SHORT QUESTIONS

20.1 Bohr's theory of hydrogen atom is based upon several assumptions. Do any of these assumptions contradict classical physics?

Ans. Yes, Bohr's first postulate contradict with classical physics. According to classical physics every moving particle radiate energy continuously therefore, accelerated electron must radiate energy but according to Bohr's theory an electron does not radiate energy when moving around the nucleus.

20.2 What is meant by a line spectrum? Explain, how line spectrum can be used for the identification of elements?

Ans. When atoms of an element are excited by absorbing the energy from the incident photon, the excited atoms returns to the ground state by the emission of energy forms a spectrum of definite spectral lines, such a spectrum is called a line spectrum. A spectrum consists of discrete lines. Thus we can identify different elements because each element has characteristic lines of definite wavelength.

20.3 Can the electron in the ground state of hydrogen atom absorb a photon of energy 13.6 eV and greater than 13.6 eV?

Ans. Yes, photon of energy 13.6 eV will be absorbed by the electron in the ground state of hydrogen atom for ionization because ionization energy of hydrogen atom is 13.6 eV. But if energy of photon is greater than 13.6 eV then surplus energy is changed into kinetic energy of electron.

20.4 How can the spectrum of hydrogen contain so many lines when hydrogen contains one electron?

Ans. Because in an excited hydrogen atom, electron falls back to ground state in different steps, emitting lines of different wavelength. (For each orbit, photon of different wavelength emits).

20.5 Is energy conserved when an atom emits a photon of light?

Ans. Yes, during excitation atom receives energy from some external source and during de-excitation same energy is emitted in the form of photon. This means that energy absorbed by atom, during excitation is equal to the energy emitted during de-excitation.

20.6 Explain why a glowing gas gives only certain wavelength of light and why that gas is capable of absorbing the same wavelengths? Give a reason why it is transparent to other wavelengths?

Ans. A glowing gas gives only certain wavelengths because in an atom there are only certain energy states and transition between these states gives light of certain wavelengths. Similarly an atom can absorb only those photons which have energy equal to energy difference between these two states and gas atoms are transparent to other wavelengths.

20.7 What do we mean when say that the atom is excited?

Ans. When electron jumps from lower energy level to high energy level by providing some energy, the atom is said to be in excited state.

20.8 Can X-rays be reflected, refracted, diffracted and polarized just like any other waves? Explain.

Ans. Yes, X-rays are electromagnetic waves and they can be diffracted, reflected, refracted and polarized but their conditions may be different from that of ordinary light e.g. light can be diffracted by diffraction grating but X-rays cannot be diffracted by grating.

20.9 What are the advantages of lasers over ordinary light?

Ans. Laser light has following advantages over ordinary light:

(i) It is mono-chromatic i.e., single wavelength while ordinary light has many wavelength.

(ii) It is phase-coherent while ordinary light has no phase coherent.

(iii) It is uni-directional while ordinary light spreads in all direction.

(iv) It is much more intense than ordinary light.

20.10 Explain why laser action could not occur without population inversion between atomic levels?

Ans. Population inversion means number of atoms in the metastable state are greater than number of atoms in ground state. Laser light is produced due to stimulated emission. For this most of electrons should be in the excited state. So population inversion is necessary for laser action.

PROBLEMS WITH SOLUTIONS

PROBLEM 20.1

A hydrogen atoms is in its ground state (n = 1). Using Bohr's theory, to calculate (a) the radius of the orbit, (b) the linear momentum of the electron, (c) the angular momentum of the electron, (d) the kinetic energy, (e) the potential energy, and (f) the total energy.

