SURE SHOT QUESTIONS 2026

Chapter – 12 (Questions)

Atoms

➢ Questions

1. A hydrogen atom initially in the ground state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon.

2. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?
   Calculate the wavelengths of the first member of Lyman and first member of Balmer series.

3. Calculate the de-Broglie wavelength associated with the electron in the 2nd excited state of hydrogen atom. The ground state energy of the hydrogen atom is 13.6 eV.

4. Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level n to level (n – 1). Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.

5. (a) Write two important limitations of Rutherford model which could not explain the observed features of atomic spectra. How were these explained in Bohr's model of hydrogen atom?
   (b) Using Bohr's postulates, obtain the expression for the radius of the nth orbit in hydrogen atom.

6. Using Bohr's postulates, derive the expression for the total energy of the electron in the secondary states of the hydrogen atom.

7. State the basic assumption of the Rutherford model of the atom. Explain, in brief, why this model cannot account for the stability of an atom.

8. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Brackett series and state to which part of the electromagnetic spectrum does it belong.

9. A hydrogen atom in the ground state is excited by an electron beam 12.5 eV energy. Find out the maximum number of lines emitted by atom from its excited state.

10. How is the stability of hydrogen atom in Bohr model explained by de-Broglie's Hypothesis?

11. (a) Draw the energy level diagram for the line spectra representing Lyman series and Balmer series in the spectrum of hydrogen atom.
    (b) Using the Rydberg formula for the spectrum of hydrogen atom, calculate the largest and shortest wavelengths of the emission lines of the Balmar series in the spectrum of hydrogen atom. (Use the value of Rydberg constant $R = 1.1 \times 10^7 m^{-1}$.

12. A proton of energy 1.6 MeV approaches a gold nucleus (Z = 79). Find the distance of its closest approach.

13. Using Bohr's postulates, derive the expression for the radius of the n^{th} orbit of an electron in a hydrogen atom. Also, find the numerical value of Bohr's radius a_0

14. What result do you expect if α -particle scattering experiment is repeated using a thin sheet hydrogen in place of a gold foil? Explain. (Hydrogen is a solid at temperature below 14K)

15. Define the distance of closest approach. An α -particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is 'r'. What will be the distance of closest approach for an α -particle of double the kinetic energy?

16. Write two important limitations of Rutherford nuclear model of the atom.

17. Using Bohr's atomic model, derive the expression for the radius of nth orbit of the revolving electron in a hydrogen atom.
    OR

Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.

OR

Using Bohr's postulates of the atomic model, derive the expression for the radius of nth electron orbit. Hence obtain the expression for Bohr's radius.

18. Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.

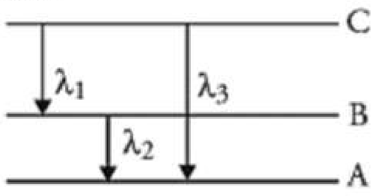
19. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Brackett series and state to which part of the electromagnetic spectrum does it belong.

20. The ground state energy of hydrogen atom is -13.6 eV. If an electron makes a transition from an energy level -1.51 eV to -3.4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.

21. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 $\overset{0}{A}$. Calculate the short wavelength limit for the Balmer series of the hydrogen spectrum.

22. (a) In Geiger – Marsden experiment, calculate the distance of closest approach for an alpha particle with energy 2.56 x 10^{-12} J. Consider that the particle approaches gold nucleus (Z = 79) in head – on position. (b) If the above experiment is repeated with a proton of the same energy, then what will be the value of the distance of closest approach?

23. (a) state Bohr's quantization condition for defining stationary orbits. How does de-Broglie hypothesis explain the stationary orbits?
(b)Find the relation between the three wavelengths λ_1, λ_2 *and* λ_3 from the energy level diagram shown below.



24. Using Bohr's postulates, obtain the expression for the total energy of the electron in the stationary states of the hydrogen atom. Hence draw the energy level diagram showing how the line spectra corresponding to Balmer series occur due to transition between energy levels.

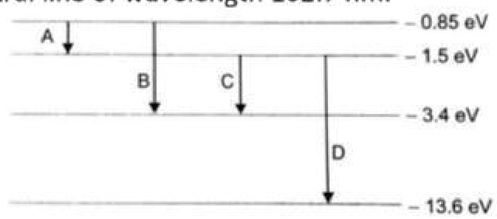
25. The ground state energy of hydrogen atom is $-13.6\ eV$. If an electron makes a transition from an energy level $-1.51\ eV$ to $-3.4\ eV$, calculate the wavelength of the spectral line emitted and the series of hydrogen spectrum to which it belongs.

26. Write two important limitations of Rutherford nuclear model of the atom.

27. Define the distance of closest approach. An α-particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is 'r'. What will be the distance of closest approach for anα-particle of double the kinetic energy?

28. The electron, in a hydrogen atom, is in its second excited state.
Calculate the wavelength of the lines in the Lyman series that can be emitted through the permissible transitions of this electron. [Given the value of Rydberg constant, R = 1.1 x 10^7 m^{-1}]

29. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.



30. (i) The radius of the innermost electron orbit of a hydrogen atom is 5.3 x 10^{-11} m. Calculate its radius in n = 3 orbit.
(ii) The total energy of an electron in the first excited state of the hydrogen atom is $-3.4\ eV$. Find out its (a) kinetic energy and (b) Potential energy in this state.

