# 11.BOHR'S THEORY

## SOLUTIONS

## TEACHING TASK

## JEE MAINS LEVEL QUESTIONS

1. The ratio of the radii of the first three Bohr orbits for a hydrogen-like ion with Z=2 is: **(FA & SA- 3 Marks / 4 Marks)**

A) 1:2:3 B) 1:4:9 C) 1:8:27 D) 4:16:36

**Answer:B**

Solution:We know the formula for the radius of the n th Bohr orbit in a hydrogen-like ion is: $r_n = \frac{n^2 a_0}{Z}$

where $a_0$ is the Bohr radius,
Z is the atomic number, and
n is the principal quantum number.
Write radii for n=1,2,3 and Z=2

$$r_1 = \frac{1^2 a_0}{2} = \frac{a_0}{2}$$

$$r_2 = \frac{2^2 a_0}{2} = \frac{4a_0}{2}$$

$$r_3 = \frac{3^2 a_0}{2} = \frac{9a_0}{2}$$

$$r_1 : r_2 : r_3 = \frac{a_0}{2} : \frac{4a_0}{2} : \frac{9a_0}{2} = 1:4:9$$

2. The ionization potential of a $He^+$ ion is:

A) 13.6 eV B) 27.2 eV C) 54.4 eV D) 6.8 eV

**Answer:C**

Solution: $IE = 13.6 \times Z^2 eV$

For helium ion ($He^+$):Z=2

$$IE = 13.6 \times 2^2 = 13.6 \times 4 = 54.4 eV$$

3. The ratio of the radius of the Bohr orbit for an electron orbiting a $Li^{2+}$ nucleus to that of an electron orbiting a hydrogen nucleus (both for n=2) is approximately:

A) 1:3 B) 1:1 C) 1:9 D) 3:1

**Answer:A**

Solution:

$$r \propto \frac{n^2}{Z}$$

$$\frac{r_{Li^{2+}}}{r_H} = \frac{4/3}{4/1} = \frac{1}{3}$$

4. In a certain Bohr orbit of a hydrogen-like ion with Z=3, the total energy is -30.6 eV. For this orbit, the kinetic energy and potential energy are respectively:

A) 30.6 eV, -61.2 eV
B) 15.3 eV, -30.6 eV
C) 30.6 eV, -30.6 eV
D) 61.2 eV, -122.4 eV

**Answer:A**

Solution:

Hydrogen-like ion Z=3
Total energy TE=-30.6eV
We are asked for Kinetic energy (KE) and Potential energy (PE)
Relations between TE=KE+PE and K=-TE,PE=2TE
Substitute E=-30.6eV
KE=-(-30.6)=+30.6eV
PE =2(-30.6)=-61.2eV

5. The energy of the second Bohr orbit of hydrogen atom is -3.41 eV. The energy of the second orbit of $Be^{3+}$ would be:

A) -13.6 eV
B) -54.4 eV
C) -27.2 eV
D) -6.8 eV

**Answer:A**

$$(TE)_{H.Like} = \frac{(T.E)_H}{n^2} Z^2$$

Solution:

$$(TE)_{Be^{3+}} = \frac{-3.41}{2^2} \times (4)^2 = \frac{-3.41}{4} \times 16 = -13.6\,eV.$$

6. The ratio of the difference in energy between the first and the second Bohr orbit to that between the second and the third Bohr orbit for $He^{+}$ is:

A) 27/5
B) 9/4
C) 32/27
D) 32/5

**Answer:A**

Solution:

$$E_n = -13.6\,\frac{z^2}{n^2}$$

Given $z = 2$

$$E_1 = -13.6 \times \frac{4}{1}$$

$$E_2 = -13.6 \times \frac{4}{4} = -13.6$$

$$E_3 = -13.6 \times \frac{4}{9}$$

$$E_1 - E_2 = -13.6 \times 4 - (-13.6) = 13.6 - 4 \times 13.6$$

$$E_2 - E_3 = -13.6 - \left(-13.6 \times \frac{4}{9}\right) = 13.6 \times \frac{4}{9} - 13.6$$

$$\frac{E_1 - E_2}{E_2 - E_3} = \frac{13.6 - 4 \times 13.6}{13.6 \times \frac{4}{9} - 13.6}$$

$$= \frac{13.6\,[1-4]}{13.6\left[\frac{4}{9} - 1\right]} = \frac{-3}{\frac{4-9}{9}} = \frac{-3}{-5/9} = \frac{27}{5}$$

7. A single electron in an ion has ionization energy equal to 122.4 eV. What is the total number of neutrons present in one ion of it if the atomic mass is 7?

