

Q1: Choose the correct alternative from the clues given at the end of each statement:

- (a) The size of the atom in Thomson's model is the atomic size in Rutherford's model. (much greater than/no different from/much less than.)
- (b) In the ground state of electrons are in stable equilibrium, while in electrons always experience a net force. (Thomson's model/ Rutherford's model.)
- (c) A classical atom based on is doomed to collapse. (Thomson's model/ Rutherford's model.)
- (d) An atom has a nearly continuous mass distribution in abut has a highly non-uniform mass distribution in(Thomson's model/ Rutherford's model.)
- (e) The positively charged part of the atom possesses most of the mass in (Rutherford's model/both the models.)

Ans:

- (a) The size of an atom in Rutherford's model and of Thomson's model is the same.
- (b) During stable equilibrium, electrons of Rutherford's model experience net force while the electrons of Thomson's model do not.
- (c) Rutherford's model is a showcase of 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 state that a larger portion of the mass of an atom is contributed by the positively charged part.

Q2: Suppose you are given a chance to repeat the alpha-particle scattering experiment using a thin sheet of solid hydrogen in place of the gold foil. (Hydrogen is a solid at temperatures below 14 K.) What results do you expect?

Ans:

We know that the mass of the 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 conclude that the alpha particle would not rebound. Implying to the fact that solid hydrogen isn't a suitable replacement to gold foil for the alpha particle scattering experiment.

Q3: What is the shortest wavelength present in the Paschen series of spectral lines?

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.

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8 \times 9}{21.76 \times 10^{-19}}$$

$$= 8.189 \times 10^{-7} = 818.9 \text{ nm}$$

Q4: A difference of 2.3 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, $E = 2.3 \text{ eV} = 2.3 \times 1.6 \times 10^{-19} = 3.68 \times 10^{-19} \text{ J}$

Consider ν as the frequency of radiation emitted when the atom transitions from the upper level to the lower level.

Following is the relation for energy:

$$E = hv$$

Where, $h = \text{Planck's constant} = 6.62 \times 10^{-34} \text{ Js}$

$$v = \frac{E}{h} = \frac{7.36 \times 10^{-19}}{6.62 \times 10^{-34}} = 11.1 \times 10^{14} \text{ Hz}$$

Hence, the frequency of the radiation is $11.1 \times 10^{14} \text{ Hz}$.

Q5: The ground state energy of hydrogen atom is -13.6 eV . What are the kinetic and potential energies of the electron in this state?

Ans:

Ground state energy of hydrogen atom, $E = -27.2 \text{ eV}$

The total energy of hydrogen atom is -27.2 eV . The kinetic energy is equal to the negative of the total energy.

Kinetic energy $= -E = -(-27.2) = 27.2 \text{ eV}$

Potential energy = negative of two times of kinetic energy.

Potential energy $= -2 \times (27.2) = -54.4 \text{ eV}$

Q6: A hydrogen atom initially in the ground level absorbs a photon, which excites it to the $n = 4$ level. Determine the wavelength and frequency of 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:

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

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

Let, E_2 be the energy of this level:

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

Following is the amount of energy absorbed by the photon:

$$E = E_2 - E_1$$

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

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

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

Where,

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

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

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.934 \times 10^{-18}}$$

$$= 10.23 \times 10^{-8} \text{ m} = 102.3 \text{ nm}$$

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

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

Therefore, 102.3 nm and $2.93 \times 10^{15} \text{ Hz}$ is the wavelength and frequency of the photon.

Q.7: (a) Using the Bohr's model, calculate the speed of the electron in a hydrogen atom in the $n = 1, 2,$ and 3 levels. (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, $e = 1.6 \times 10^{-19} \text{ C}$

ϵ_0 = Permittivity of free space = $8.85 \times 10^{-12} \text{ N}^{-1} \text{ C}^2 \text{ m}^{-2}$

h = Planck's constant = $6.62 \times 10^{-34} \text{ Js}$

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

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

$$v_2 = \frac{e^2}{n_2 2 \epsilon_0 h} = \frac{(1.6 \times 10^{-19})^2}{2 \times 2 \times 8.85 \times 10^{-12} \times 6.62 \times 10^{-34}} = 1.09 \times 10^6 \text{ m/s}$$

Therefore, in a hydrogen atom, the speed of the electron at different levels that is $n=1$, $n=2$, and $n=3$ is $2.18 \times 10^6 \text{ m/s}$ and $1.09 \times 10^6 \text{ m/s}$.