31. Using Bohr's second postulate of quantization of orbital angular momentum show that the circumference of the electron in the orbital state in hydrogen atom is n times the de-Broglie wavelength associated with it.

SURE SHOT QUESTIONS 2026

New

Chapter – 12 (Solutions)

Atoms

➢ Questions

1. A hydrogen atom initially in the ground state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon.

Ans. Energy of hydrogen atom in nth state

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

According to question, $h\nu = E_4 - E_1$

$$h\nu = -13.6\left(\frac{1}{16}-1\right)eV = 13.6\times\frac{15}{16}eV$$

$$\nu = 13.6\times\frac{15}{16}\times\frac{1.6\times10^{-19}}{6.63\times10^{-34}} = 3\times10^{15}\,Hz$$

2. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?

Calculate the wavelengths of the first member of Lyman and first member of Balmer series.

Ans. Here, $\Delta E = 12.5eV$

Energy of an electron in n^{th} orbit of hydrogen atom is,

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

In ground state, n = 1

E_1 = -13.6 eV

Energy of an electron in the excited state after absorbing a photon of 12.5 eV energy will be

$$E_n = -13.6 + 12.5 = -1.1eV$$

$$\therefore\ n^2 = \frac{-13.6}{E_n} = \frac{-13.6}{-1.1} = 12.36 \Rightarrow n = 3.5$$

Here, state of electron cannot be fraction.

So, n = 3 (2^{nd} excited state).

The wavelength λ of the first member of Lyman series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2}-\frac{1}{2^2}\right] = \frac{3}{4}R$$

$$\Rightarrow \lambda = \frac{4}{3R} = \frac{4}{3\times1.097\times10^7}$$

$$\Rightarrow \lambda = 1.215\times10^{-7}m$$

$$\Rightarrow \lambda = 121\times10^{-9}m \Rightarrow \lambda = 121nm$$

The wavelength λ' of the first member of the Balmer series is given by

$$\frac{1}{\lambda'} = R\left[\frac{1}{2^2}-\frac{1}{3^2}\right] = \frac{5}{36}R$$

$$\Rightarrow \lambda' = \frac{36}{5R} = \frac{36}{5\times(1.097\times10^7)}$$

$$= 6.56\times10^{-7}m = 656\times10^{-9}m = 656\,nm$$

3. Calculate the de-Broglie wavelength associated with the electron in the 2^{nd} excited state of hydrogen atom. The ground state energy of the hydrogen atom is 13.6 eV.

Ans. de-Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$, where K is the kinetic energy.

Now, energy of electron,

$$K = \frac{13.6z^2}{n^2} = \frac{13.6}{3^2} = 1.51eV = 2.41\times10^{-19}J$$

$$\therefore\ \lambda = \frac{h}{\sqrt{2mK}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9\times10^{-31}\times2.41\times10^{-19}}}$$

$$= 1\times10^{-9}m = 1\,nm$$

4. Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level n to level (n – 1). Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.

Ans. From Bohr's theory, the frequency ν of the radiation emitted when an electron de-excites from level n_2 to level n_1 is given as

$$v = \frac{E_2 - E_1}{h}$$

$$v = \frac{me^4}{8\varepsilon_0^2 h^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Given $n_1 = n-1, n_2 = n$,

$$v = \frac{me^4}{8\varepsilon_0^2 h^3}\frac{2n-1}{(n-1)^2 n^2}$$

For large n, 2n – 1 = 2n, n – 1 = n

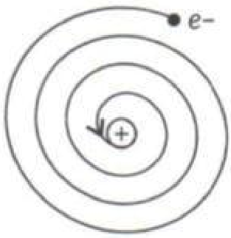
Thus, $v = \frac{me^4}{4\varepsilon_0^2 h^3 n^3}$

$$v = \frac{v}{2\pi r} = \frac{me^4}{4\varepsilon_0^2 h^3 h^3}$$

Which is same as orbital frequency of electron in nth orbit.

5. (a) Write two important limitations of Rutherford model which could not explain the observed features of atomic spectra. How were these explained in Bohr's model of hydrogen atom?
(b) Using Bohr's postulates, obtain the expression for the radius of the nth orbit in hydrogen atom.

Ans. (a) Limitation of Rutherford's model; Rutherford's atomic model is inconsistent with classical physics. According to electromagnetic theory, an electron is a charged particle moving in the circular orbit around the nucleus and is accelerated, so it should emit radiation continuously and thereby loose energy. Due to this, radius of the electron would decrease continuously and also the atom should then produce continuous spectrum, and ultimately electron will fall into the nucleus and atom will collapse in 10^{-8} s. But the atom is fairly stable and it emits line spectrum.



(ii) Rutherford's model is not able to explain the spectrum of even most simplest H – spectrum.
Bohr's postulates to resolve observed features of atomic spectrum:

(i) Quantum condition: Of all the possible circular orbits allowed by the classical theory, the electrons are permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$.

h being Planck's constant. Therefore, for any permitted orbit,

$$L = mvr = \frac{nh}{2\pi},\ n = 1, 2, 3, \ldots,$$

Where n is called the principal quantum number, and this equation is called Bohr's quantisation condition.