Data

Ground state of hydrogen atom $= n = 1$

To Find

(a) Radius of the orbit $= r_1 = ?$

(b) Linear momentum of the electron $= P = ?$

(c) Angular momentum of the electron $= L = ?$

(d) Kinetic energy $= K.E = ?$

(e) Potential energy $= P.E = ?$

(f) Total energy $= T.E = ?$

SOLUTION

(a) According to Bohr theory of H. atom

$$\boxed{r_n = \frac{n^2h^2}{4\pi^2Ke^2m}}$$

For ground state

$$n = 1$$

$$h = 6.63 \times 10^{-34}\ \text{J.s}$$

$$K = 9 \times 10^{9}\ \text{Nm}^2/\text{c}^2$$

$$e = 1.6 \times 10^{-19}\ \text{c}$$

$$m = 9.1 \times 10^{-31}\ \text{kg}$$

Putting the values

$$r_1 = \frac{(1)^2\,(6.63 \times 10^{-34})^2}{4(3.14)^2 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2 \times 9.1 \times 10^{-31}}$$

$$= \frac{43.95 \times 10^{-68}}{8268.81 \times 10^{9-38-31}}$$

$$= 5.3 \times 10^{-3} \times 10^{-68} \times 10^{+60}$$

$$= 5.3 \times 10^{-11}\ \text{m}$$

$$r_1 = 0.53 \times 10^{-10}\ \text{m}$$

(b) For linear momentum of the electron

As we know that

$$V_n = \frac{2\pi Ke^2}{nh}$$

Multiply on both sides by m

$$mV_n = \frac{2\pi Kme^2}{nh}$$

But $mV_n = P$

$$\boxed{P = \frac{2\pi Kme^2}{nh}}$$

Putting the values

$$P_1 = \frac{2(3.14)(9\times10^{9})\times9.1\times10^{-31}\times(1.6\times10^{-19})^2}{1\times6.63\times10^{-34}}$$

$$= \frac{1316.68}{6.63}\times 10^{9-31-38+34}$$

$$= 198.4\times 10^{-26}$$

$$P_1 = 1.98\times 10^{-24}\text{ kg m/s}$$

(c) For angular momentum of the electron

As we know that

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

As $mV_nr_n = L$

$$\boxed{L = \frac{nh}{2\pi}}$$

Putting the values

$$L_1 = \frac{1\times 6.63\times 10^{-34}}{2(3.14)}$$

$$L_1 = 1.05\times 10^{-34}\text{ kg m}^2/\text{s}$$

(d) For kinetic energy

$$K.E = \frac{1}{2}mV_n^2$$

As $mV_n = \frac{Ke^2}{r_n}$

So $\boxed{K.E = \frac{1}{2}\frac{Ke^2}{r_n}}$

$$= \frac{1}{2}\times\frac{9\times 10^{9}\times(1.6\times 10^{-19})^2}{0.53\times 10^{-10}}$$

$$= \frac{23.04 \times 10^{9-38+10}}{1.06}$$

$$= 21.73 \times 10^{-19}\ \text{J}$$

In electron volt

$$\text{K.E} = \frac{21.73 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= 13.58$$

$$\text{K.E} = 13.6\ \text{eV}$$

(e) For potential energy of the electron

$$\boxed{\text{P.E} = -\frac{\text{Ke}^2}{r_n}}$$

$$= -\frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{0.53 \times 10^{-10}}$$

$$= -\frac{23.04}{0.53} \times 10^{-38+10+9}$$

$$= -43.47 \times 10^{-19}\ \text{J}$$

$$= -\frac{43.47 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV}$$

$$= -27.16\ \text{eV}$$

$$\text{P.E} = -27.2\ \text{eV}$$

(f) For total energy of the electron

$$\text{T.E} = \text{Sum of K.E} + \text{P.E}$$

$$= 13.6 + (-27.2)$$

$$\text{T.E} = -13.6\ \text{eV}$$

Result

(a) Radius of the orbit $= r_1 = 0.53 \times 10^{-10}$ m

(b) Linear momentum $= P = 1.98 \times 10^{-24}$ kg m/s

(c) Angular momentum $= L = 1.05 \times 10^{-34}$ kg m^2/s

(d) Kinetic energy of electron = K.E = 13.6 eV

(e) Potential energy of electron = P.E = –27.2 eV

(f) Total energy of the electron = T.E = –13.6 eV

PROBLEM 20.2

What are the energies in eV of quanta of wavelength? λ = 400, 500 and 700 nm.

