Paragraph for questions 1 to 3

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. **[JEE 2010]**

1. The state S_1 is :-

(A) 1s (B) 2s (C) 2p (D) 3s

2. 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

3. The orbital angular momentum quantum number of the state S_2 is :-

(A) 0 (B) 1 (C) 2 (D) 3

Li^{2+}, $S_1 \Rightarrow n - l - 1 = 1$

Energy of $S_2 > S_1$, for S_2, $n - l - 1 = 1$

$E_{S_2} = -13.6\ eV.$

or, $\dfrac{-13.6 Z^2}{n^2} = -13.6$

or, $\dfrac{Z^2}{n^2} = 1$

Also, for Li^{2+}, $z=3$

$\because \frac{z^2}{n^2}=1 \Rightarrow \frac{3^2}{n^2}=1 \Rightarrow \boxed{n=3}$

Also, for S_2, $n-l-1=1$

or, $3-l-1=1$

or, $l=1 \Rightarrow$ P orbital.

$\therefore \boxed{S_2 = 3P}$

Q1: $\because$ S_1 has one radial node,

Option A: 1s, no. of radial node = 0

~~B~~: 2S, " " " " = 1

C: 2P, " " " " = 0

D: 3S, " " " " = 2

So (B) is the correct answer.

Q2: for S_1, $z=3$, $n=2$

$E_{S_1} = \frac{-13.6 z^2}{n^2}$

or, $E_{S_1} = \frac{z^2}{n^2} \times E_{H_1}$ ($E_{H_1} = -13.6$ = H-atom ground state energy)

or, $E_{S_1} = \frac{3^2}{2^2} \times E_{H_1}$

or, $\boxed{\frac{E_{S_1}}{E_{H_1}} = 2.25}$ Ans.

Q3 orbital ang. momentum Q.N. for state $S_2 = l = 1$ Ans.

4. The maximum number of electrons that can have principal quantum number, n=3, and spin quantum number, $m_s = -1/2$, is **[JEE 2011]**

$n=3 \Rightarrow$ Total no. of electrons $= 2n^2 = 2\times3^2 = 18$

and total no. of orbitals $= n^2 = 3^2 = 9$

Out of these 18 electrons 9 will have spin $= \frac{1}{2}$

and other 9 will have spin $= -\frac{1}{2}$.

$\therefore$ max^m no. of electrons having $n=3$ and $m_s = -\frac{1}{2} = \boxed{9}$

Ans

5. 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 : :- [JEE 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

Energy of incident light $= E = \frac{1240}{\lambda} = \frac{124\cancel{0}}{30\cancel{0}} = 4.13$ eV.

So metal with work function less than 4.13 eV will show photo electric effect. So only

Li, Na, K and Mg will show photoelectric effect.

$\therefore$ no. of metals $= \boxed{4}$

6. The kinetic energy of an electron in the second Bohr orbit of a hydrogen atom is [a_0 is Bohr radius]

$z=1$

[JEE 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) $\frac{h^2}{8\pi^2 ma_0^2}$

$\because$ From Bohr's Postulate,

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

For 2nd Bohr orbit, $n=2$

$\therefore mvr = \frac{h}{\pi}$ — (1)

Also, $r = \frac{n^2}{Z} a_0$ ($a_0 = 0.529\text{Å} =$ Bohr's radius)

or, $r = \frac{2^2}{1} a_0 \Rightarrow r = 4a_0$ — (2)

from ① and ②, $mv \times 4a_0 = \frac{h}{\pi}$

or, $mv = \frac{h}{4\pi a_0}$

or, $m^2v^2 = \frac{h^2}{16\pi^2 a_0^2}$

or, $mv^2 = \frac{h^2}{16\pi^2 m a_0^2}$

or, $\frac{1}{2}mv^2 = \frac{h^2}{32\pi^2 m a_0^2}$

or, $\boxed{KE = \frac{h^2}{32\pi^2 m a_0^2}}$ Ans.

$\therefore$ (c) is correct.