(ii) Stationary orbits: While resolving in the permissible orbits, an electron does not radiate energy. These non-radiating orbits are called stationary orbits.

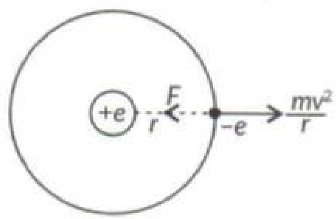
(iii) Frequency condition: An atom can emit or absorb radiation in the form of discrete energy photons only when an electron jumps from a higher to a lower orbit or from a lower to a higher orbit, respectively.

$$hv = E_i - E_f$$

Where v is frequency of radiation emitted, E_i and E_f are the energies associated with stationary orbits of principal quantum number n_i and n_f respectively (whre $n_i > n_f$).

(b) Radius of nth orbit of hydrogen atom: In H-atom, an electron having charge -e revolves around the nucleus of charge +e in a circular orbit of radius r, such that necessary centripetal force is provided by the electrostatic force of attraction between the electron and nucleus.

i.e., $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e.e}{r^2}$ or $mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$ ....(i)



from Bohr's quantization condition

$mvr = \frac{nh}{2\pi}$ or $v = \frac{nh}{2\pi mr}$ ....(ii)

Using equation (ii) in (i), we get

$$m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \text{ or } \frac{mn^2h^2}{4\pi^2 m^2 r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

Or $r = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2}$ ....(iii)

Where n = 1, 2, 3, ... is principal quantum number.
Equation (iii), gives the radius of nth orbit of H – atom.
So the radii of the orbits increase proportionally with

n^2 i.e., $[r \propto n^2]$. Radius of first orbit of H – atom is called Bohr radius a_0 and is given by

$$a_0 = \frac{h^2\varepsilon_0}{\pi m e^2} \text{ for } n=1 \text{ or } a_0 = 0.529\overset{0}{A}$$

So, radius of n^{th} orbit of H – atom then becomes

$$r = n^2 \times 0.529\overset{0}{A}$$

6. Using Bohr's postulates, derive the expression for the total energy of the electron in the secondary states of the hydrogen atom.

Ans. (i) According to Bohr's postulates, in a hydrogen atom, as single electron revolves around a nucleus of charge +e. For an electron moving with a uniform sped in a circular orbit of a given radius, the centripetal force is provided by coulomb force of attraction between the electron and the nucleus. The gravitational attraction may be neglected as the mass of electron and proton is very small.

So, $$\frac{mv^2}{r} = \frac{ke^2}{r^2} \quad \left(\text{Where, } k = \frac{1}{4\pi\varepsilon_0}\right)$$

Or $$mv^2 = \frac{ke^2}{r} \qquad \text{.............(i)}$$

Where, m = mass of electron

r = radius of electronic orbit

v = velocity of electron

Again, by Bohr's second postulates

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

Where, n = 1, 2, 3........ or $v = \frac{nh}{2\pi mr}$

Putting the value of v in eq.(i)

$$m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{ke^2}{r} \Rightarrow r = \frac{n^2h^2}{4\pi^2kme^2} \qquad \text{.....(ii)}$$

Kinetic energy of electron,

$$E_k = \frac{ke^2}{2}\frac{4\pi^2kme^2}{n^2h^2} = \frac{2\pi^2k^2me^4}{n^2h^2}$$

Potential energy of electron,

$$E_p = -\frac{k(e)\times(e)}{r} = -\frac{ke^2}{r}$$

Using eq. (ii), we get

$$E_p = -ke^2 \times \frac{4\pi^2kme^2}{n^2h^2} = -\frac{4\pi^2kme^4}{n^2h^2}$$

Hence, total energy of the electron in the n^{th} orbit

$$E = E_p + E_k$$

$$= -\frac{4\pi^2k^2me^4}{n^2h^2} + \frac{2\pi^2k^2me^4}{n^2h^2} = -\frac{2\pi^2k^2me^4}{n^2h^2}$$

$$-\frac{13.6}{n^2} eV$$

When the electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference of energies of the two energy levels is emitted as a radiation of particular wavelength. It is called a spectral line.

7. State the basic assumption of the Rutherford model of the atom. Explain, in brief, why this model cannot account for the stability of an atom.

Soln. Assumptions of Rutherford's atomic model:

(i) Every atom consists of a tiny central core called the atomic nucleus, in which the entire positive charge and atmost entire mass of the atom are concentrated.

(ii) The size of nucleus is of the order of 10^{-15} m, which is very small as compared to the size of the atom which is of the order of 10^{-10} m.

(iii) The atomic nucleus is surrounded by certain number of electrons. As atom on the whole is electrically neutral, the total negative charge of electrons surrounding the nucleus is equal to total positive charge on the nucleus.

(iv) The electrons revolve around the nucleus in various circular orbits.

According to electromagnetic theory, electron revolving around the nucleus are continuously accelerated. Since an accelerated charge emits energy, the radius of the circular path of a revolving electron should go on decreasing and ultimately it should fall into the nucleus. So, it could not explain the structure of the atom. As matter is stable, we cannot expect the atoms to collapse.

8. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Brackett series and state to which part of the electromagnetic spectrum does it belong.

