Atomic Structure

Question1

The electron in hydrogen atom undergoes transition from higher orbits to an orbit of radius 476.1 pm . This transition corresponds to which of the following series?

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Options:

A.

Lyman

B.

Paschen

C.

Balmer

D.

Pfund

Answer: B

Solution:

For hydrogen atom, radius is given by

$$r_n = n^2 \cdot a_0 \qquad \ldots (i)$$
$$a_0 = 52.9\text{pm (Bohr's radius)}$$
$$r_n = 476.1\text{pm}$$

Substituting the given values in Eq. (i),

$n^2 \approx 9, n = 3$

Transition is to $n = 3$, so it is a Paschen series.

Question2

Identify the incorrect statement from the following?

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Options:

A.

m, designates the orientation of the orbital.

B.

The probability density of electron is expressed by $|\psi|^3$.

C.

The total information about electron in atom is stored in its ψ.

D.

Total number of orbitals in a sub level is equal to $(2l + 1)$.

Answer: B

Solution:

Among the given statements, statement given in option

(b) is incorrect. It's correct form is,

The probability density of electron is expressed by $|\psi|^2$.

Question3

The radius of stationary state $(n = 2)$ of hydrogen atom is $x$pm. The radius of stationary state $(n = 3)$ of He^+ion (in pm) is

Options:

A.

$9/8x$

B.

$9x/8$

C.

$16x/9$

D.

$9/16x$

Answer: B

Solution:

Radius of nth orbit of hydrogen and hydrogen like atom, $r_n = \frac{n^2 a_0}{Z}$

For $n = 2, r_n = x\text{pm}, Z = 1$ (for H-atom)

$x = \frac{2^2(a_0)}{1} \Rightarrow a_0 = \frac{x}{4}$ $\ldots(i)$

For $n = 3, Z = 2, r_n = ?$

(for He^+ atom)

$$r_n = \frac{(3)^2 a_0}{2} = \frac{9a_0}{2}$$
$$\Rightarrow r_n = \frac{9 \times x}{2 \times 4} = \frac{9x}{8}$$

Question4

When electromagnetic radiation of wavelength 310 nm falls on the surface of a metal having work function 3.55 eV , the velocity of

photoelectrons emitted is $x \times 10^5 \mathrm{~ms}^{-1}$. The value of x is (Nearest integer) $\left(m_e=9 \times 10^{-31} \mathrm{~kg}\right)$

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Options:

A.

2

B.

4

C.

5

D.

6

Answer: B

Solution:

Given, $\lambda=310 \mathrm{~nm}$

$=310 \times 10^{-9} \mathrm{~m}$
$\phi=3.55 \mathrm{eV} \Rightarrow v=x \times 10^5 \mathrm{~m} / \mathrm{s}$
$x=?$

Energy of incident photon,

$$E=\frac{h c}{\lambda}=\frac{6.626 \times 10^{-34} \times 3 \times 10^8}{310 \times 10^{-9}}$$
$$E=6.412 \times 10^{-19} \mathrm{~J}$$

Kinetic energy of photoelectrons,

$\mathrm{KE}=E-\phi$

$\mathrm{KE}=6.412 \times 10^{-19}-3.55 \times 1.6 \times 10^{-19}$
$\mathrm{KE}=0.732 \times 10^{-19} \mathrm{~J}$

Velocity of photoelectrons,

$$v=\sqrt{\frac{2\mathrm{KE}}{m_e}}$$

$$=\sqrt{\frac{2\times0.732\times10^{-19}}{9\times10^{-31}}}$$

$v=4\times10^5\ \mathrm{m/s}$

or $\quad x=4$

Question5

If n, l represent the principal and azimuthal quantum numbers respectively, the formula used to know the number of radial nodes possible for a given orbital is

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Options:

A. $(n-l)$

B. $(n-1+1)$

C. $(n-1-1)$

D. $(n-2)$

Answer: C

Solution:

Angular nodes are given by ' l ' quantum number and radial nodes are determined by $n-l-1$, where n is principal quantum number, l is azimuthal quantum number.