7. 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. **[JEE 2013]**

Given, $\lambda_{He\ at\ -73^\circ C} = M \times \lambda_{Ne\ at\ 727^\circ C}$.

or, $M = \dfrac{\lambda_{He\ at\ -73^\circ C}}{\lambda_{Ne\ at\ 727^\circ C}}$

or, $M = \dfrac{m_{Ne} \times v_{Ne}}{m_{He} \times v_{He}}$ $\because \lambda = \dfrac{h}{mv} \Rightarrow \lambda \propto \dfrac{1}{mv}$

or, $M = \dfrac{20 \times \sqrt{T_{Ne}}}{4 \times \sqrt{M_{Ne}}} \times \dfrac{M_{He}}{T_{He}}$ $\because u_{rms} = \sqrt{\dfrac{3RT}{M}} \Rightarrow u_{rms} \propto \sqrt{\dfrac{T}{M}}$

or, $M = 5 \times \sqrt{\dfrac{1000}{200} \times \dfrac{4}{20}} = 5 \times \sqrt{1} = \boxed{5}$ Ans

8. In an atom, the total number of electrons having quantum numbers $n = 4$, $|m_\ell| = 1$ and $m_s = -\frac{1}{2}$ is [JEE 2014]

$n = 4$, $|m_\ell| = 1 \Rightarrow$ |magnetic quantum number| $= 1$

In each subshell except 's' there will be two orbitals for which $m_\ell = -1$ and $m_\ell = +1 \Rightarrow |m_\ell| = 1$.