Soln. Bohr's quantization condition: The electron can revolve round the nucleus only in those circular orbits in which angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$ i.e.,

$$mvr = \frac{nh}{2\pi}, n = 1, 2, 3, ...$$

The shortest wavelength of Brackett series is given as

$$\frac{1}{\lambda} = 1.097\times10^7\left[\frac{1}{4^2} - \frac{1}{\infty^2}\right] = \frac{1.097\times10^7}{16}$$

$\Rightarrow \quad \lambda = 1.4585 \times 10^{-6} m$

This wavelength lies in the infrared region of electromagnetic spectrum.

9. A hydrogen atom in the ground state is excited by an electron beam 12.5 eV energy. Find out the maximum number of lines emitted by atom from its excited state.

Soln. Given: $\Delta E = 12.5\ eV$

Let the electron jump from n = 1 to n = n level.

$$\Delta E = E_n - E_1$$

$$\therefore \quad 12.5 = -\frac{13.6}{n^2} - \left(\frac{-13.6}{1^2}\right)$$

$$12.5 = 13.6\left(1 - \frac{1}{n^2}\right)$$

$$1 - \frac{12.5}{13.6} = \frac{1}{n^2}$$

$$\frac{1.1}{13.6} = \frac{1}{n^2}$$

$$\frac{13.6}{1.1} = n^2$$

$$12.36 = n^2$$

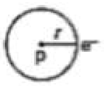
$$n = 3.5$$

$$n = 3^{rd}$$

10. How is the stability of hydrogen atom in Bohr model explained by de-Broglie's Hypothesis?

Soln. (a) From Bohr's model – An atom has a number of stable orbits in which an electron can reside without the emission of radiant energy. Each orbit corresponds to a certain energy level.

$\because$ Electron revolves is circular orbit



$$\therefore \quad \frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2}$$

The motion of an electron in circular orbits is restricted in such a manner that its angular momentum is an integral multiple of $h/2\pi$

Thus, $L = mvr = \dfrac{nh}{2\pi}$

$$E_n = \frac{-13.6}{r^2} z^2 eV$$

$$Z = 1 \text{ for } H_2 \text{ atom}$$

$$E_n = \frac{-13.6}{r^2} eV$$

From de-Broglie hypothesis

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

And from Bohr model

$$n\lambda = 2\pi r$$

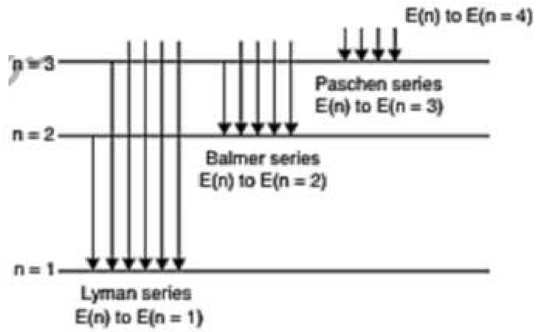
$$\lambda = \frac{2\pi r}{r}$$

$$\frac{h}{mv} = \frac{2\pi r}{n}$$

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

11. (a) Draw the energy level diagram for the line spectra representing Lyman series and Balmer series in the spectrum of hydrogen atom.
(b) Using the Rydberg formula for the spectrum of hydrogen atom, calculate the largest and shortest wavelengths of the emission lines of the Balmar series in the spectrum of hydrogen atom. (Use the value of Rydberg constant $R = 1.1 \times 10^7 m^{-1}$.

Soln. (a) Energy level diagram showing lyman and balmer series:



Spectrum wavelengths of both series for hydrogen atom

(b) Rydberg formula,

$$\frac{1}{\lambda} = 1.1 \times 10^7 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\frac{1}{\lambda_1} = 1.1 \times 10^7 \left[\frac{1}{4} - \frac{1}{9}\right]$$

$$\frac{1}{\lambda_1} = 1.1 \times 10^7 \times 0.1389$$

$$\lambda_1 = \frac{1}{1.1} \times 10^7 \times 0.1389$$

$$\lambda_1 = \frac{100 \times 10^{-9}}{0.153}$$
$$\lambda_{max}(\lambda_1) = 653.6\text{nm}$$
$$\frac{1}{\lambda_2} = \frac{1.1\times10^7}{4}$$
$$\lambda_2 = \frac{4}{1.1 \times 10^7}$$
$$= \frac{400}{1.1} \times 10^{-9}$$
$$\lambda_{min}(\lambda_2) = 363.6\text{nm}$$

12. A proton of energy 1.6 MeV approaches a gold nucleus (Z = 79). Find the distance of its closest approach.

Ans. At the distance of closet approach the whole kinetic energy get converted into potential energy.

