orbtial has 1 radial node.



(C) (III) (iii) (P) $\Rightarrow$ incorrect, because probability density for 2p at nucleus is zero.

(D) (I) (ii) (S) $\Rightarrow$ incorrect, because 1s orbital has no radial node.

7. Ans. (D)

Sol. The option (D) is incorrect because in the wave function of 1s orbital , no angular function should be present.

8. Ans. (D)

Sol. We have to select only correct combination hence, the option (D) is correct.

For 1s orbital : $\Psi_{n,l,m} \;\alpha \left(\frac{Z}{a_0}\right)^{3/2} e^{\frac{-zr}{a_0}}$

Energy needed to excite : from n = 2 to n = 4

$\Delta E_{2-4} = 13.6\ Z^2 \times \frac{3}{16} eV$

Energy needed to excite from : n = 2 to n = 6

$\Delta E_{2-6} = 13.6\ Z^2 \times \frac{8}{36}$

$\Delta E_{2-4} = \frac{27}{32}\ E_{2-6}$ (hence, true)

9. Ans. (B)

Sol. For 1s, radial part of wave function is

$\psi_{(r)} = 2\left(\frac{1}{a_0}\right)^{\frac{3}{2}} e^{-\frac{r}{a_0}}$

probability of finding an e^- in a spherical shell of thickness, 'dr' at distance 'r' from nucleus,

$P = \psi^2_{(r)} \cdot 4\pi r^2 dr = 16\pi r^2 \left(\frac{1}{a_0}\right)^3 e^{\frac{-2r}{a_0}} dr$

So P is zero at r = 0 and r = ∞.