Data

Wavelength $= \lambda_1 = 400\ \text{nm} = 400 \times 10^{-9}$ m

Wavelength $= \lambda_2 = 500\ \text{nm} = 500 \times 10^{-9}$ m

Wavelength $= \lambda_3 = 700\ \text{nm} = 700 \times 10^{-9}$ m

To Find

Energy in eV of quanta = E_1 = ?

Energy in eV of quanta = E_2 = ?

Energy in eV of quanta = E_3 = ?

SOLUTION

By formula

$$\boxed{E = \frac{hc}{\lambda}}$$

For 1st wavelength λ_1

$$E_1 = \frac{hc}{\lambda_1}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{400 \times 10^{-9}}$$
$$= 0.049 \times 10^{-34+8+9}$$
$$= 0.049 \times 10^{-17}$$
$$= 4.9 \times 10^{-19}\ \text{J}$$
$$= \frac{4.9 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV}$$
$$E_1 = 3.06\ \text{eV}$$

For 2nd wavelength λ_2

$$\boxed{E_2 = \frac{hc}{\lambda_2}}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{500 \times 10^{-9}}$$
$$= 0.0397 \times 10^{-17}\ \text{J}$$
$$= \frac{0.0397 \times 10^{-17}}{1.6 \times 10^{-19}}\ \text{eV}$$
$$E_2 = 0.0248 \times 10^{2}$$
$$= 2.48\ \text{eV}$$

For third wavelength λ_3

$$E_2 = \frac{hc}{\lambda_3} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{700 \times 10^{-9}}$$
$$= 0.0284 \times 10^{-17}$$
$$= 2.84 \times 10^{-19}\ \text{J}$$
$$= \frac{2.84 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV}$$
$$E_3 = 1.75\ \text{eV}$$

Result

Energy in eV of quanta $= E_1 = 3.06$ eV

Energy in eV of quanta $= E_2 = 2.48$ eV

Energy in eV of quanta $= E_3 = 1.75$ eV

PROBLEM 20.3

An electron jumps from a level $E_f = -3.5 \times 10^{-19}$ J to $E_i = -1.20 \times 10^{-18}$ J. What is the wavelength of the emitted light?

Data

Energy of electron in ground state $= E_f = -3.5 \times 10^{-19}$ J

Energy of electron in excited state $= E_i = -1.20 \times 10^{-18}$ J

To Find

Wavelength $= \lambda = ?$

SOLUTION

By formula

$$hf = E_f - E_i$$

But

$$f = \frac{c}{\lambda}$$

$$\frac{hc}{\lambda} = E_f - E_i$$

$$\boxed{\lambda = \frac{hc}{E_f - E_i}}$$

Putting the values

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{-3.5 \times 10^{-19} - (-1.20 \times 10^{-18})}$$

$$= \frac{19.89 \times 10^{-26}}{-3.5 \times 10^{-19} + 1.20 \times 10^{-18}}$$

$$= \frac{19.89 \times 10^{-26}}{-3.5 \times 10^{-19} + 12 \times 10^{-19}}$$

$$= \frac{19.89 \times 10^{-26}}{10^{-19}(-3.5 + 12)}$$

$$= \frac{19.89 \times 10^{-26+19}}{8.5}$$

$$= 2.34 \times 10^{-7} \text{ m}$$

$$= 234 \times 10^{-9} \text{ m}$$

$$= 234 \text{ nm}$$

Result

Wavelength $= \lambda = 234$ nm

PROBLEM 20.4

Find the wavelength of the spectral line corresponding to the transition in hydrogen from n = 6 state to n = 3 state?