So, $KE = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{2Ze^2}{r}$

where r is distance of closest approach.

$$r = \frac{2Ze^2}{KE \times 4\pi\varepsilon_0}$$

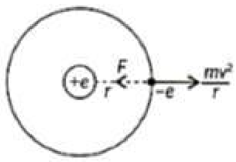
Here, $Z = 79, \frac{1}{4\pi\varepsilon_0} = 9\times10^9, e = 1.6\times10^{-19}$

$$\therefore \quad r = \frac{2\times79\times(1.6\times10^{-19})^2\times9\times10^9}{1.6\times10^6\times1.6\times10^{-19}} = 14.22\times10^{-14}\text{ m.}$$

13. Using Bohr's postulates, derive the expression for the radius of the n^{th} orbit of an electron in a hydrogen atom. Also, find the numerical value of Bohr's radius a_0

Ans. In H-atom, an electron having charge -e revolves around the nucleus of charge +e in a circular orbit of radius r, such that necessary centripetal force is provided by the electrostatic force of attraction between the electron and nucleus.

$$\text{i.e.,}\quad \frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e.e}{r^2} \quad \text{or} \quad mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \qquad ...(i)$$



From Bohr's quantization condition

$$mvr = \frac{nh}{2\pi} \quad \text{or} \quad v = \frac{nh}{2\pi mr} \qquad ...(ii)$$

Using equation (ii) in (i), we get

$$m\cdot\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \quad \text{or} \quad \frac{m\cdot n^2h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\text{or} \quad r = \frac{n^2h^2\varepsilon_0}{\pi me^2} \qquad ...(iii)$$

where n = 1, 2, 3, ... is principal quantum number.
Equation (iii), gives the radius of n^{th} orbit of H-atom. So the radii of the orbits increase proportionally with n^2 i.e., $[r \propto n^2]$. Radius of first orbit of H-atom is called Bohr radius a_0 and is given by

$$a_0 = \frac{h^2\varepsilon_0}{\pi me^2} \text{ for } n = 1 \text{ or } a_0 = 0.529\text{ Å}$$

So, radius of n^{th} orbit of H-atom then becomes

$r = n^2 \times 0.529$ Å

14. What result do you expect if α -particle scattering experiment is repeated using a thin sheet hydrogen in place of a gold foil? Explain. (Hydrogen is a solid at temperature below 14K)

Ans. In the α -particle scattering experiment, if a thin sheet of solid hydrogen is used in place of a gold foil, then the scattering angle would not be large enough because the mass of hydrogen (1.67×10^{-27}) is less than the mass of incident α -particle (6.64×10^{-27}). Thus, the mass of scattering particle is more than the target nucleus. As a result, α -particles would not bounce back if solid hydrogen is used in the α -particle scattering.

15. Define the distance of closest approach. An α -particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is 'r'. What will be the distance of closest approach for an α -particle of double the kinetic energy?

Ans. The distance from the nucleus, where all kinetic energy of α -particles is completely converted into potential energy is known as the distance of closest approach.

$$r = \frac{1}{4\pi\varepsilon_0}.\frac{2Ze^2}{K} \; or \; r \propto \frac{1}{K}$$

If kinetic energy will be doubled, then the distance of closest approach will become half.

16. Write two important limitations of Rutherford nuclear model of the atom.

Ans. The two important limitations of Rutherford nuclear model of the atom are:
(i) This model cannot explain about the stability of matter.

(ii) It cannot explain the characteristic line spectra of atoms of different elements.

17. Using Bohr's atomic model, derive the expression for the radius of nth orbit of the revolving electron in a hydrogen atom.

OR

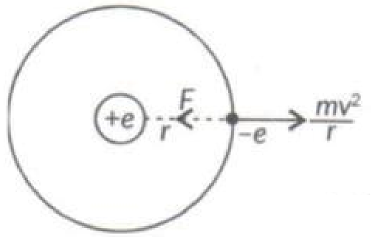
Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom.

OR

Using Bohr's postulates of the atomic model, derive the expression for the radius of nth electron orbit. Hence obtain the expression for Bohr's radius.

Ans. Radius of nth orbit of hydrogen atom: In H – atom, an electron having charge -e revolves around the nucleus of charge +e in a circular orbit of radius r, such that necessary centripetal force is provided by the electrostatic force of attraction between the electron and nucleus.

i.e., $$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e.e}{r^2} \; or \; mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$ .....(i)



From Bohr's quantization condition

$$mvr = \frac{nh}{2\pi} \; or \; v = \frac{nh}{2\pi mr}$$ ....(ii)

Using equation (ii) in (i), we get

$$m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \; or \; \frac{mn^2h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

Or $$r = \frac{n^2h^2\varepsilon_0}{\pi me^2}$$ ....(iii)

Where n = 1, 2, 3, ... is principal quantum number.

Equation (iii), gives the radius of nth orbit of H – atom. So the radii of the orbits increase proportionally with n^2 i.e., $[r \propto n^2]$. Radius of first orbit of H – atom is called Bohr radius a_0 and is given by

$$a_0 = \frac{h^2\varepsilon_0}{\pi me^2} \; for \; n = 1 \; or \; a_0 = 0.529\,\overset{0}{A}$$

So, radius of nth orbit of H – atom then becomes

$$r = n^2 \times 0.529\,\overset{0}{A}$$

18. Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.

Ans. Limitation of Rutherford's model:

Rutherford's atomic model is inconsistent with classical physics, that is why, Rutherford's model is not able to explain the spectrum of even most simplest H-spectrum. Bohr's postulates to resolve observed features of atomic spectrum:

Bohr's quantization condition: Of all the possible circular orbits allowed by the classical theory, the electrons ae permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$, $h$being Planck's constant.