A) 2 B) 3 C) 4 D) 5

**Answer:B**

Solution:

$$IE_{H\,like} = IE_H \times z^2$$

$$122.4 = 13.6 \times z^2$$

$$z^2 = \frac{122.4}{13.6} = 9$$

$$z = 3$$

8. In a hydrogen atom, the difference in orbital radius between two states is 5 times the first Bohr radius. Identify the transition if the initial state is n=3:

**(FA & SA- 2 Marks )**

A) $3 \to 1$ B) $3 \to 2$ C) $4 \to 3$ D) $5 \to 3$

**Answer:C**

Solution:

$r_n \propto \frac{n^2}{Z}$

$r_f - r_i = 5$

$r_i = 3^2 = 9$, $r_f = n_f^2 = ?$

$r_f - 9 = 5$

$n_f^2 - 9 = 5$

$n_f^2 = 14 \Rightarrow n_f = 3.741 \cong 4$

Transition from $4 \to 3$

9. In a hydrogen-like ion with Z=2, two electrons move in circular orbits of radii R and 4R. The ratio of the time taken by them to complete one revolution is:
A) 1:8 B) 8:1 C) 1:4 D) 4:1

**Answer:A**

Solution:

$$T \propto \frac{n^3}{z^2}$$

$$r_n \propto \frac{n^2}{z}$$

$$r_1 = R = \frac{n^2}{2^2}$$

$$r_2 = 4R = \frac{n_2^2}{2^2}$$

$$\frac{r_1}{r_2} = \frac{R}{4R} = \frac{\frac{n_1^2}{4}}{\frac{n_2^2}{4}}$$

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

$$\frac{n_1^2}{n_2^2} = \frac{1^2}{2^2}$$

$$n_1 = 1, n_2 = 2$$

$$T_1 = \frac{(1)^3}{2^2} = \frac{1}{4}, \quad T_2 = \frac{2^3}{2^2} = 2$$

$$\frac{T_1}{T_2} = \frac{1/4}{2} = \frac{1}{8}$$

10. When a hydrogen atom emits a photon of energy 2.55 eV, the orbital angular momentum changes by:

A) $\hbar$ B)2$\hbar$ C) 3$\hbar$ D4$\hbar$

**Answer:B**

Solution:2.55 eV corresponds to the 4 $\rightarrow$ 2 transition (E4 = -0.85 eV, E2 = -3.40 eV, $\Delta$E = 2.55 eV).

$\Delta$n = 2. Using the (question's) Bohr quantization convention (mvr = n·h u), the change in L = 2·$\hbar$. (If using the strict modern form L=n$\hbar$, the change would be 2$\hbar$.)

11. Energy of an electron moving in the third orbit of $B^{4+}$ ion is:

**(FA & SA- 5 Marks / 8 Marks)**

A) -13.6 eV B) -30.6 eV C) -24.4 eV D) -54.4 eV

**Answer:B**

Solution:

$E_n = -13.6 \cdot \frac{Z^2}{n^2}$

For, Boron, Z = 5

Given n = 3.

$E_3 = -13.6 \times \frac{5^2}{9} = \frac{-340}{9} = 37.77$

12. According to Bohr's theory of hydrogen atom:
    A) Angular momentum is quantized as $n\hbar$
    B) Orbits are circular only
    C) Energy is inversely proportional to $n^2$
    D) All of the above

**Answer:D**

Solution:All given statements are true:
    A) Angular momentum quantized as $n\hbar$
    B) Orbits circular
    C) Energy $\alpha$ $1/n^2$

13. If the speed of an electron in the Bohr's first orbit of hydrogen is v, the speed in the second orbit of $He^+$ is:
    A) v   B) 2v   C) v/2   D) 4v

**Answer:A**

Solution:

$V \propto \frac{Z}{n}$.

For Bohr's 1st orbit velocity = V.

$V = \frac{Z}{n} = \frac{1}{1} = 1$.

For $He^+$, velocity = V', Z = 2, n = 2

$V' = \frac{Z}{n} = \frac{2}{2} = 1$.

$V = V' = 1$

$\boxed{V' = V}$

14. With increasing principal quantum number in a hydrogen-like species, the energy difference between two consecutive orbits:
    A) Increases   B) Decreases

C) Remains constant D) First increases then decreases

**Answer:B**

Solution:As the principal quantum number (n) increases, the electron is further away from the nucleus, and the energy levels become closer together. Consequently, the energy difference between two consecutive energy levels decreases.