Data

State $= p = 3$

State $= n = 6$

To Find

Wavelength of spectral line $= \lambda = ?$

SOLUTION

By formula

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

As R_h = Rydberg constant

$$= 1.0974 \times 10^7 \text{ m}^{-1}$$

Therefore,

$$\frac{1}{\lambda} = 1.0974 \times 10^7\left(\frac{1}{3^2} - \frac{1}{6^2}\right)$$

$$= 1.0974 \times 10^7\left(\frac{1}{9} - \frac{1}{36}\right)$$

$$= 1.0974 \times 10^7\left(\frac{4-1}{36}\right)$$

$$\frac{1}{\lambda} = 1.0974 \times 10^7 \times \frac{3}{36}$$

$$\lambda = \frac{36}{3 \times 1.0974 \times 10^7}$$

$$= 10.94 \times 10^{-7} \text{ m}$$

$$= 1094 \times 10^{-9} \text{ m}$$

$$\lambda = 1094 \text{ nm}$$

Result

Wavelength of spectral lines $= \lambda = 1094$ nm

PROBLEM 20.5

Compute the shortest wavelength radiation in the Balmer series? What value of n must be used?

Data

The formula for Balmer Series is

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

To Find

Shortest wavelength $= \lambda_s = ?$

SOLUTION

Now $$\boxed{\frac{1}{\lambda_s} = R_h\left(\frac{1}{2^2}-\frac{1}{n^2}\right)}$$

For shortest wavelength put $n = \infty$

$$\frac{1}{\lambda_s} = R_H\left(\frac{1}{2^2}-\frac{1}{\alpha}\right)$$

$$\frac{1}{\lambda_s} = \frac{R_H}{4}$$

$$\lambda_s = \frac{4}{R_H}$$

$$\lambda_s = \frac{4}{1.0974 \times 10^7}$$

$$= 3.644 \times 10^{-7}\ \text{m}$$

$$= 364.4 \times 10^{-9}\ \text{m}$$

$$\lambda_s = 364.4\ \text{nm}$$

Result

Shortest wavelength = λ = 364.4 nm

Value of n = ∞

PROBLEM 20.6

Calculate the longest wavelength of radiation for the Paschen series.

Data

The formula for Paschen series is

$$\frac{1}{\lambda} = R_h\left(\frac{1}{3^2}-\frac{1}{n^2}\right)$$

To Find

Longest wavelength = λ_L = ?

SOLUTION

Since $$\frac{1}{\lambda} = R_H\left(\frac{1}{3^2}-\frac{1}{n^2}\right)$$

For longest wavelength = n = 4

$$\frac{1}{\lambda_L} = R_h\left(\frac{1}{9}-\frac{1}{4^2}\right)$$

$$= 1.0974 \times 10^7\left(\frac{1}{9}-\frac{1}{16}\right)$$

$$= 1.0974 \times 10^7 \left(\frac{16-9}{144}\right)$$

$$= 1.0974 \times 10^7 \times \frac{7}{144}$$

$$\frac{1}{\lambda_L} = 0.0533 \times 10^7$$

$$\lambda_L = \frac{1}{0.0533 \times 10^7} = 18.74 \times 10^{-7}$$

$$\lambda_L = 1875 \times 10^{-9} \text{ m}$$

$$= 1875 \text{ nm}$$

Result

Longest wavelength $= \lambda_L = 1875$ nm

PROBLEM 20.7

Electrons in an X-ray tube are accelerated through a potential difference 3000 V. If these electrons were slowed down in a target, what will be the minimum wavelength of X-rays produced?

Data

Potential difference $= V = 3000$ volts

To Find

Minimum wavelength of X-rays $= \lambda_{min} = ?$

SOLUTION

By formula

$$Ve = hf$$

But $$f = \frac{c}{\lambda_{min}}$$

$$Ve = \frac{hc}{\lambda_{min}}$$

$$\boxed{\lambda_{min} = \frac{hc}{Ve}}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{3000 \times 1.6 \times 10^{-19}}$$

$$= \frac{19.89 \times 10^{-34+8+19}}{4800}$$

$$= 4.14 \times 10^{-3} \times 10^{-7}$$

$$\lambda_{min} = 4.14 \times 10^{-10} \text{ m}$$

Result

Minimum wavelength of X-rays $= \lambda_{min} = 4.14 \times 10^{-10}$ m

PROBLEM 20.8

The wavelength of K X-ray from copper is 1.377×10^{-10} m. What is the energy difference between the two levels from which this transition results?