Question6

If the radius of first orbit of hydrogen like ion is 1.763×10^{-2} nm, the energy associated with that orbit (in J) is

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Options:

A. $+1.962 \times 10^{-17}$

B. -1.962×10^{-17}

C. -0.872×10^{-17}

D. -2.18×10^{-18}

Answer: B

Solution:

Given that the radius of the first orbit of a hydrogen-like ion is 1.763×10^{-2} nm, we can find the energy associated with that orbit using Bohr's postulates.

Calculate Atomic Number Z:

According to Bohr's model, the radius of the n-th orbit is given by:

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

For the first orbit ($n = 1$), we have:

$$r_1 = \frac{a_0}{Z}$$

Given $r_1 = 1.763 \times 10^{-2}$ nm and the Bohr radius $a_0 = 0.0529$ nm, we can solve for Z:

$$Z = \frac{a_0}{r_1} = \frac{0.0529 \text{ nm}}{1.763 \times 10^{-2} \text{ nm}} \approx 3$$

Calculate the Energy E_1:

Using Bohr's expression for the energy of the n-th orbit:

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

For the ground state ($n = 1$):

$$E_1 = \frac{3^2 \times (-13.6 \text{ eV })}{1^2} = -122.4 \text{ eV}$$

Convert Energy to Joules:

We convert the energy from electron volts to joules using the conversion factor $1 \text{ eV} = 1.6 \times 10^{-19}$ J:

$$E_1 = -122.4 \times 1.6 \times 10^{-19} = -1.962 \times 10^{-17} \text{ J}$$

Thus, the energy associated with the first orbit is -1.962×10^{-17} J.

Question7

The wavelength of an electron is 10^3 nm. What is its momentum in kgms^{-1} ? ($h = 6.625 \times 10^{-34} \mathrm{Js}$)

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Options:

A. 6.625×10^{-31}

B. 6.625×10^{-37}

C. 6.625×10^{-28}

D. 6.625×10^{-34}

Answer: C

Solution:

To find the momentum of an electron given its wavelength, we can use the de Broglie relation.

Given:

Wavelength, $\lambda = 10^3$ nm, which can be converted to meters as follows:

$\lambda = 10^3 \times 10^{-9} = 10^{-6}$ m

Planck's constant, $h = 6.625 \times 10^{-34}$ Js

The de Broglie wavelength formula is:

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

Solving for momentum p, we rearrange the formula:

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

Substituting the given values into the equation:

$p = \frac{6.625 \times 10^{-34}}{10^{-6}}$

Calculating the result:

$p = 6.625 \times 10^{-28}$ kg m/s

Therefore, the momentum of the electron is 6.625×10^{-28} kg m/s.

Question8

Two statements are given below :

Statement I : In H atom, the energy of $2s$ and $2p$ orbitals is same.

Statements II : In He atom, the energy of $2s$ and $2p$ orbitals is same.

The correct answer is

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Options:

A. Both statements I and II are correct.

B. Both statements I and II are not correct.

C. Statement I is correct but statement II is not correct.

D. Statement I is not correct but statement II is correct.

Answer: C

Solution:

Statement I is correct but Statement II is incorrect. For single electron species energy depends only on value of n and not l.

But in case He , the energy depends on both n and l for $2s$ energy is $2+0=2$ and for $2p, 2+1=3$.

Hence, $2p$ has more energy.

Question9

The wavenumber of first spectral line of Lyman series of He^{+} ion is $x\ \mathrm{m}^{-1}$. What is the wave number (in^{-1}) of second spectral line of Balmer series of Li^{2+} ion?

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Options:

A. $\frac{9x}{16}$

B. $\frac{16x}{9}$

C. $\frac{8x}{27}$

D. $\frac{27x}{8}$

Answer: A

Solution:

The wave number is given by the formula,

$$\bar{v} = \frac{1}{\lambda} = RZ^2\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

Case (i) First spectral line of Lyman series of He^+has wave number $x \mathrm{~m}^{-1}$.