Therefore, for any permitted orbit,

$$L = mvr = \frac{nh}{2\pi}, n = 1, 2, 3.....,$$

Where n is called the principal quantum number, and this equation is called Bohr's quantisation condition.

19. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Brackett series and state to which part of the electromagnetic spectrum does it belong.

Ans. Bohr's quantization condition : The electron can resolve around the nucleus only in those circular orbits in which angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$ i.e.,

$$mvr = \frac{nh}{2\pi}, n = 1, 2, 3, ...$$

The shortest wavelength of Brackett series is given as

$$\frac{1}{\lambda} = 1.097 \times 10^7\left[\frac{1}{4^2} - \frac{1}{\infty^2}\right] = \frac{1.097 \times 10^7}{16}$$

$$\Rightarrow \lambda = 1.4585 \times 10^{-6} m$$

This wavelength lies in the infrared region of electromagnetic spectrum.

20. The ground state energy of hydrogen atom is -13.6 eV. If an electron makes a transition from an energy level -1.51 eV to -3.4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.

Ans. The energy levels of H_2 atom is given as

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

$$\Rightarrow -1.51 = \frac{-13.6}{n^2}$$

$$\Rightarrow n^2 = \frac{13.6}{1.51} \approx 9 \Rightarrow n = 3$$

$$E_n = \frac{-13.6}{n^2} \Rightarrow -3.4 = \frac{-13.6}{n^2}$$

$$n^2 = \frac{13.6}{3.4} \Rightarrow n^2 = 4 \Rightarrow n = 2$$

Thus an electron makes a transition from n = 3 energy level to n = 2 energy level.

$$\therefore \frac{hc}{\lambda_{32}} = \frac{me^4}{8\varepsilon_0^2 h^2}\left(\frac{1}{n_2^2} - \frac{1}{n_3^2}\right)$$

$$\frac{hc}{\lambda_{32}} = 21.76\times10^{-19}\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\lambda_{32} = \frac{hc}{21.76\times10^{-19}\left(\frac{1}{4} - \frac{1}{9}\right)}$$

$$= \frac{6.625\times10^{-34}\times3\times10^8\times36}{21.76\times10^{-19}\times5}$$

$$= \frac{715.5\times10^{-26}}{108.85\times10^{-19}} = 6.57\times10^{-7}\,m$$

It belongs to Balmer series.

21. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 $\overset{0}{A}$. Calculate the short wavelength limit for the Balmer series of the hydrogen spectrum.

Ans. Given, short wavelength limit of Lyman series,

$$\frac{1}{\lambda_L} = R\left(\frac{1}{1^2} - \frac{1}{\infty}\right) \Rightarrow \frac{1}{913.4\overset{0}{A}} = R\left(\frac{1}{1^2} - \frac{1}{\infty}\right)$$

$$\lambda_L = \frac{1}{R} = 913.4\overset{0}{A}$$

For the short wavelength limit of Balmer series,

$$n_1 = 2,\; n_2 = \infty$$

$$\frac{1}{\lambda_B} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right) \Rightarrow \lambda_B = \frac{4}{R} =$$

$$4\times913.4\overset{0}{A} = 3653.6\overset{0}{A}$$

22. (a) In Geiger – Marsden experiment, calculate the distance of closest approach for an alpha particle with energy 2.56 x 10^{-12} J. Consider that the particle approaches gold nucleus (Z = 79) in head – on position. (b) If the above experiment is repeated with a proton of the same energy, then what will be the value of the distance of closest approach?

Ans. (a) Let the minimum distance of approach be r_0. At this distance, the whole of the kinetic energy of the alpha – particle will be converted into the electrical potential energy.
The positive charge on the gold nucleus = Ze = 79e and the positive charge on the α -particle = 2e

At $r = r_0,\; KE = PE$

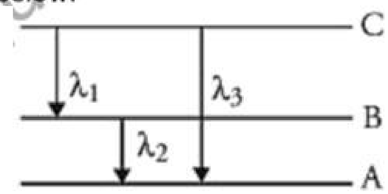
$$2.56\times10^{-12} = \frac{1}{4\pi\varepsilon_0}\frac{(79e)(2e)}{r_0}$$

$$\therefore r_0 = \frac{(9\times10^9)(79)(2)(1.6\times10^{-19})^2}{2.56\times10^{-12}} = 14.2\times10^{-15}\,m$$

(b) If proton is used instead of alpha particle, r_0 will become half.

$$\therefore r'_0 = \frac{r_0}{2} = 7.1\times10^{-15}\,m$$

23. (a) state Bohr's quantization condition for defining stationary orbits. How does de-Broglie hypothesis explain the stationary orbits?
(b)Find the relation between the three wavelengths λ_1, λ_2 and λ_3 from the energy level diagram shown below.

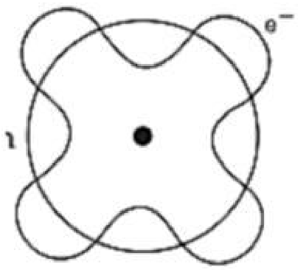


Soln. (a) Quantization condition: Of all possible circular orbits allowed by the classical theory, the electrons are permitted to circulate only in those orbits in which the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$; h being Planck's constant.