Data

Wavelength of K X-ray $= \lambda = 1.377 \times 10^{-10}$ m

To Find

Energy difference $= \Delta E = ?$

SOLUTION

As we know that

$$\Delta E = hf$$

But $$f = \frac{c}{\lambda}$$

$$\Delta E = \frac{hc}{\lambda}$$

Putting the values

$$\Delta E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.377 \times 10^{-10}}$$

$$= \frac{19.89 \times 10^{-34+8+10}}{1.377}$$

$$= 14.4 \times 10^{-16} \text{ J}$$

$$= 1.44 \times 10^{-15} \text{ J}$$

In electron volt

$$\Delta E = \frac{1.44 \times 10^{-15}}{1.6 \times 10^{-19}} \text{ eV}$$

$$= 0.903 \times 10^{-15+19}$$

$$= 0.903 \times 10^{4} \text{ eV}$$

$$= 9.03 \times 10^{3} \text{ eV}$$

$$\Delta E = 9.03 \text{ KeV}$$

Result

Energy difference $= \Delta E = 9.03$ KeV

PROBLEM 20.9

A tungsten target is struck by electrons that have been accelerated from rest through 40 kV potential difference. Find the shortest wavelength of the bremsstrahlung radiation emitted.

Data

Potential difference $= V = 40$ K volt

$= 40 \times 10^{3}$ volt

To Find

Shortest wavelength $= \lambda_{min} = ?$

SOLUTION

As we know that

$$\boxed{Ve = \frac{hc}{\lambda_{min}}}$$

$$\lambda_{min} = \frac{hc}{Ve}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{40 \times 10^{3} \times 1.6 \times 10^{-19}}$$

$$= \frac{19.89 \times 10^{-34+8+19-3}}{64}$$

$$\lambda_{min} = 0.310 \times 10^{-10} \text{ m}$$

Result

Shortest wavelength $= \lambda_{min} = 0.310 \times 10^{-10}$ m

PROBLEM 20.10

The orbital electron of a hydrogen atom moves with a speed of 5.456×10^{5} ms^{-1}:

(a) Find the value of the quantum number "n" associated with this electron

(b) Calculate the radius of this orbit, and

(c) The energy of the electron in this orbit.

Data

Speed of electron $= V_n = 5.456 \times 10^{5}$ m/s

To Find

(a) Value of quantum number $= n = ?$

(b) Radius of this orbit $= r_n = ?$

(c) Energy of electron in this orbit $= E_n = ?$

SOLUTION

(a) By formula

$$\boxed{V_n = \frac{2\pi Ke^2}{nh}}$$

$$n = \frac{2\pi Ke^2}{V_n h}$$

As $K = 9 \times 10^{9}$ Nm^2/c^2

$e = 1.6 \times 10^{-19}$ c

$h = 6.63 \times 10^{-34}$ J.s

$$n = \frac{2(3.14) \times 9 \times 10^{9} \times (1.6 \times 10^{-19})^{2}}{5.456 \times 10^{5} \times 6.63 \times 10^{-34}}$$

$$= \frac{144.69 \times 10^{9-38}}{36.17 \times 10^{5-34}}$$

$$= \frac{144.69 \times 10^{-29}}{36.17 \times 10^{-29}}$$

$$n = 4.00$$

So the value of quantum number $= n = 4$

(b) For radius of 4^{th} orbit

$$\boxed{r_n = 0.053\, n^2\ \text{nm}}$$

$$r_4 = 0.053 \times (4)^2\ \text{nm}$$

$$r_4 = 0.848\ \text{nm}$$

$$= 0.85\ \text{nm}$$

Radius of this orbit $= r_4 = 0.85$ nm

(c) For the energy of electron in 4^{th} orbit

$$\boxed{E_n = -\frac{E_o}{n^2}}$$

But $E_o = 13.6$ eV

and $n = 4$

$$E_4 = -\frac{13.6}{4^2}\ \text{eV}$$

$$E_4 = -0.85\ \text{eV}$$

Result

(a) Value of quantum number $= n = 4$

(b) Radius of 4^{th} orbit $= r_4 = 0.85$ nm

(c) Energy of electron in 4^{th} orbit $= E_4 = -0.85$ eV