Substitute the value in equation (i).

$$x = R(2)^2\left[\frac{1}{(1)^2} - \frac{1}{(2)^2}\right]$$

As $n_i = 2$ and $n_f = 1$ for first spectral line of Lyman series

$$x = R \times 4 \times \frac{3}{4} \Rightarrow x = 3R$$

Case (ii) 2nd spectral line of Balmer series of Li^{2+}, let wave number be y.

$$y = R(3)^2 \times \left[\frac{1}{(2)^2} - \frac{1}{(4)^2}\right]$$

As $n_i = 4$ and $n_f = 2$ for 2 nd spectral line of Balmer series for Li^{2+} ion.

Substitute the value of R from Eq. (ii) in Eq. (iv).

$$y = \frac{x}{3} \times (3)^2 \times \frac{3}{16} \Rightarrow y = \frac{9x}{16} \mathrm{~m}^{-1}$$

Question10

The uncertainty in determination of position of a small ball of mass 10 g is 10^{-33} m. With what % of accuracy its speed can be measured, if it has a speed of 52.5 ms^{-1}? $(h = 6.6 \times 10^{-34} \mathrm{Js})$

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Options:

A. 1.0%

B. 20%

C. 10%

D. 2.0%

Answer: C

Solution:

Given,

$\Delta x = 10^{-33}$ m, $m = 10$ g, $v = 52.5$ m/s,

$h = 6.6 \times 10^{-34}$ Js.

According to Heisenberg's uncertainty principle,

$\Delta x \cdot \Delta p = \frac{h}{4\pi}$ or $\Delta x \cdot \Delta v \cdot m = \frac{h}{4\pi}$

lst step is to calculate uncertainty in velocity

$\Delta v = \frac{h}{4\pi m \Delta x}$

Substitute all values in Eq. (ii),

$$\Delta v = \frac{6.6 \times 10^{-34}}{4\pi \times 10 \times 10^{-3} \times 10^{-33}}$$

$$= 5.25 \text{ m/s}$$

% of accuracy is

$\frac{\Delta v}{v} \times 100 \Rightarrow \frac{5.25}{52.5} \times 100 = 10\%$

Question11

The kinetic energy of electrons emitted, when radiation of frequency 1.0×10^{15} Hz hits a metal, is 2×10^{-19} J. What is the threshold frequency of the metal (in Hz)? $\left(h = 6.6 \times 10^{-34} \text{Js}\right)$

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Options:

A. 35×10^{15}

B. 3.3×10^{14}

C. 6.97×10^{15}

D. 6.97×10^{14}

Answer: D

Solution:

Given,

Radiation frequency,

$\mathrm{v} = 1.0 \times 10^{15}$ Hz

Kinetic energy, $\mathrm{KE} = 2 \times 10^{-19}$ J

According to Einstein's equation for photoelectric effect,

$h v = h v_0 + \frac{1}{2} m v^2$

or $h v = h v_0 + \mathrm{KE} \quad \ldots$ (i)

where, v_0 is threshold frequency

$\frac{h v - \mathrm{KE}}{h} = v_0 \quad \ldots$ (ii)

Substitute all the values, in above formula,

$$\frac{6.6 \times 10^{-34} \times 1 \times 10^{15} - 2 \times 10^{-19}}{6.6 \times 10^{-34}} = v_0$$

$v_0 = 6.97 \times 10^{14}$ Hz

Question12

Identify the pair of species having same energy from the following. (The number given in the bracket corresponds to principal quantum number (n) in which the electron is present.)

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Options:

A. $\mathrm{H}(n=1) . \mathrm{L}^{2+}(n=1)$

B. $\mathrm{L}^{2+}(n=3), \mathrm{Be}^{3+}(n=4)$

C. $\mathrm{He}^{+}(n=1), \mathrm{Li}^{2+}(n=3)$

D. $\mathrm{H}(n=3), \mathrm{Li}^{2+}(n=3)$

Answer: B

Solution:

Energy according to Bohr's postulate is given by

$E=-13.6 \frac{Z^2}{n^2} \mathrm{eV}$

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

$E=-13.6 \frac{(3)^2}{(3)^2} ; E=-13.6 \mathrm{eV}$

For $\mathrm{Be}^{3+},(n=4, Z=4)$

$E=-13.6 \frac{(4)^2}{(4)^2} ; E=-13.6 \mathrm{eV}$

Hence, Li^{2+} and Be^{3+} have same energy.

