NCERT SOLUTIONS
CLASS-XII PHYSICS
CHAPTER-12
ATOM - RUTHERFORD'S MODEL

Q1: Pick an appropriate option to justify the given statement:
(a) Size of an atom in Rutherford's model is _________ the size of an atom compared to of Thomson's model. (Less than, Greater than, no different than)

(b) Even in the case of stable equilibrium _________ electrons experience a net force, though _______ electrons do not. [Rutherford's model, Thomson's model]

(c) _____ is a showcase of a model of an atom which is bound to fail. [Rutherford's model, Thomson's model]

(d) Mass distribution is uniform in __________ but highly irregular in __________ . [Rutherford's model, Thomson's model, both the models]

(e) _____ states that a larger portion of the mass of an atom is contributed by the positively charged part.
Ans:

(a) Size of an atom in Rutherford's model is the same as the size of an atom compared to of Thomson's model.

(b) Even in the case of stable equilibrium Rutherford's model electrons experience a net force, though Thomson's model electrons do not.

(c) Rutherford's model is a showcases a model of an atom which is bound to fail.

(d) Mass distribution is uniform in Thomson's model but highly irregular in Rutherford's model.

(e) Both of the models states that a larger portion of the mass of an atom is contributed by the positively charged part.

Q2: If you were conducting the alpha particle scattering experiment again, how would you say that the results would vary replacing gold foil by sheets of solid hydrogen knowing that hydrogen solidifies at temperatures below 14k.

Ans:

We know that mass of incident alpha particle (6.64×10^{-27}kg) is more than the mass of hydrogen (1.67×10^{27}Kg). Hence, the target nucleus is lighter, from which we can infer that alpha particle would not bounce back. Implying to the fact that solid hydrogen isn't a suitable replacement to gold foil for the alpha particle scattering experiment.

Q3: In the Paschen series of spectral lines, what's the shortest wavelength present?

Ans:

By Rydberg's formula :

$$\frac{hc}{\lambda} = 21.76 \times 10^{-19}\left[\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right]$$

Planck's constant $h = 6.6 \times 10^{-34}$ Js

Speed of light $c = 3 \times 10^{8}$ m/s

n_1 and n_2 are integers.

To obtain shortest wavelength we substitute $n_1 = 3$ and $n_2 = \infty$

$$\frac{hc}{\lambda} = 21.76 \times 10^{-19}\left[\frac{1}{(3)^2} - \frac{1}{(\infty)^2}\right]$$

i.e. $\lambda = \frac{6.6\times10^{-34}\times3\times10^{8}\times9}{21.76\times10^{-19}} = 8.189 \times 10^{-7}$ = **818.9 nm**

Q4: A difference of 4.6 eV separates two energy levels in an atom. What is the frequency of radiation emitted when the atom makes a transition from the upper level to the lower level?

Ans:

Separation of two energy levels in an atom, E = 4.6 eV = $4.6 \times 1.6 \times 10^{-19}$ **= 7.36×10^{-19} J**

Let v be the frequency of radiation emitted when the atom transitions from the upper level

to the lower level.

We have the relation for energy as:

E = hv

Where, **h = Planck's constant = 6.62×10^{-34} Js**

$v = \frac{E}{h} = \frac{7.36 \times 10^{-19}}{6.62 \times 10^{-32}}$ **= 11.1×10^{14} Hz**

Hence, the frequency of the radiation is 11.1×10^{14} Hz.

Q5: The ground state energy of hydrogen atom is −27.2 eV. In this state find the kinetic & potential energies of the electron?

Ans:

Ground state energy of hydrogen atom, **E = − 27.2 eV**

This is the total energy of a hydrogen atom. Kinetic energy is equal to the negative of the total energy.

Kinetic energy = − E = − (− 27.2) **= 27.2 eV**

Potential energy = negative of two times of kinetic energy.

Potential energy = − 2 × (27.2) **= − 54.4 eV**

Q6: An atom of hydrogen in the ground level initially absorbs a photon, which excites it to the n = 3 level. FInd the wavelength and frequency of the photon.