## JEE ADVANCED LEVEL QUESTIONS

**Multicorrect Answer Type :**

1. To which of the following is Bohr's theory applicable?

A) H (Hydrogen atom) B) $He^{+}$ (Helium ion)

C) $Li^{2+}$(Lithium doubly ionized) D) $Be^{3+}$ (Beryllium triply ionized)

**Answer:A,B,C,D**

Solution:Bohr's theory applies only to single-electron species, i.e., systems having only one electron.

All are hydrogen-like ions with 1 electron.

2. Bohr's theory is not applicable to:

A) He (neutral helium)

B) $Li^{+}$(singly ionized lithium)

C) $H_2^{+}$ (hydrogen molecular ion)

D) $Ne^{9+}$ (neon with one electron)

**Answer:A,B,C**

Solution:Bohr's theory fails for multi-electron atoms/molecules.

A) He (neutral helium) – 2 electrons

B) $Li^{+}$– Actually $Li^{+}$ has 2 electrons (Z=3, 2 $e^{-}$)

C) $H_2^{+}$ – hydrogen molecular ion – Bohr model is for single nucleus, not for molecules

D) $Ne^{9+}$– 1 electron only (Z=10, 1 $e^{-}$) --> Bohr's theory works for this.

3. For which of the following species will the radius of the first Bohr orbit be smaller than that of hydrogen?

A) D (Deuterium) B) $He^{+}$ C) $Li^{2+}$ D) T (Tritium)

**Answer:B,C**

Solution: $r_n = \frac{a_0 n^2}{Z}$

For n = 1, smaller radius means larger Z.

| Species | Z | $r_1$ relative to H | Smaller |
|---|---|---|---|
| D (Deuterium) | 1 | same as H (tiny difference due to mass) | ˜ same |
| $He^{+}$ | 2 | r = a0/2 | smaller |
| $Li^{2+}$ | 3 | r = a0/3 | smaller |
| T (Tritium) | 1 | same as H | ˜ same |

**Assertion and Reason Type:**

A) Both (A) and (R) are true and (R) is the correct explanation of(A)
B) Both (A) and (R) are ture and (R) is not the correct explanation of (A)
C) (A) is true but (R) is false
D) (A) is false but (R) is true

4. **Assertion (A)** : In a hydrogen-like atom, the velocity of an electron in the n=2 orbit of $Li^{2+}$ is greater than that in the n=1 orbit of H.
**Reason (R)** : Velocity of electron is directly proportional to atomic number Z and inversely proportional to n.

**Answer:A**

Solution:

$$V \propto \frac{Z}{n}$$

For $Li^{2+}$, $Z=3$, $n=2$

$$V_{Li} \propto \frac{3}{2}$$

For H, $Z=1$, $n=1$.

$$V_H \propto \frac{1}{1}.$$

∴ Velocity of $Li^{2+}$ in $2^{nd}$ orbit is higher than H in $1^{st}$ orbit

5. **Assertion (A)** : The radius of the first Bohr orbit in deuterium (D) is the same as in hydrogen (H).
**Reason (R)** : Bohr radius depends only on $n^2/Z$ and is independent of nuclear mass.

**Answer:D**

Solution:

$$r = \frac{n^2h^2}{4\pi^2 m Z e^2}$$

For deuterium the mass increases, so the radius will slightly reduced.
Radius depends on mass.

**Comprehension Type:**

Angular momentum of the revolving electron in $n^{th}$ orbit is given by

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

$$v = \frac{nh}{2\pi mr}$$

put the value of 'r' in the equation

$$\text{then, } v = \frac{nh \times 4\pi^2 mZe^2 K}{2\pi mn^2 h^2}$$

$$v = \frac{2\pi Ze^2 K}{nh}$$

6. For a hydrogen-like ion with atomic number Z, how does the velocity of an electron in the n th orbit change when the value of n is doubled?

A) Becomes half
B) Becomes double
C) Becomes four times
D) Remains the same

**Answer:A**

Solution: $v \propto \frac{1}{n} \Rightarrow v_2 = \frac{v_1}{2}$

Velocity becomes half

7. If the atomic number Z of a hydrogen-like ion is increased to 4Z while the electron remains in the same orbit n, how does the velocity change?