Question13

Which one of the following corresponds to the wavelength of line spectrum of H atom in its Balmer series ? ($R=$ Rydberg constant)

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Options:

A. $\frac{9}{8R}$

B. $\frac{100}{21R}$

C. $\frac{25}{24R}$

D. $\frac{16}{15R}$

Answer: B

Solution:

In the Balmer series of the hydrogen atom, the electron transition occurs from a higher energy level ($n \geq 3$) to the second energy level ($n = 2$). The wavelength (λ) for these transitions is given by the Rydberg formula:

$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$

For different n values, this can be used to calculate the wavelength:

For $n = 3$

$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{9}\right) = R\left(\frac{9-4}{36}\right) = \frac{5R}{36}$

Therefore, $\lambda = \frac{36}{5R}$

For $n = 4$

$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{16}\right) = R\left(\frac{16-4}{64}\right) = \frac{3R}{16}$

Therefore, $\lambda = \frac{16}{3R}$

For $n = 5$

$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{25}\right) = R\left(\frac{25-4}{100}\right) = \frac{21R}{100}$

Therefore, $\lambda = \frac{100}{21R}$

For $n = 6$

$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{36}\right) = R\left(\frac{36-4}{144}\right) = \frac{32R}{144} = \frac{8R}{36}$

Therefore, $\lambda = \frac{36}{8R} = \frac{9}{2R}$

Clearly, the correct option, based on our calculations with the transitions that correspond to the Balmer series, is from the option **for** $n = 5$**:**

Option B: $\frac{100}{21R}$

Question14

The wavelength of second line of Balmer series of hydrogen atom is λnm. What is the wavelength of first line of Lyman series of He^+ion (in nm)?

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Options:

A. $\lambda/16$

B. $16/\lambda$

C. $16/3\lambda$

D. $3\lambda/16$

Answer: A

Solution:

For the Balmer series of the hydrogen atom, we use the formula:

$\frac{1}{\lambda} = R_{\mathrm{H}}\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$

For the second line of the Balmer series, $n = 4$. Therefore, the equation simplifies to:

$$\begin{aligned}\frac{1}{\lambda} &= R_{\mathrm{H}}\left[\frac{1}{4} - \frac{1}{16}\right] \\ &= \frac{3R_{\mathrm{H}}}{16} \\ \lambda &= \frac{16}{3R_{\mathrm{H}}}\end{aligned}$$

Next, for the Lyman series of the He^+ ion, the formula is:

$\frac{1}{\lambda_{\mathrm{He}^+}} = 4R_{\mathrm{H}}\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$

For the first line of the Lyman series, $n = 2$. Substituting this value gives:

$$\begin{aligned}\frac{1}{\lambda_{\mathrm{He}^+}} &= 4R_{\mathrm{H}}\left[1 - \frac{1}{4}\right] \\ &= 4R_{\mathrm{H}} \cdot \frac{3}{4} \\ &= 3R_{\mathrm{H}}\end{aligned}$$

Thus, calculating the wavelength:

$\lambda_{\mathrm{He}^+} = \frac{1}{3R_{\mathrm{H}}}$

We now find the relationship between λ_{He^+} and λ:

$$\begin{aligned}\frac{\lambda_{\mathrm{He}^+}}{\lambda} &= \frac{1}{3R_{\mathrm{H}}} \times \frac{3R_{\mathrm{H}}}{16} \\ \lambda_{\mathrm{He}^+} &= \frac{\lambda}{16}\end{aligned}$$

Therefore, the wavelength of the first line of the Lyman series for the He^+ ion is $\frac{\lambda}{16}$.

Question15

Consider the following.

I. The electron spin quantum number describes the orientation of the spin of the nucleus with respect to the magnetic field.