Ans:

For ground level, **n_1= 1**

Let, **E_1** be the energy of this level. It is known that **E_2** is related with **n_1** as:

$E_1 = \frac{-13.6}{(n_1)^2}$ eV $= \frac{-13.6}{1^2}$ = 13.6 eV

The atom is excited to a higher level, **n_2= 3**

Let, E_2 be the energy of this level:

$E_2 = \frac{-13.6}{(n_2)^2}$ eV $= \frac{-13.6}{3^2} = \frac{-13.6}{9}$ eV

The amount of energy absorbed by the photon is given as:

E = E_2− E_1

$= \frac{-13.6}{9} - (-13.6) = \frac{13.6 \times 8}{9}$ eV $= \frac{13.6 \times 8}{9} \times 1.6 \times 10^{-19}$ = 1.934×10^{-18} J

For a photon of wavelength λ, the expression of energy is written as:

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

Where,

h = Planck's constant = 6.6×10^{-34} Js

c = Speed of light = 3×10^{8} m/s

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

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.934 \times 10^{-18}}$ = 10.23 x 10^{-8} m **= 102.3 nm**

And, frequency of a photon is given by the relation:

$v = \frac{c}{\lambda} = \frac{3 \times 10^8}{10.23 \times 10^{-8}}$ **= 2.93 x 10^{15} Hz**

Hence, the wavelength of the photon is 102.3 nm while the frequency is 2.93 × 10^{15} Hz.

Q.7: (a) Calculate the speed of an electron, in a hydrogen atom in the n = 1 and 2 levels using the Bohr's model

(b) Calculate the orbital period in each of these levels.

Ans:

(a) Let v_1 be the orbital speed of the electron in a hydrogen atom in the ground state level, n_1= 1. For charge (e) of an electron, v_1 is given by the relation,

$v_1 = \frac{e^2}{n_1 4 \pi \epsilon_0 \left(\frac{h}{2\pi}\right)} = \frac{e^2}{2 \epsilon_0 h}$

Where, **e = 1.6 × 10^{-19} C**

ϵ_0 = Permittivity of free space = 8.85 × 10^{-12} N^{-1} C^2 m^{-2}

h = Planck's constant **= 6.62 × 10^{-34} Js**

$v_1 = \frac{(1.6 \times 10^{-19})^2}{2 \times 8.85 \times 10^{-12} \times 6.62 \times 10^{-34}}$ = 0.0218 x 10^8 **= 2.18 × 10^6 = 10^6 m/s**

For level n_2**= 2**, we can write the relation for the corresponding orbital speed as:

$v_2 = \frac{e^2}{n_2 2 \epsilon_0 h} = \frac{(1.6 \times 10^{-19})^2}{2 \times 2 \times 8.85 \times 10^{-32} \times 6.62 \times 10^{-34}}$ **= 1.09 × 10^6 m/s**

Hence, the speed of the electron in a hydrogen atom in n = 1, n = 2, and n = 3 is 2.18 × 10^6 m/s, 1.09 × 10^6 m/s.

(b) Let, T_1 be the orbital period of the electron when it is in level n_1**= 1.**

Orbital period is related to orbital speed as:

$T_1 = \frac{2\pi r_1}{v_1}$ [Where, r1 = Radius of the orbit]

$= \frac{{n_1}^2 \, h^2 \, \epsilon_0}{\pi \, m e^2}$

h = Planck's constant = 6.62 × 10^{-34} Js

e = Charge on an electron = 1.6 × 10^{-19} C

0 = Permittivity of free space = 8.85 × 10^{-12} N^{-1} C^2 m^{-2}

m = Mass of an electron = 9.1 × 10^{-31} kg

$T_1 = \frac{2\pi r_1}{v_1}$

$= \frac{2 \, \pi \times (2)^2 \times (6.62 \times 10^{-34})^2 \times 8.85 \times 10^{-12}}{2.18 \times 10^6 \times \pi \times 9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2}$ **= 15.27 × 10^{-17} = 1.527 × 10^{-16} s**

For level n_2 = 2, we can write the period as:

$T_2 = \frac{2\pi r_2}{v_2}$ [Where, r2 = Radius of the electron in n2 = 2]

$= \frac{(n_2)^2 \, h^2 \, \epsilon_0}{\pi \, m e^2} = \frac{2 \, \pi \times (2)^2 \times (6.62 \times 10^{-34})^2 \times 8.85 \times 10^{-12}}{1.09 \times 10^6 \times \pi \times 9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2}$ **= 1.22 × 10^{-15}s**

Hence, the orbital period in each of these levels is 1.52 × 10^{-16} s, 1.22 × 10^{-15} s.