A) Becomes 4 times
B) Becomes 2 times
C) Becomes 1/4 times
D) Remains the same

**Answer:A**

Solution: $v \propto Z \Rightarrow v_2 = 4v_1$

Velocity becomes four times

**Integer Type:**

8. The ratio of the radius of the 2nd Bohr orbit to the radius of the 1st Bohr orbit in a hydrogen atom (Z=1) is:_______________

**Answer:4**

Solution:

$$r_n \propto \frac{n^2}{Z}$$

$2^{nd}$ orbit, $n=2, Z=1$.

$$r_2 \propto \frac{4}{1}$$

$1^{st}$ orbit, $n=1, Z=1$

$$r_1 \propto \frac{1}{1}$$

$$\frac{r_2}{r_1} = \frac{4}{1}$$

9. The ratio of the radius of the 2nd Bohr orbit of a hydrogen atom (Z=1) to the radius of the 1st Bohr orbit of a $He^+$ ion (Z=2) is:___________

**Answer:8**

Solution:

$$r_n \propto \frac{n^2}{Z}$$

For $2^{nd}$ orbit of 'H'

$n=2, Z=1$.

$$r_H = \frac{2^2}{1} = 4.$$

For $1^{st}$ orbit of $He^+$.

$n=1, Z=2$

$$r_{He^+} = \frac{1}{2}$$

$$\frac{r_H}{r_{He^+}} = \frac{4}{\frac{1}{2}} = \frac{8}{1}.$$

**Matrix Matching Type:**

10. **Column-I** **Column-II**

A) Radius of the $n^{th}$ Bohr orbit $\alpha$ 1. $\frac{n^2}{Z}$

B) Total energy of an electron in the n $^{th}$ orbit $\alpha$ 2. $-\frac{Z^2}{n^2}$

C) Velocity of electron in the n$^{th}$ orbit $\alpha$ 3. $\frac{Z}{n}$

D) Time period of revolution in the n $^{th}$ orbit $\alpha$ 4. $\frac{n^3}{Z^2}$

**Answer:A-1,B-2,C-3,d-4**

Solution:A) Radius of the n$^{th}$ Bohr orbit $\alpha$ 1. $\frac{n^2}{Z}$

B) Total energy of an electron in the n $^{th}$ orbit $\alpha$ 2. $-\frac{Z^2}{n^2}$

C) Velocity of electron in the n$^{th}$ orbit $\alpha$ 3. $\frac{Z}{n}$

D) Time period of revolution in the n $^{th}$ orbit $\alpha$ 4. $\frac{n^3}{Z^2}$

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## LEARNERS TASK

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## CONCEPTUAL UNDERSTANDING QUESTIONS (CUQ's)

1. The angular momentum of an electron in a stationary orbit of a hydrogen atom is quantized according to:
   A) Planck B) Rutherford C) Bohr D) Thomson

**Answer:C**

Solution: Bohr proposed that $mvr = \frac{nh}{2\pi}$

angular momentum is quantized

2. Bohr's model explains the spectral lines of:
   A) Hydrogen (H) B) Helium (He) neutral
   C) Lithium (Li) neutral D) Oxygen (O)

**Answer:A**

Solution:Bohr's theory successfully explains the line spectra of hydrogen and hydrogen-like (single-electron) species, not multi-electron atoms like neutral He or Li

3. For which of the following is Bohr's model strictly applicable?
   A) H atom B) $He^+$ ion C) $Li^{2+}$ ion D) All of the above

**Answer:D**

Solution:Bohr's model is valid for hydrogen-like (one-electron) systems, i.e.,H, $He^+$, $Li^{2+}$, $Be^{3+}$, etc

4. The total energy of an electron in the n-th orbit of $He^+$ ion is:

A) -13.6eV B) -54.4 eV C) -122.4 eV D) -30.6 eV

**Answer:B**

Solution: $E_1 = -13.6Z^2 eV$, for He $Z = 2 \Rightarrow E_1 = -13.6 \times 4 = -54.4$

5. The radius of the first Bohr orbit in $Li^{2+}$ ion compared to hydrogen is:
A) Same B) Half C) One-third D) Four times

**Answer:C**

Solution:

$$r_n = \frac{n^2 a_0}{Z}$$

$$For Hydrogen n = 1, Z = 1$$

$$r_H = \frac{1^2 a_0}{1} = a_0$$

$$For Li, n = 1, Z = 3$$

$$r_{Li^{2+}} = \frac{1^2 a_0}{3} = \frac{a_0}{3}$$

$$\frac{r_{Li^{2+}}}{r_H} = \frac{\frac{a_0}{3}}{a_0} = \frac{1}{3}$$



6. The velocity of an electron in the second orbit of H atom compared to the first orbit:
A) Same B) Half C) Double D) Quarter

**Answer:B**

Solution:The velocity of an electron in the second orbit of a hydrogen atom is half the velocity of an electron in the first orbit. This is because velocity is inversely proportional to the principal quantum number n, $v \alpha \frac{1}{n}$

and for the second orbit, n=2 while for the first orbit, n=.