Subshell	no. of orbitals with $\lvert m_\ell \rvert = 1$
s	0
p	2
d	2
f	2

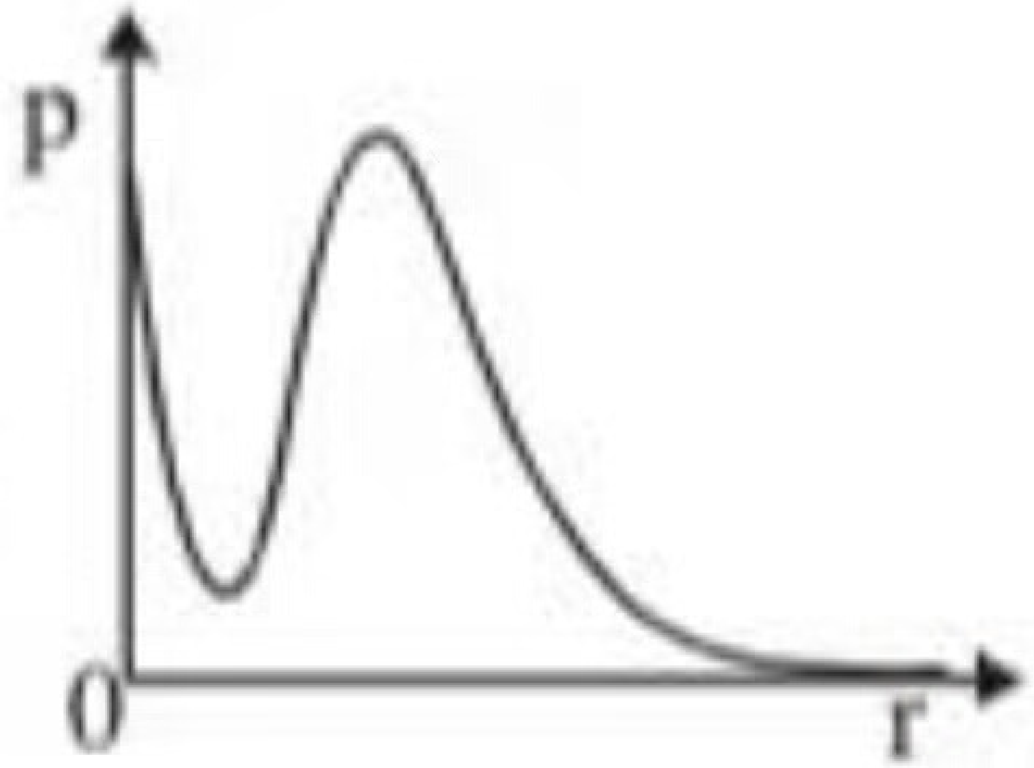
Total no. of orbitals $= 6$

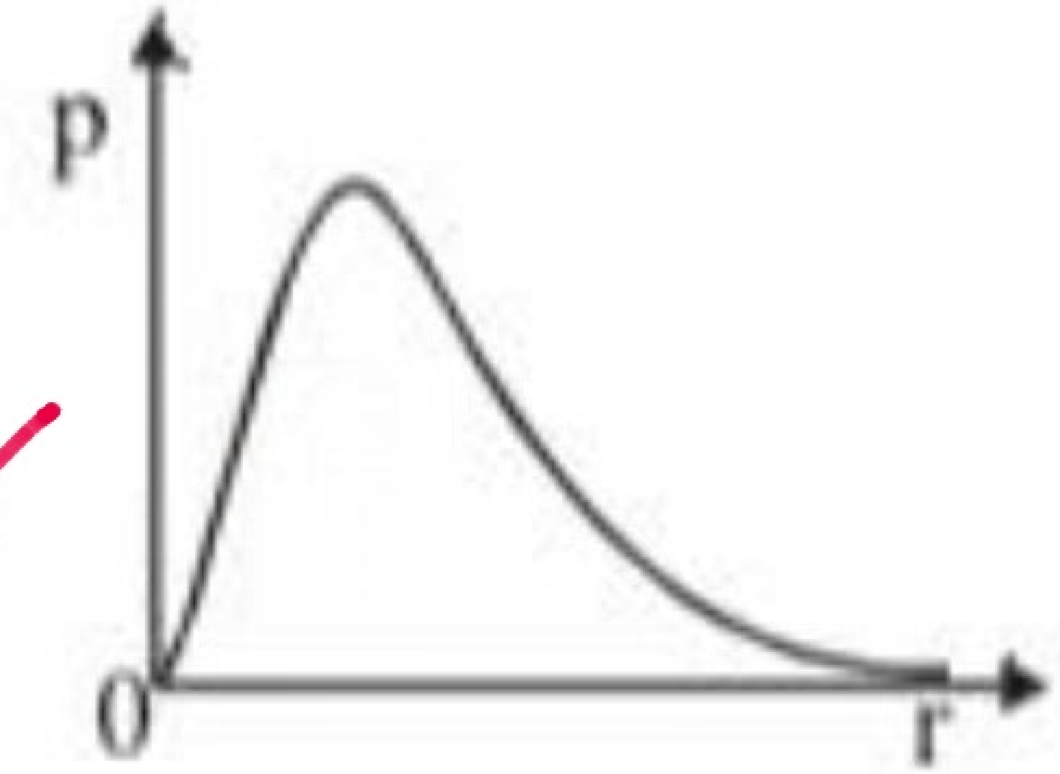
$\therefore$ no. of electrons $= 12$

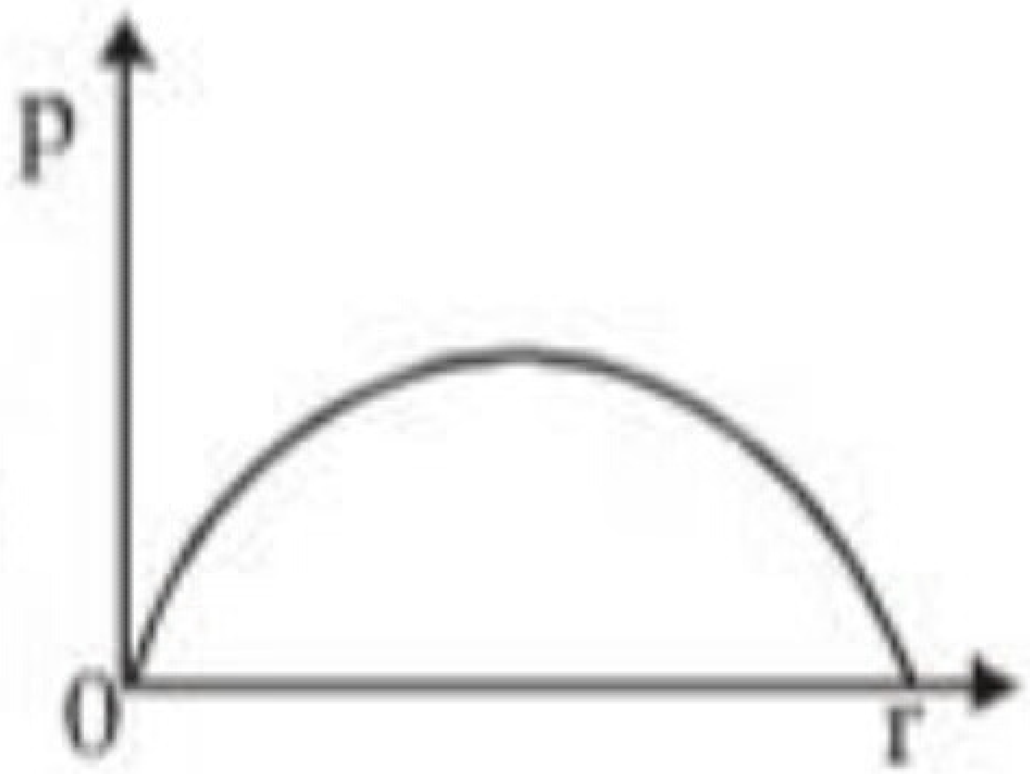
Out of these 12 electrons 6 electrons will have $m_s = \frac{1}{2}$ and other 6 electrons will have $m_s = -\frac{1}{2}$.