Q8: The radius of the inner most electron orbit of a hydrogen atom is 0.53 × 10^{-11} m. What are the radii of the n = 2 and n = 3 orbits?

Ans:

The radius of the innermost orbit of a hydrogen atom, r_1 **= 5.3 × 10^{-11} m.**

Let r_2 be the radius of the orbit at n = 2. It is related to the radius of the inner most orbit as:

$r_2 = (n)^2 r_1$ = 4 × 5.3 × 10^{-11} **= 2.12 × 10^{-10}**

For **n = 3**, we can write the corresponding electron radius as:

$r_3 = (n)^2 r_1$ = 9 × 5.3 x 10^{-11} **= 4.77 × 10^{-10}**

Hence, the radii of an electron for n = 2 and n = 3 orbits are 2.12 × 10^{-10} m and 4.77 × 10^{-10} m respectively.

Q9: A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. What series of wavelengths will be emitted?

Ans:

It is given that the energy of the electron beam used to bombard gaseous hydrogen at room temperature is 12.5 eV. Also, the energy of the gaseous hydrogen in its ground state at room temperature is −13.6 eV.

When gaseous hydrogen is bombarded with an electron beam, the energy of the gaseous hydrogen becomes −13.6 + 12.5 eV i.e., −1.1 eV.

Orbital energy is related to orbit level (n) as:

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

For n = 3, E = -13.6 / 9 **= – 1.5 eV**

This energy is approximately equal to the energy of gaseous hydrogen.

It can be concluded that the electron has jumped from n = 1 to n = 3 level.

During its de-excitation, the electrons can jump from n = 3 to n = 1 directly,

which forms a line of the Lyman series of the hydrogen spectrum.

We have the relation for wave number for Lyman series as:

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

Where, R_y= Rydberg constant = 1.097 × 10^7 m^{-1}

λ= Wavelength of radiation emitted by the transition of the electron

For n = 3, we can obtain λ as:

$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{1^2} - \frac{1}{3^2}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(1 - \frac{1}{9}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{8}{9}\right)$$

$\lambda = \frac{9}{8 \times 1.097 \times 10^7}$ **= 102.55 nm**

If the electron jumps from **n = 2 to n = 1**, then the wavelength of the radiation is given

as:

$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{1^2} - \frac{1}{2^2}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(1 - \frac{1}{4}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{3}{4}\right)$$

$\lambda = \frac{4}{3 \times 1.097 \times 10^7}$ **= 121.54 nm**

If the transition takes place from n = 3 to n = 2, then the wavelength of the radiation is

given as:

$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{2^2} - \frac{1}{3^2}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{4} - \frac{1}{9}\right)\ \frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{5}{36}\right)$$

$\lambda = \frac{36}{5 \times 1.097 \times 10^7}$ **= 656.33 nm**

This radiation corresponds to the Balmer series of the hydrogen spectrum.

Hence, in Lyman series, two wavelengths i.e., 102.5 nm and 121.5 nm are emitted and in the

Hence, in Lyman series, two wavelengths i.e., [illegible] nm and [illegible] nm are emitted and in the Balmer series, one wavelength i.e., 656.33 nm is emitted.

Q10: In accordance with the Bohr's model, find the quantum number that characterizes the earth's revolution around the sun in an orbit of diameter 3 × 10^{11} m with orbital speed 3 × 10^{4} m/s. (Mass of earth = 6.0 × 10^{24} kg.)

Ans:

Radius of the orbit of the Earth around the Sun, r = 1.5 × 10^{11} m

Orbital speed of the Earth, v = 3 × 10^{4} m/s

Mass of the Earth, m = 6.0 × 10^{24} kg

According to Bohr's model, angular momentum is quantumized and given as:

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

h = Planck's constant = 6.62 × 10^{-34} Js

n = Quantum number

$n = \frac{mvr2\pi}{h} = \frac{2\pi \times 6 \times 10^{24} \times 3 \times 10^{4} \times 1.5 \times 10^{11}}{6.62 \times 10^{-34}}$ **= 25.61 ×10^{73} = 2.6 × 10^{74}**

Hence, the quantam number that characterizes the Earth revolution is 2.6 × 10^{74}

Additional Questions:

Q11: Choose a suitable solution to the given statements which justify the difference between Thomson's model and Rutherford's model

(a) In the case of scattering of alpha particles by a gold foil, average angle of deflection of alpha particles stated by Rutherford's model is(less than, almost the same as, much greater than)stated by Thomson's model.