Therefore, the velocity in the second orbit is $v_2 = \frac{v_1}{2}$

7. For a $He^+$ ion, the energy difference between the n=3 and n=2 orbit is:
A) 12.1 eV B) 40.8 eV C) 7.55 eV D) 13.6 eV

**Answer:C**

Solution:

$$E_n = -13.6 \cdot \frac{Z^2}{n^2}$$

For $He^+$, $Z = 2$

$$E_2 = -13.6 \times \frac{2^2}{2^2} = -13.6$$

$$E_3 = -13.6 \times \frac{2^2}{3^2} = -\frac{13.6 \times 4}{9} = -6.$$

$$E_3 - E_2 = -6 - [-13.6] = 7.55\,ev.$$

8. What is the ratio of the radii of the 3rd orbits of $He^{+}$ and $Li^{2+}$

A) 1:1 B) 9:4 C) 27:8 D) 3:2

**Answer:D**

Solution:

$$r_n = \frac{n^2 a_0}{Z}$$

$$r_{He^+} = \frac{3^2 a_0}{2}$$

$$r_{Li^{2+}} = \frac{3^2 a_0}{3}$$

$$r_{He^+} : r_{Li^{2+}} = \frac{3^2 a_0}{2} / \frac{3^2 a_0}{3} = \frac{1}{2} / \frac{1}{3} = \frac{3}{2}$$

9. According to Bohr's theory, the angular momentum of an electron in the n=4 orbit of $Be^{3+}$ ion is:

A) 2 $\hbar$ B) 3 $\hbar$ C) 4 $\hbar$ D) 5 $\hbar$

**Answer:C**

Solution: $L = n\hbar$, for n=4 -->$L = 4\hbar$

10. For a hydrogen-like ion with atomic number Z, if the electron jumps from n=2 to n=1:

A) Energy is absorbed B) Energy is emitted

C) Energy remains the same D) Cannot be determined

**Answer:B**

Solution:When an electron jumps from a higher energy level to a lower energy level, energy is emitted in the form of a photon.

Here: n=2 $\rightarrow$ n=1 is a downward transition, so energy is emitted.

## JEE MAINS LEVEL QUESTIONS

1. The angular momentum of an electron present in the excited state of a hydrogen-like ion is $3\hbar$. The electron is present in:

A) Third orbit B) Second orbit C) Fourth orbit D) Fifth orbit

**Answer:A**

Solution:Angular momentum in the Bohr model is:

$$L = n\hbar$$

$$\hbar = \frac{h}{2\pi}$$

$$L = 3\hbar$$

$$n = 3$$

2. If the electron of a helium ion ($He^+$) is present in the first orbit, the total energy of the electron is: **(FA & SA- 3 Marks / 4 Marks)**

A) -13.6 eV B) -54.4 eV C) -27.2 eV D) -6.8 eV

**Answer:B**

Solution: $E_1 = -13.6Z^2 = -13.6 \times 4 = -54.4eV$

3. Which one of the following statements is not correct?

A) For $Li^{2+}$ ion, $E_n = -13.6\frac{9}{n^2}eV$

B) The angular momentum of the electron in the ground state of $He^+$ is $\hbar$

C) The radius of the first Bohr orbit of $He^+$ is 0.529A°

D) The velocity of an electron in the first orbit of H is $2.18 \times 10^6$ m/s

**Answer:C**

Solution:A) For $Li^{2+}$ ion, $E_n = -13.6\frac{9}{n^2}eV$ ---True

B) The angular momentum of the electron in the ground state of $He^+$ is $\hbar$ -->True

C) False: $He^+ = a_0/Z = 0.529A°/2 = 0.2645A°$, not 0.529 Å

D) True (standard value~ $2.18 \times 10^6$ m/s)

4. Which of the following electronic transitions in a $Li^{2+}$ ion will require the largest amount of energy?

A) From n=1 to n=2 B) From n=2 to n=3

C) From n=$\infty$ to n=1 D) From n=3 to n=5

**Answer:A**

Solution:

$Li^{2+}$ ion, $Z = 3$.

$E_n = -13.6 \frac{Z^2}{n^2}$

$E_1 = -13.6 \cdot \frac{9}{1} = -122.4$.

$E_2 = -13.6 \cdot \frac{9}{4} = -30.6$.

$E_3 = -13.6 \cdot \frac{9}{9} = -13.6$.

$E_5 = -13.6 \frac{9}{25} = 4.896$.