II. The orbitals represented by the quantum numbers $n=3, l=2, m=+2$ and $n=3, l=2, m=-2$ have the same energy.

III. The energy of a photon is directly proportional to wavelength but inversely proportional to wave number.

IV. Lyman series of lines appear in ultra-violet region.

The correct statements are

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Options:

A. II and IV only

B. I and II only

C. II, III and IV only

D. I, III and IV only

Answer: A

Solution:

The correct statements are II and IV only. While statements I and III are incorrect.

The direction of spin is described by spin quantum number. This quantum number gives information about the direction of spinning of electron present in any orbit.

Hence, statement I is incorrect.

Energy of photon is given by $E=\frac{hc}{\lambda}$

$\therefore$ Energy is inversely proportional to wavelength (λ).

Atso, $E=hc\bar{v}$

$\therefore$ Energy is directly proportional to wave number (v). So, statement III is also incorrect.

Question16

The radius of third orbit of hydrogen atom is Rpm. The radius of second orbit of He^{+}ion (in pm is)

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Options:

A. $\frac{4}{3} R$

B. $\frac{3}{4} R$

C. $\frac{9}{2} R$

D. $\frac{2}{9} A$

Answer: D

Solution:

Let's work through the problem step by step.

For hydrogen-like systems, the radius of the nth orbit is given by:

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

where:

n is the principal quantum number,

Z is the atomic number (nuclear charge), and

a_0 is the Bohr radius.

For the hydrogen atom (with $Z = 1$) in the third orbit:

$r_3 = 3^2 \cdot a_0 = 9a_0$

We are given that:

$9a_0 = R$

Hence, the Bohr radius in this context is:

$a_0 = \frac{R}{9}$

For the He^+ ion, the nucleus has $Z = 2$. For the second orbit ($n = 2$), the radius is:

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

Substitute the value of a_0 into the expression for r_2:

$r_2 = 2\left(\frac{R}{9}\right) = \frac{2}{9} R$

Thus, the radius of the second orbit of the He^+ ion is $\frac{2}{9} R$.

The correct answer is Option D.

Question17

The threshold frequency of a metal is $10^{15}\ s^{-1}$. The ratio of maximum kinetic energies of the photoelectrons, when the metal is made to strike with radiations of frequencies $1.5 \times 10^{15}\ s^{-1}$ and $2.0 \times 10^{15}\ s^{-1}$ respectively is

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Options:

A. $2:1$

B. $1:2$

C. $4:3$

D. $3:4$

Answer: B

Solution:

Given:

Threshold frequency of the metal, $v_0 = 10^{15}\ s^{-1}$

First frequency, $v_1 = 1.5 \times 10^{15}\ s^{-1}$

Second frequency, $v_2 = 2.0 \times 10^{15}\ s^{-1}$

We need to find the ratio of the maximum kinetic energies of the photoelectrons, $\frac{(KE_{\ max})_1}{(KE_{\ max})_2}$.

Using the photoelectric effect equation:

$hv = hv_0 + \text{KE}$

Therefore, the kinetic energy (KE) is given by:

$\text{KE} = h(v - v_0)$

The ratio of the maximum kinetic energies is calculated as follows:

$\frac{(\text{KE}_{\text{max}})_1}{(\text{KE}_{\text{max}})_2} = \frac{h(v_1 - v_0)}{h(v_2 - v_0)}$

Substitute the given values:

$\frac{(\text{KE}_{\text{max}})_1}{(\text{KE}_{\text{max}})_2} = \frac{h(1.5 \times 10^{15} - 1 \times 10^{15})}{h(2 \times 10^{15} - 1 \times 10^{15})}$

Simplifying the expression:

$\frac{\text{KE}_1}{\text{KE}_2} = \frac{0.5 \times 10^{15}}{1 \times 10^{15}}$

Thus:

$\frac{\text{KE}_1}{\text{KE}_2} = \frac{1}{2} \quad \text{or} \quad \text{KE}_1 : \text{KE}_2 = 1 : 2$