(b) Is the likelihood of reverse scattering (i.e., dispersing of α-particles at points more prominent than 90°) anticipated by Thomson's model (considerably less, about the same, or much more prominent) than that anticipated by Rutherford's model?

(c) For a small thickness T, keeping other factors constant, it has been found that amount of alpha particles scattered at direct angles is proportional to T. This linear dependence implies?

(d) To calculate average angle of scattering of alpha particles by thin gold foil, which model states its wrong to skip multiple scattering?

Ans:

(a) almost the same

The normal point of diversion of alpha particles by a thin gold film anticipated by Thomson's model is about the same as from anticipated by Rutherford's model. This is on the grounds that the average angle was taken in both models.

(b) much less

The likelihood of scattering of alpha particles at points more than 90° anticipated by Thomson's model is considerably less than that anticipated by Rutherford's model.

(c) Dispersing is predominantly because of single collisions. The odds of a single collision increment linearly with the amount of target molecules. Since the quantity of target particles increment with an expansion in thickness, the impact likelihood depends straightly on the thickness of the objective.

(d) Thomson's model

It isn't right to disregard multiple scattering in Thomson's model for figuring out the average angle of scattering of alpha particles by a thin gold film. This is on the grounds that a solitary collision causes almost no deflection in this model. Subsequently, the watched normal scattering edge can be clarified just by considering multiple scattering.

Q12: The gravitational attraction amongst proton and electron in a hydrogen atom is weaker than the coulomb attraction by a component of around 10^{-40}. Another option method for taking a gander at this case is to assess the span of the first Bohr circle of a hydrogen particle if the electron and proton were bound by gravitational attraction. You will discover the appropriate response fascinating.

Ans:

Radius of the first Bohr orbit is given by the relation:

$$r_1 = \frac{4\pi\epsilon_0\left(\frac{h}{2\pi}\right)^2}{m_e e^2} \text{ —(1)}$$

Where,

ϵ_0 = Permittivity of free space

h = Planck's constant = 6.63×10^{-34} Js

m_e = Mass of an electron = 9.1×10^{-31} kg

e = Charge of an electron = 1.9×10^{-19} C

m_p = Mass of a proton = 1.67×10^{-27} kg

r = Distance between the electron and the proton

Coulomb attraction between an electron and a proton is given as:

$$F_C = \frac{e^2}{4\pi\epsilon_0 r^2} \text{ —(2)}$$

Gravitational force of attraction between an electron and a proton is given as:

$$F_G = \frac{Gm_e m_p}{r^2} \text{ —(3)}$$

Where,

G = Gravitational constant = 6.67×10^{-11} N m^2/kg^2

If the electrostatic (Coulomb) force and the gravitational force between an electron and

a proton are equal, then we can write:

$\therefore F_G = F_C$

$$\frac{Gm_e m_p}{r^2} = \frac{e^2}{4\pi\epsilon_0 r^2}$$

$$Gm_e m_p = \frac{e^2}{4\pi\epsilon_0} \text{ —(4)}$$

Putting the value of **equation (4) in equation (1)**, we get:

$$r1 = \frac{\left(\frac{h}{2\pi}\right)^2}{Gm_e m_p}$$

$$r1 = \frac{\left(\frac{6.63\times10^{-34}}{2\times3.14}\right)^2}{6.67\times10^{-11}\times1.67\times10^{-27}\times(9.1\times10^{-31})^2} = 1.21 \times 10^{29} \text{ m}$$

It is known that the universe is 156 billion light years wide or 1.5×10^{27} m wide. Hence, we can conclude that the radius of the first Bohr orbit is much greater than the estimated size of the whole universe.

Q13: Obtain an expression for the frequency of radiation emitted when a hydrogen atom de excites from level n to level (n − 1). For large n, show that this frequency equals the classical frequency of revolution of the electron in the orbit. When a hydrogen atom de excites itself from a higher level to a lower level say from n to n – 1, find an expression for its frequency of radiation. Also for a large value of n, show that this frequency equals classical frequency of revolution of the electron in the orbit.