$E_\infty = -13.6 \cdot \frac{9}{\infty} = 0$.

A) $n=1$ to $n=2$

$E_1 - E_2 = -122.4 - [-30.6] = -91.8$ — Highest.

B) $n=2$ to $n=3$.

$E_2 - E_3 = -30.6 - [-13.6] = -17$

C) $n=\infty$ to $n=1$

$E_\infty - E_1 = 0 - [-122.4] = 122.4$.

In this case energy is emitted. Not required.

D) $n=3$ to $n=5$.

$E_3 - E_5 = -13.6 - [-4.896]$

$= -8.704$.

5. The minimum energy required to excite a $He^+$ ion from its ground state:

**(FA & SA- 2 Marks )**

A) 40.8 eV B) 54.4 eV C) 13.6 eV D) 10.2 eV

**Answer:A**

Solution:For $He^+$ ,Z=2, ground state is n=1.

$$E_n = -\frac{Z^2(13.6)}{n^2} = -\frac{4(13.6)}{n^2} = -\frac{54.4eV}{n^2}$$

Minimum excitation is from n=1 $\rightarrow$ n=2:

$$\Delta E = E_2 - E_1 = -\frac{54.4eV}{2^2} - (-\frac{54.4eV}{1^2}) = -13.6 + 54.4 = 40.8eV$$

6. The energy difference between the states n=2 and n=3 is 'E' eV in a hydrogen-like ion with Z=2. The ionization potential of this ion is:
A) 3.2E B) 7.2E C) 5.6E D) 13.2E

**Answer:B**

Solution:The energy of an electron in a hydrogen-like ion is given by the formula:

$$E_n = -13.6\frac{Z^2}{n^2}$$

The energy difference between the states n=2 and n=3 is E, which can be expressed as:

$$E = E_3 - E_2 = -13.6Z^2(\frac{1}{3^2} - \frac{1}{2^2})$$

$$E = -13.6Z^2\left(\frac{1}{9} - \frac{1}{4}\right) = -13.6Z^2\left(\frac{4-9}{36}\right)$$

$$E = -13.6Z^2\left(\frac{-5}{36}\right) = 13.6Z^2\left(\frac{5}{36}\right)$$

The ionization potential (IP) is the energy required to remove an electron from the ground state n=1 to the ionized state n=$\infty$.

$$IP = E_\infty - E_1 = 0 - (-13.6\frac{Z^2}{1^2})$$

$$IP = 13.6Z^2$$

$$E = 13.6Z^2(\frac{5}{36})$$

$$13.6Z^2 = E\left(\frac{36}{5}\right)$$

$$IP = 13.6Z^2$$

$$IP = E\left(\frac{36}{5}\right) = 7.2E$$

7. The minimum energy required to be supplied to a $He^+$ ion to push its electron from the 2nd orbit to the 3rd orbit:
A) 7.56 eV B) 10.2 eV C) 40.8 eV D) 13.6 eV

**Answer:A**

Solution: $\Delta E = 54.4(\frac{1}{4} - \frac{1}{9}) = 54.4 \times \frac{5}{36} \approx 7.56\,eV$

8. The ionization energy of the ground state of a hydrogen-like ion is 54.4 eV. The energy of an electron in its second orbit would be:

A) -13.6 eV B) -27.2 eV C) -6.8 eV D) -3.4 eV

**Answer:A**

Solution:Step 1: IP corresponds to energy of ground state

$$IP = |E_1| = 54.4 eV \Rightarrow E_1 = -54.4 eV$$

Energy of n = 2

$$E_2 = \frac{E_1}{n^2} = \frac{-54.4}{2^2} = -54.4/4 = -13.6 eV$$

9. The velocity of an electron in the first Bohr orbit of a hydrogen-like ion with Z=3 is v. Its velocity in the second orbit would be:

**(FA & SA- 5 Marks / 8 Marks)**

A) v/2 B) 2v C) 3v/2 D) 2v/3

**Answer:A**

Solution: $v \propto \frac{Z}{n} \Rightarrow \frac{v_2}{v_1} = \frac{3/2}{3/1} = \frac{1}{2} \Rightarrow v_2 = v/2$

10. The radius of the second Bohr orbit in a hydrogen atom is $2.12\times10^{-10}$ m. What is the radius of the third Bohr orbit in a $Li^{2+}$ ion?