Therefore, for any permitted orbit,

$$L = mvr = \frac{nh}{2\pi};\; n = 1, 2, 3, ...$$

Where L, m and v are the angular momentum, mass and speed of the electron respectively, r is the radius of the permitted orbit and n is positive integer called principle quantum number.
The above equation is Bohr's famous quantum condition. When an electron of mass m is confined to move in a line of length l with velocity v, the de-Broglie wavelength λ associated with electron is:



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

Or p = Linear momentum

$$\Rightarrow \quad p = \frac{h}{\lambda} = \frac{h}{2l/n} = \frac{nh}{2l}$$

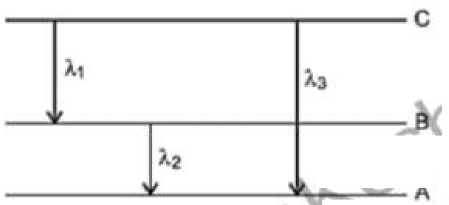
When electron revolves in a circular orbit of radius 'r' then $2l = 2\pi r$.

$$\therefore \quad p = \frac{nh}{2\pi r} \; or \; p \times r = \frac{nh}{2\neq}$$

Or angular momentum $|\vec{L}| = p \times r$ is an integral Multiple of $h/2\pi$, which is Bohr's quantisation of angular momentum.

(b) $E_{CB} = \frac{hc}{\lambda_1}$

$E_{BA} = \frac{hc}{\lambda_2}$



$$E_{CA} = \frac{hc}{\lambda_3}$$

Now, $E_{CA} = E_{CB} + E_{BA}$

Where E_{CB} = Energy gap between level B and C,

E_{BA} = Energy gap between level A and B,

E_{CA} = Energy gap between level A and C.

$$\frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$$

$$\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

$$\lambda_3 = \frac{\lambda_1 \lambda_2}{\lambda_2 + \lambda_1}$$

24. Using Bohr's postulates, obtain the expression for the total energy of the electron in the stationary states of the hydrogen atom. Hence draw the energy level diagram showing how the line spectra corresponding to Balmer series occur due to transition between energy levels.

Soln. In a hydrogen atom,
Radius of electron orbit,

$$r = \frac{n^2h^2}{4\pi^2 kme^2} \quad \text{..........(i)}$$

And angular momentum

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

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

On putting value of r we get value of v as = $\frac{2\pi ke^2}{nh}$

So, kinetic energy,

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{2\pi ke^2}{nh}\right)^2$$

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

Potential energy

$$E_p = \frac{-k(e)\times(e)}{r} = -\frac{ke^2}{r}$$

Using equation (i), we get

$$E_p = -ke^2 \times \frac{4\pi^2kme^2}{n^2h^2}$$

$$= -\frac{4\pi^2k^2me^4}{n^2h^2}$$

Hence, total energy of the electron in the n[th] orbit

$$E = E_p + E_k$$

$$= -\frac{4\pi^2k^2me^4}{n^2h^2} + \frac{2\pi^2k^2me^4}{n^2h^2}$$

$$= -\frac{2\pi^2k^2me^4}{n^2h^2}$$

We know $k = \frac{1}{4\pi\varepsilon_0} = 9\times10^9\ Nm^2C^{-2}$

h (Planck's constant) = $6.6\times10^{-34} Js$

m for H – atom = $1.67\times10^{-27} kg$

$$e = 1.6\times10^{-19}C$$

Substituting these values, we get

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

When the electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference of energies of the two energy levels is emitted as a radiation of particular wavelength. It is called a spectral line.

In H – atom, when an electron jumps from the orbit n_i to orbit n_f, the wavelength of the emitted radiation is given by,

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

Where,

$R \rightarrow$ Rydberg's constant = $1.09678 \times 10^7\ m^{-1}$

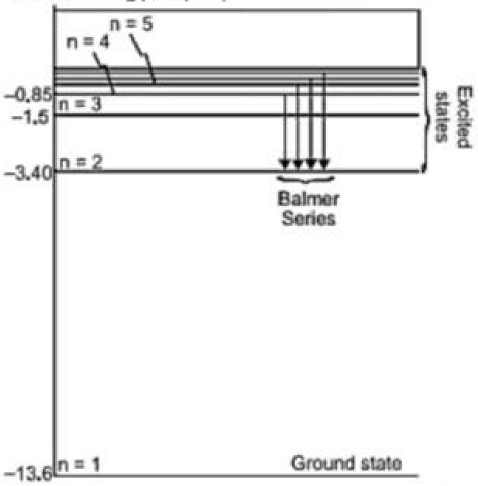
For Balmer series, $n_f = 2$ and $n_i = 3, 4, 5, ...$

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

Where, $n_i = 3, 4, 5, ...$

These spectral lines lie in the visible region.

Total energy, E(eV)



25. The ground state energy of hydrogen atom is $-13.6\ eV$. If an electron makes a transition from an energy level $-1.51\ eV$ to $-3.4\ eV$, calculate the wavelength of the spectral line emitted and the series of hydrogen spectrum to which it belongs.