Ans:

It is given that an atom of hydrogen de excites from an upper level to a lower level **(from n to n − 1).**

We have the relation for energy (E1) of radiation at level n as:

$E_1 = h\nu_1 = \frac{hme^4}{\dots} \times \left(\frac{1}{\dots}\right)$ —(1)

$$E_1 = hv_1 = \frac{hme^4}{(4\pi)^3\epsilon_0^2(\frac{h}{2\pi})^3} \times \left(\frac{1}{n^2}\right) \text{—(1)}$$

Where,

ϵ_0 = Permittivity of free space

h = Planck's constant = 6.63 × 10^{-34} Js

m = Mass of an atom of hydrogen

e = Charge of an electron = 1.9 × 10^{-19} C

v_1 = Frequency of radiation at level n

Now, the relation for energy (**E_2**) of radiation at level (n − 1) is given as:

$$E_2 = hv_2 = \frac{hme^4}{(4\pi)^3\epsilon_0^2(\frac{h}{2\pi})^3} \times \left(\frac{1}{(n-1)^2}\right) \text{—(2)}$$

Where,

v_2 = Frequency of radiation at level (n – 1)

Energy (E) released as a result of de-excitation:

E = **$E_2 - E_1$**

hv = **$E_2 - E_1$—(3)**

Where,

v = Frequency of radiation emitted

Putting values from **equations (1) and (2) in equation (3)**, we get:

$$v = \frac{me^4}{(4\pi)^3\epsilon_0^2(\frac{h}{2\pi})^3} \times \left(\frac{1}{(n-1)^2} - \frac{1}{n^2}\right) v = \frac{me^4(2n-1)}{(4\pi)^3\epsilon_0^2(\frac{h}{2\pi})^3 n^2(n-1)^2}$$

For large n, we can write (2n – 1) $\simeq$ 2n and (n – 1) $\simeq$ = n.

$$v = \frac{me^4}{32\pi^3\epsilon_0^2(\frac{h}{2\pi})^3 n^2} \text{—(4)}$$

Classical relation of frequency of revolution of an electron is given as:

$$v_c = v/2\pi r \text{—(5)}$$

Where, Velocity of the electron in the n^{th} orbit is given as:

$$v = \frac{e^2}{4\pi\epsilon_0\left(\frac{h}{2\pi}\right)n} \text{—(6)}$$

And, radius of the n^{th} orbit is given as:

$$r = \frac{4\pi\epsilon_0(\frac{h}{2\pi})^2}{me^4} n^2 \text{—(7)}$$

Putting the values of equations (6) and (7) in equation (v), we get:

$$v = \frac{me^4}{32\pi^3\epsilon_0^2(\frac{h}{2\pi})^3 n^3}$$

Hence, the frequency of radiation emitted by the hydrogen atom is equal to its classical orbital frequency.

Q14: Normally, in an atom an electron can be expected to be in any orbit surrounding the nucleus. Then how do we calculate the size of an atom? Why is an atom not, say hundred times bigger than its actual size? This question had greatly troubled Bohr before he arrived at his model of an atom that has been said in the text. To get an idea of the simulations he must have to go through before his discovery, let us try as follows with the basic constants of nature and check if we can get a quantity with the dimensions of length that is roughly equal to the known size of an atom (~ 10^{-10} m).

(i) Develop a value with the measurements of length from the key constants e, m_e, and C. Calculate its numerical value.

(ii) With your calculations you will come to an answer wherein the value is much smaller than the actual size as it involves C. But we know that atomic energies are non-relativistic hence c should not play any part. This must have made Bohr to overlook c in search for a different factor to get the right atomic size. As Plank's constant h had already made its appearance elsewhere, with its help Bohr was able to find the right atomic size. Find a quantity with dimension of length h, m_e, and e and verify that its numerical value has the correct order of magnitude.

and c and verify that its numerical value has the correct order of magnitude.

Ans:

(a) Charge on an electron, e = 1.6 × 10^{-19} C

Mass of an electron, me = 9.1 × 10^{-31} kg

Speed of light, c = 3 ×10^{8} m/s

Let us take a quantity involving the given quantities as $\left(\frac{e^2}{4\pi\epsilon_0 m_e c^2}\right)$

Where, ϵ_0 **= Permittivity of free space**

And, the numerical value of the taken quantity will be:

$\frac{1}{4\pi\epsilon_0} \times \frac{e^2}{m_e c^2} = 9 \times 10^9 \times \frac{(1.6\times10^{-19})^2}{9.1\times10^{-31}\times(3\times10^8)^2}$ **= 2.81 × 10^{-15} m**

Hence, the calculated value of size is much lower than the actual value of size of an atom.