A) $1.59\times10^{-10}$ m B) $3.18\times10^{-10}$ m C) $4.77\times10^{-10}$ m D) $6.36\times10^{-10}$m

**Answer:A**

Solution:

$$r_n = \frac{n^2 a_0}{Z}$$

For H, 2nd orbit $r = 2.12\times10^{-10}$m.

$$2.12\times10^{-10} m = \frac{4 a_0}{1}$$

$$a_0 = \frac{2.12\times10^{-10}}{4}$$

For $Li^{2+}$, 3rd orbit, n=3, Z=3

$$r_{Li^{2+}} = \frac{3^2 \cdot a_0}{3} = \frac{9\times2.12\times10^{-10}}{3\times4}$$

$$= 1.59\times10^{-10} m.$$

## JEE ADVANCED LEVEL QUESTIONS

**Multicorrect Answer Type :**

1. Which of the following statements are wrong regarding Bohr's model?
   A)For a hydrogen-like ion, the radius of the orbit is proportional to $n^2/Z$
   B)The velocity of an electron in the nth orbit is independent of the nuclear charge
   C) The total energy of an electron in the ground state of $He^+$ is the same as in the ground state of H
   D)The angular momentum of an electron in the nth orbit depends on Z

**Answer:B,C,D**

Solution:B is wrong — velocity $v_n \propto Z/n$, so it does depend on nuclear charge.

C is wrong — $E_n \propto -Z^2/n^2$, so $He^+$ (Z=2) ground-state energy is different from H (Z=1).

D is wrong — Bohr angular momentum depends only on n ( $L = n\hbar$ in the correct form ), not on Z.

2. According to Bohr’s theory, which of the following quantities are quantized for hydrogen-like ions?
   A) Radius of the orbit
   B) Velocity of the electron
   C) Angular momentum
   D) Magnetic moment

**Answer:A,B,C,D**

Solution:Radius $r_n$ is fixed by n ($r_n \propto n^2/Z$).

Velocity $v_n$ takes discrete values ($v_n \propto Z/n$).

Angular momentum L is quantized ($L = n\hbar$).

Magnetic moment (orbital) is proportional to L, so it is quantized as well.

**Assertion and Reason Type:**

A)Both (A) and (R) are true and (R) is the correct explanation of(A)
B) Both (A) and (R) are ture and (R) is not the correct explanation of (A)
C) (A) is true but (R) is false
D) (A) is false but (R) is true

3. **Assertion** : The radius of the first Bohr orbit in $Li^{2+}$ ion is smaller than in hydrogen.
   **Reason** : Bohr radius is inversely proportional to the nuclear charge Z.

**Answer:A**

Solution:Assertion: For $Li^{2+}$ (Z = 3) , $r_1 = a_0/Z$, so it is smaller than for H (Z = 1).

Reason: Bohr radius scales as $r_n \propto n^2/Z$ (i.e. inversely with Z).

The reason directly explains why the radius is smaller

4. **Assertion** : The total energy of the electron in the first orbit of $He^+$ ion is four times that of hydrogen.
   **Reason** : Total energy of an electron in a hydrogen-like ion is proportional

to $Z^2$.

**Answer:A**

Solution:Assertion: $E_1(H) = -13.6$, $E_1(He^+) = -13.6 \times 4 = -54.4eV \Rightarrow$ magnitude four times (more negative).

Reason: $E_n \propto -Z^2/n^2$, so energy scales with $Z^2$.

The proportionality to $Z^2$ explains the factor of four for $He^+$ (Z=2).

5. **Assertion** : The spectral lines of $He^+$ are at shorter wavelengths than hydrogen lines.

**Reason** : Wavelength of emitted radiation in hydrogen-like ions is inversely proportional to $Z^2$.

**Answer:A**

Solution:Assertion: Lines for $He^+$ are at shorter wavelengths (higher photon energies) than corresponding H lines — true because transition energies are larger for larger Z

Reason: Since transition energies scale $\alpha Z^2$, wavelengths scale as $\lambda \propto 1/\Delta E \propto 1/Z^2$, so $\lambda$ is smaller for larger Z

**Integer Type:**

6. For a $He^+$ ion, the difference between the radii of the 2nd and 4th Bohr orbit is equal to the radius of which orbit? Find n.