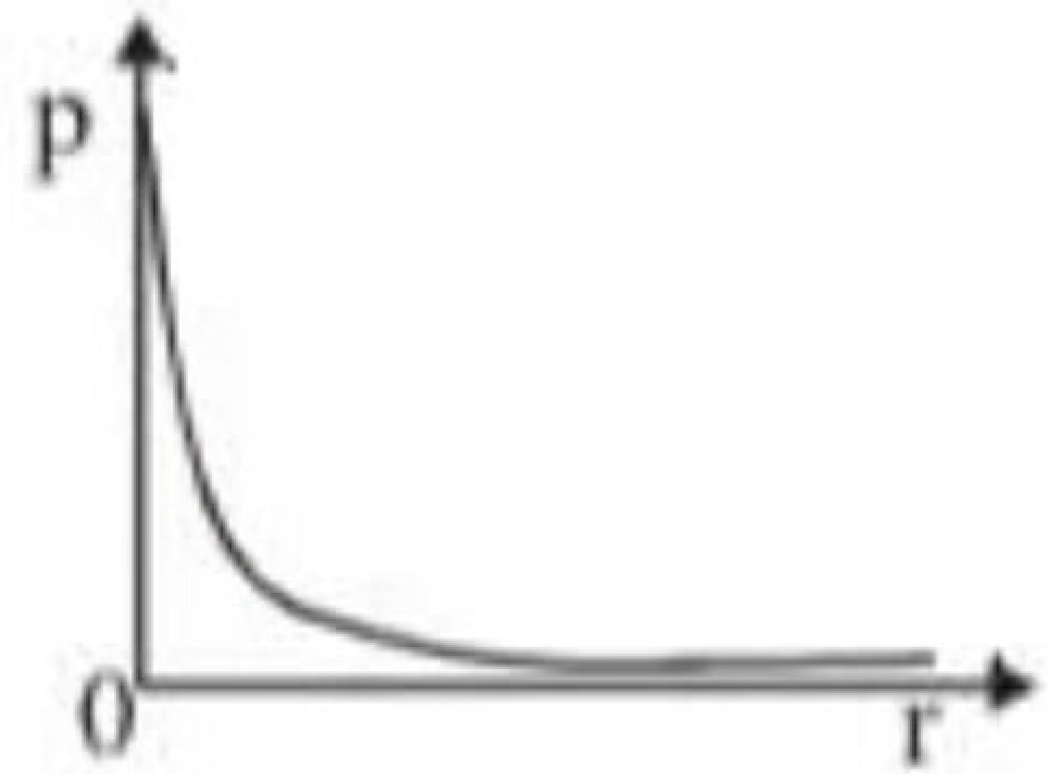
$\therefore \boxed{\text{Ans} = 6}$

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 2016]**

(A) 

(B) 

(C) 

(D) 

$P = 4\pi r^2 \psi^2(r)$

For 1s orbital,

→ no. of radial node $= n-l-1$

$= 1-0-1 = 0$.

→ no. of maxima $= n-l = 1-0 = 1$.

Graph for $4\pi r^2 \psi^2(r)$ vs r will start from origin.