(b) Charge on an electron, e = 1.6 × 10^{-19} C

Mass of an electron, me = 9.1 × 10^{-31} kg

Planck's constant, h = 6.63 ×10^{-34} Js

Let us take a quantity involving the given quantities as $\frac{4\pi\epsilon_0\left(\frac{h}{2\pi}\right)^2}{m_e e^2}$

Where, ϵ_0 **= Permittivity of free space**

And, $\frac{1}{4\pi\epsilon_0}$ **= 9 × 10^9 Nm^{2}C^{-2}**

The numerical value of the taken quantity will be:

$4\pi\epsilon_0 \times \frac{(\frac{h}{2\pi})^2}{m_e e^2} = \frac{1}{9\times10^9} \times \frac{(\frac{6.63\times10^{-34}}{2\times3.14})^2}{9.1\times10^{-31}\times(1.6\times10^{-19})^2}$ **= 0.53 × 10^{-19}m**

Hence, the value of the quantity taken is of the order of the atomic size.

Q15: In the case of a hydrogen atom, the energy of an electron (total energy) in the first excited state is -4.3 eV. In this state, find:

(a) Kinetic energy of electron?

(b) Potential energy of electron?

(c) If we change the value of zero potential, which of the answers above would change?

Ans:

(a) Total energy of the electron, E = −4.3 eV

Kinetic energy of the electron is equal to the negative of the total energy.

K = −E = − (4.3) **= +4.3 eV**

Hence, the kinetic energy of the electron in the given state is +4.3 eV.

(b) Potential energy (U) of the electron is equal to the negative of twice of its kinetic energy.

U = −2 K = − 2 × 4.3 **= − 8.6 eV**

Hence, the potential energy of the electron in the given state is − 8.6 eV.

(c) According to the reference point taken potential energy varies.

In this case we have taken the potential energy of the reference point as 0. Thus, if the reference point is changed, then the value of potential energy of the system varies, which in turn will change the total energy of the system as total energy is the sum of potential and kinetic energy .

Q16: If Bohr's quantization postulate (angular momentum = nh/2π) is a basic law of nature, it should be equally valid for the case of planetary motion as well. Why then do we never speak of

should be equally valid for the case of planetary motion as well. Why then do we never speak of quantization of orbits of planets around the sun?

Ans:

We never speak of quantization of orbits of planets around the Sun because the angular momentum associated with planetary motion is largely relative to the value of Planck's constant (h). The angular momentum of the Earth in its orbit is of the order of 10^{70}h. This leads to a very high value of quantum levels n of the order of 10^{70}. For large values of n, successive energies and angular momenta are relatively very small. **Hence, the quantum levels for planetary motion are considered continuous.**

Q17: Obtain the first Bohr's radius and the ground state energy of a muonic hydrogen atom [i.e., an atom in which a negatively charged muon (μ−) of mass about 207me orbits around a proton].

Ans:

Mass of a negatively charged muon, $\mathbf{m_P = 207\ m_e}$

According to Bohr's model:

Bohr radius, $r_e \alpha \left(\frac{1}{m_e}\right)$

And, energy of a ground state electronic hydrogen atom, $E_e\ \alpha\, m_e$

Also, energy of a ground state muonic hydrogen atom, $\mathbf{E_u = m_u}$

We have the value of the first bohr orbit, r_e = 0.53 A **= 0.53 × 10^{-10} m**

Let, r_μ be the radius of muonic hydrogen atom.

At equilibrium, we can write the relation as:

$\mathbf{m_p\ r_p = m_e\ r_e}$

207 m_e × r_u = m_e r_e

R_u = (0.53 × 10^{-10})/ 207 = 2.56 × 10^{-13} m

Hence, the value of the first Bohr radius of a muonic hydrogen atom is **2.56 × 10^{-13} m**.

We have,

$\mathbf{E_e = -\ 13.6\ eV}$

Take the ratio of these energies as:

$$\frac{E_e}{E_u} = \frac{m_e}{m_u} = \frac{m_e}{207\ m_e}$$

E_u = 207 E_e = 207 × (– 13.6) **= – 2.81 keV**

Hence, the ground state energy of a muonic hydrogen atom is −2.81 keV