**Answer:3**

Solution:

$$r_n = \frac{n^2 a_0}{Z}$$

For $He^+$, 2nd orbit, $Z = 2, n = 2$

$$r_{He^+},\ r_2 = \frac{4a_0}{2} = 2a_0.$$

For 4th orbit, $n = 4$

$$r_4 = \frac{16a_0}{2} = 8a_0$$

$$r_n = r_4 - r_2.$$

$$\frac{n^2 a_0}{Z} = 8a_0 - 2a_0.$$

$$\frac{n^2 a_0}{Z} = a_0(6)$$

$$n^2 = 6 \times 2 = 12.$$

$$n^2 = 12.$$

$$n = \sqrt{12} = 2\sqrt{3} = 3.46 \cong 3.$$

7. The number of wavelengths in the 4th Bohr orbit of $Li^{2+}$ ion is ___________

**Answer:4**

Solution:By Bohr's quantization the circumference of the n-th orbit contains exactly n de Broglie wavelengths. So for the 4th orbit the number of wavelengths = 4

**Comprehension Type:**

The total energy of an electron revolving in a particular orbit is

T.E. = K.E. + P.E.

where :

P.E. = Potential energy , K.E. = Kinetic energy , T.E. = Total energy

The K.E. of an electron = $\frac{1}{2}mv^2$

and the P.E. of an electron $= -\frac{KZe^2}{r}$

Hence, T.E. $= \frac{1}{2}mv^2 - \frac{KZe^2}{r}$

we know that, $\frac{mv^2}{r} = \frac{KZe^2}{r^2}$ or $mv^2 = \frac{KZe^2}{r}$ K.E. $= \frac{1}{2}\frac{KZe^2}{r}$

substituting the value of $mv^2$ in the above equation :

$$T.E. = \frac{KZe^2}{2r} - \frac{KZe^2}{r} = -\frac{KZe^2}{2r}$$

$$T.E. = -\frac{KZe^2}{2r} \qquad T.E. = -K.E. = \frac{P.E.}{2}$$

8. In a hydrogen-like atom, the total energy T.E. of an electron in the n-th orbit is related to its kinetic energy K.E. as:

A) T.E.=K.E. B) T.E.=2K.E. C) T.E.=-K.E. D) T.E.=-2K.E

**Answer:C**

Solution:

$$K.E. = \frac{Z^2e^4m}{8\epsilon_0^2n^2h^2} = -T.E.$$

$$K.E. = -T.E. \text{and} P.E. = 2T.E.$$

$$T.E. = -K.E.$$

9. The total energy of an electron in the n-th Bohr orbit of a hydrogen atom is given by

$A) E_n = -13.6/n eV$

$B) E_n = -13.6n^2 eV$

$C) E_n = -13.6/n^2 eV$

$D) E_n = -13.6/n^2 eV$

**Answer:C**

Solution: $E_n = -\frac{13.6}{n^2} eV$

**Matrix Matching Type:**

10. **List - I** **List - II**

| List - I | List - II |
|---|---|
| A) Energy of electron in nth orbit of $He^+$ | 1. $-\frac{Z^2 13.6eV}{n^2}$ |
| B) Velocity of electron in nth orbit of $Li^{2+}$ | 2. $\frac{Ze^2}{2\varepsilon_0 hn}$ |
| C) Rydberg constant for $He^+$ | 3. $R \alpha Z^2$ |
| D) Radius of nth orbit of $Be^{3+}$ | 4. $\frac{n^2h^2}{4\pi^2 mZe^2}$ |

**Answer:A-1,B-2,C-3,D-4**

Solution:

| | |
|---|---|
| A) Energy of electron in nth orbit of $He^+$ | 1. $-\frac{Z^2 13.6eV}{n^2}$ |
| B) Velocity of electron in nth orbit of $Li^{2+}$ | 2. $\frac{Ze^2}{2\varepsilon_0 hn}$ |
| C) Rydberg constant for $He^+$ | 3. $R \alpha Z^2$ |
| D) Radius of nth orbit of $Be^{3+}$ | 4. $\frac{n^2h^2}{4\pi^2 mZe^2}$ |

# KEY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | TEACHING TASK | | | | | |
| | | | JEE MAINS LEVEL QUESTIONS | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| B | C | A | A | A | A | B | C | A | B |
| 11 | 12 | 13 | 14 | | | | | | |
| B | D | A | B | | | | | | |
| | | | JEE ADVANCED LEVEL QUESTIONS | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| A,B,C,D | A,B,C | B,C | A | D | A | A | 4 | 8 | A-1,B-2,C- |
| | | | | LEARNERS TASK | | | | | |
| | | | CONCEPTUAL UNDERSTANDING QUESTIONS (CUQ's) | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| C | A | D | B | C | B | C | D | C | B |
| | | | | JEE MAINS LEVEL QUESTIONS | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| A | B | C | A | A | B | A | A | A | A |
| | | | | JEE ADVANCED LEVEL QUESTIONS | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| B,C,D | A,B,C,D | A | A | A | 3 | 4 | C | C | |
| 10-A-1,B-2,C-3,D-4 | | | | | | | | | |