[redacted]

orbital	(no. of radial node = n-l-1)
1s	1-0-1=0
2s	2-0-1=1
$2p_z$	2-1-1=0
$3d_{z^2}$	3-2-1=0

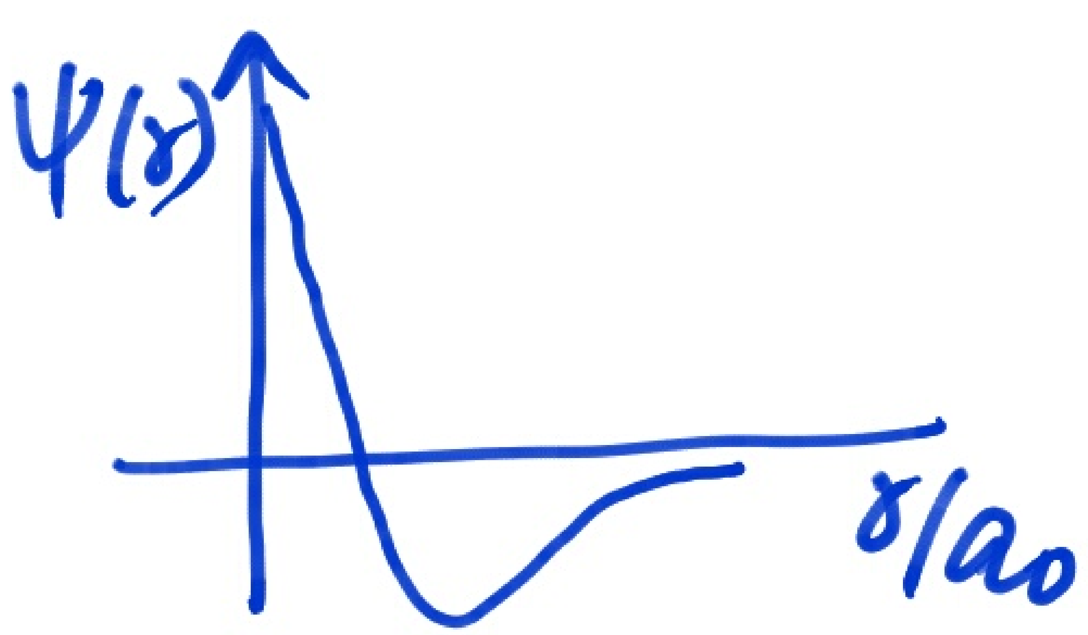
→ $\psi_{nlm} \propto \left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0} \Rightarrow l=0,\ n-l-1=0 \Rightarrow n=1$

∴ 1s orbital.

→ $\psi_{nlm} \propto \left(\frac{Z}{a_0}\right)^{3/2} r\, e^{\frac{-Zr}{2a_0}} \cos\theta \Rightarrow l=1,\ n-l-1=0 \Rightarrow n=2$

∴ $2P_z$ orbital ∵ Only θ is present ⇒ z orbital

In P_z orbital, nodal plane is XY plane.

P) 

Graph is not started from origin ⇒ s orbital ⇒ $l=0$,
Also no. of radial node $=1 \Rightarrow n-l-1=1 \Rightarrow n=2$
∴ This graph is for 2s orbital.

q) Probability density $= \psi^2(r)$

R) Probability density is maximum at nucleus for 's' orbitals.

[S] Energy needed to excite electron from $n=2$ to $n=4$ is given as:

$$E_{2-4} = 13.6z^2\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = 13.6z^2 \times \left[\frac{1}{4} - \frac{1}{16}\right] = 13.6z^2\left[\frac{3}{16}\right]$$

Energy needed to excite electron from $n=2$ to $n=6$ is:

$$E_{2-6} = 13.6z^2\left[\frac{1}{2^2} - \frac{1}{6^2}\right] = 13.6z^2\left[\frac{1}{4} - \frac{1}{36}\right] = 13.6z^2\left[\frac{8}{36}\right]$$

Clearly,

$$\frac{E_{2-4}}{E_{2-6}} = \frac{3}{16} \times \frac{36}{8} = \frac{27}{32}$$

10. 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)

(A) incorrect ∵ 1s orbital, no nodal plane.

B) correct, (II) 2s orbital, no. of radial node = $n-l-1 = 2-0-1 = 1$.

Also, graph (P) is for 's' orbital because it is not started from origin. Also, in graph: no. of radial node = 1

or, $n-l-1 = 1 \Rightarrow n = 2 \Rightarrow$ graph (P) is for 2s orbital.

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

(A) (II) (ii) (Q) (B) (I) (i) (S) (C) (I) (i) (R) (D) (I) (iii) (R)

A) (II) 2s-orbital, ii) no. of radial node = $n-l-1 = 2-0-1 = 1$.