Soln. Energy difference = $E_f - E_i$

$= 3.4eV - 1.51eV$

$= 1.89eV$

$= 1.89 \times 1.6 \times 10^{-19}$ J

$E = h\nu$

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

$$1.89 \times 1.6 \times 10^{-19} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.89 \times 1.6 \times 10^{-19}}$$

$$= \frac{6.6 \times 10^{-7} \times 3}{1.89 \times 1.6}$$

$$= 6.54 \times 10^{-7} m$$

$$= 654 nm$$

As this spectrum is in visible range. This radiation lies in Balmer series.

26. Write two important limitations of Rutherford nuclear model of the atom.

Soln. (i) According to Rutherford model, electron orbiting around the nucleus, continuously radiated energy due to the acceleration; hence the atom will not remain stable.

(ii) As electron spirals inwards; its angular velocity and frequency change continuously; therefore it will emit a continuous spectrum.

27. Define the distance of closest approach. An α-particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is 'r'. What will be the distance of closest approach for an α-particle of double the kinetic energy?

Soln. It is the distance of charged particle from the centreb of the nucleus, at which the whole of the initial kinetic energy of the (far off) charged particle gets converted into the electric potential energy of the system.

Distance of closest approach (r_c) is given by

$$r_c = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{K}$$

'K' is doubled, $\therefore r_c$ becomes $\frac{r}{2}$

28. The electron, in a hydrogen atom, is in its second excited state.
Calculate the wavelength of the lines in the Lyman series that can be emitted through the permissible transitions of this electron. [Given the value of Rydberg constant, R = $1.1 \times 10^7\ m^{-1}$]

Soln. For second excited state, n = 3

Hence two possible transition of the Lyman series:

$3 \rightarrow 1$ and $2 \rightarrow 1$.

Wavelength for transition $3 \rightarrow 1, n_f = 1, n_i = 3$

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

$$\frac{1}{\lambda}=1.1\times10^7\left(\frac{1}{1}-\frac{1}{9}\right)$$

$$=1.1\times10^7\left(\frac{8}{9}\right)$$

$$\Rightarrow \quad \lambda=\frac{9}{8\times1.1\times10^{7}}$$

$$=1.023\times10^{-7}$$

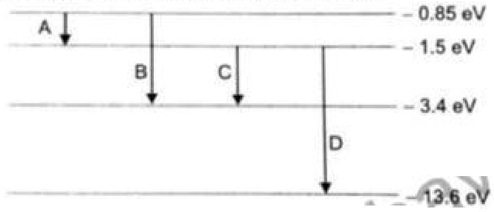
$$=102.3nm$$

For transition $2\rightarrow1,\ n_f=1,\ n_i=2$

$$\frac{1}{\lambda}=1.1\times10^7\left(1-\frac{1}{4}\right)$$

$$\Rightarrow \quad \lambda=212nm$$

29. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.



Soln. $$\Delta E=\frac{hc}{\lambda}=\frac{6.6\times10^{-34}\times3\times10^8}{102.7\times10^{-9}}J$$

$$=\frac{6.6\times10^{-34}\times3\times10^8}{102.7\times10^{-9}\times1.6\times10^{-19}}eV$$

$$=\frac{66\times3000}{1027\times16}=12.04eV$$

Now, $$\Delta E=|-13.6-(-1.50)|$$

$$=12.1eV$$

Hence, transition shown by arrow D corresponds to emission of $\lambda=102.7$ nm.

30. (i) The radius of the innermost electron orbit of a hydrogen atom is 5.3 x 10^{-11} m. Calculate its radius in n = 3 orbit.

(ii) The total energy of an electron in the first excited state of the hydrogen atom is $-3.4\ eV$. Find out its (a) kinetic energy and (b) Potential energy in this state.

Soln. (i) Radius of orbit

$$r_n=n^2r_0$$

Where, r_0 is Bohr's radius = $5.3\times10^{-11}m$radius of n = 3 orbit

$$r_3=(3)^2\times5.3\times10^{-11}m$$

$$=47.7\times10^{-11}m$$

$$=4.77\times10^{-10}m$$

(ii) Given total energy $E=-\frac{e^2}{8\pi\varepsilon_0 r}=-3.4eV$

(a) Kinetic energy, $K=\frac{e^2}{8\pi\varepsilon_0 r}=-$ Total energy

Hence Kinetic energy, $K=-(-3.4)\text{eV}=3.4\text{eV}$

(b) Potential energy, $P=-\frac{e^2}{4\pi\varepsilon_0 r}=2\times$ total energy

= -6.8 eV

31. Using Bohr's second postulate of quantization of orbital angular momentum show that the circumference of the electron in the orbital state in hydrogen atom is n times the de-Broglie wavelength associated with it.

Soln. According to Bohr's second postulate quantization of angular momentum

$$mv_nr_n=n\frac{h}{2\pi}$$

Or $$r_n=\frac{nh}{2\pi mv_n} \quad \text{..........(i)}$$

Where h is the Planck's constant

Circumference of the electron in the n^{th} orbital state in hydrogen atom.

$$2\pi r_n=2\pi\frac{nh}{2\pi mv_n}$$ (Using (i))

$$2\pi r_n=n\frac{h}{mv_n} \quad \text{.............(ii)}$$

But de Broglie wavelength of the electron

$$\lambda=\frac{h}{mv_n} \quad \text{................(iii)}$$

From (ii) and (iii), we get

$$2\pi r_n=n\lambda$$