$\because \psi(r) \propto \left(\frac{1}{a_0}\right)^{3/2} \therefore$ Probability density $= \psi^2(r) \propto \left(\frac{1}{a_0}\right)^3$.

$\therefore$ (A) is correct.

(B) correct, (I) 1s orbital, $\psi(r) \propto \left(\frac{Z}{a_0}\right)^{3/2} e^{(-Zr/a_0)}$

$\Rightarrow l=0$ & $n-l-1=0 \Rightarrow n=1 \Rightarrow \boxed{1s}$

(S) $E_{2-4} = 13.6Z^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right] = 13.6Z^2\left[\frac{1}{4}-\frac{1}{16}\right] = 13.6Z^2 \times \frac{3}{16}$

$E_{2-6} = 13.6Z^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right] = 13.6Z^2\left[\frac{1}{4}-\frac{1}{36}\right] = 13.6Z^2 \times \frac{8}{36}$

Clearly $\frac{E_{2-4}}{E_{2-6}} = \frac{3}{16} \times \frac{36}{8} = \frac{27}{32}$

(C) Correct. (I) 1s orbital

(i) $\psi(r) \propto \left(\frac{Z}{a_0}\right)^{3/2} e^{-\left(\frac{Zr}{a_0}\right)}$, $l=0$ and $n-l-1=0 \Rightarrow n=1$

$\therefore$ 1s orbital.

(R) For all 's' orbitals probability density is maximum at nucleus.

(D) Incorrect. (I) 1s orbital.

iii) $\psi(r,\theta,\phi) \propto \left(\frac{Z}{a_0}\right)^{3/2} r\, e^{-\left(\frac{Zr}{2a_0}\right)} \cos\theta$

$\because$ $l=1$ and $n-l-1=0 \Rightarrow n=2 \Rightarrow$ orbital $= 2P_z$.

Also $\cos\theta$ is present $\Rightarrow$ z orbital.

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

(A) (I) (iv) (R) (B) (I) (i) (P) (C) (II) (i) (Q) (D) (I) (i) (S)

A) Incorrect, $\because$ (I) 1s orbital $\Rightarrow$ no nodal plane.

B) Incorrect $\because$ (I) 1s orbital $\Rightarrow$ no node, while node is present in graph (P).

C) Incorrect $\because$ (II) 2s orbital while (i) is for 1s orbital.

D) Correct: (I) 1s orbital

(i) Given $\psi(r)$ is for 1s orbital.

(S) True.

13. 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 2019]**

(1) It has 2 angular nodes

(2) It has 3 radial nodes

(3) It is a 4d state

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

For He^+, $E = -3.4\,eV$, $l = 2$, $m = 0$ $\therefore$ $E = \frac{-13.6Z^2}{n^2} = -3.4 \Rightarrow n^2 = \frac{13.6 \times 4}{3.4} \Rightarrow n = 4$

1) no. of angular node $= l = 2 \Rightarrow$ True.

2) no. of radial node $= n - l - 1 = 4 - 2 - 1 = 1 \Rightarrow$ false.

3) $\because n = 4$, $l = 2 \Rightarrow$ 4d state $\Rightarrow$ True.

4) Since it is a single electron species, no intervening electrons are present. So nuclear charge $= 2e$.

$\therefore$ False statement.

14. **Answer the following by appropriately matching the lists based on the information given in the paragraph** **[JEE 2019]**

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.

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?

(1) (II), (R) (2) (I), (P) ✓(3) (I), (T) (4) (II), (Q)

I) $r = \frac{0.529 n^2}{Z} A^\circ \Rightarrow r \propto n^2.$

II) Angular momentum $= mvr = \frac{nh}{2\pi} \Rightarrow$ Angular momentum $\propto n$

III) $KE = \frac{1}{2} mv^2 = \frac{1}{2} \times m \times \left(V_0 \times \frac{Z}{n}\right)^2 = \frac{1}{2} \frac{m Z^2 V_0^2}{n^2} \Rightarrow KE \propto n^{-2}.$

IV) $PE = \frac{-KZe^2}{r} = \frac{-KZ^2e^2}{0.529 n^2} \Rightarrow PE \propto n^{-2}.$

15. Answer the following by appropriately matching the lists based on the information given in the paragraph [JEE 2019]

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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?

(1) (III), (S) (2) (IV), (Q) (3) (IV), (U) (4) (III), (P)