(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:

$$T_1 = \frac{2\pi r_1}{v_1} \quad [\text{Where, } r_1 = \text{Radius of the orbit}] = \frac{n_1^2 h^2 \epsilon_0}{\pi m e^2}$$

h = Planck's constant = $6.62 \times 10^{-34} \text{ Js}$

e = Charge on an electron = $1.6 \times 10^{-19} \text{ C}$

ϵ_0 = Permittivity of free space = $8.85 \times 10^{-12} \text{ N}^{-1} \text{ C}^2 \text{ m}^{-2}$

m = Mass of an electron = $9.1 \times 10^{-31} \text{ kg}$

$$T_1 = \frac{2\pi r_1}{v_1} = \frac{2 \pi \times (2)^2 \times (6.62 \times 10^{-34})^2 \times 8.85 \times 10^{-12}}{2.18 \times 10^6 \times \pi \times 9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2} = 15.27 \times 10^{-17} = 1.527 \times 10^{-16} \text{ s}$$

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

$$T_2 = \frac{2\pi r_2}{v_2} \quad [\text{Where, } r_2 = \text{Radius of the electron in } n_2 = 2] = \frac{(n_2)^2 h^2 \epsilon_0}{\pi m e^2} = \frac{2 \pi \times (2)^2 \times (6.62 \times 10^{-34})^2 \times 8.85 \times 10^{-12}}{1.09 \times 10^6 \times \pi \times 9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2} = 1.22 \times 10^{-15} \text{ s}$$

Therefore, $1.52 \times 10^{-16} \text{ s}$ and $1.22 \times 10^{-15} \text{ s}$ are the orbital periods in each levels.

Q8: The radius of the innermost electron orbit of a hydrogen atom is $5.3 \times 10^{-11} \text{ m}$. What are the radii of the $n = 2$ and $n = 3$ orbits?

Ans:

The radius of the innermost orbit of a hydrogen atom, $r_1 = 5.3 \times 10^{-11} \text{ m}$.

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

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

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

$$r_3 = (n)^2 r_1 = 9 \times 5.3 \times 10^{-11} = 4.77 \times 10^{-10}$$

Therefore, $2.12 \times 10^{-10} \text{ m}$ and $4.77 \times 10^{-10} \text{ m}$ are the radii of an electron for $n = 2$ and $n = 3$ orbits are 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 $-13.6 + 12.5 \text{ eV}$ i.e., -1.1 eV .

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

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

For $n = 3$, $E = -13.6 / 9 = -1.5 \text{ eV}$

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 = $1.097 \times 10^7 \text{ m}^{-1}$

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

For $n = 3$, we can obtain λ as:

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

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

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

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

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

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

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

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

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

Therefore, there are two wavelengths that are emitted in Lyman series and they are 102.5 nm and 121.5 nm and one wavelength in the Balmer series which is 656.33 nm.

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 $3 \times 10^{11} \text{ m}$ with orbital speed $3 \times 10^4 \text{ m/s}$. (Mass of earth = $6.0 \times 10^{24} \text{ kg}$.)

Ans:

Radius of the orbit of the Earth around the Sun, $r = 1.5 \times 10^{11} \text{ m}$

Orbital speed of the Earth, $v = 3 \times 10^4 \text{ m/s}$

Mass of the Earth, $m = 6.0 \times 10^{24} \text{ kg}$

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

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

h = Planck's constant = $6.62 \times 10^{-34} \text{ Js}$

n = Quantum number

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

Therefore, the earth revolution can be characterized by the quantum number 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 number 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:

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

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:

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

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

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

Where,

G = Gravitational constant = 6.67×10^{-11} N m²/kg²

Considering electrostatic force and the gravitational force between an electron and a proton to be equal, we get:

$$\therefore F_G = F_C$$

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

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

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

$$r_1 = \frac{\left(\frac{h}{2\pi}\right)^2}{Gm_e m_p} \quad r_1 = \frac{\left(\frac{6.63 \times 10^{-34}}{2 \times 3.14}\right)^2}{6.67 \times 10^{-11} \times 1.67 \times 10^{-27} \times (9.1 \times 10^{-31})^2} = 1.21 \times 10^{29} \text{ m}$$

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:

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

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 (E₂) of radiation at level (n - 1) is given as:

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

Where,

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

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

$$E = E_2 - E_1$$

$$hv = E_2 - E_1 \quad \text{---(3)}$$

Where,

v = Frequency of radiation emitted

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

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

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

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

Classical relation of frequency of revolution of an electron is:

$$v_c = v/2\pi r \quad \text{---(5)}$$

Where, Velocity of the electron in the nth orbit is:

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

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

$$r = \frac{4\pi\epsilon_0 \left(\frac{h}{2\pi}\right)^2}{m_e e^4} n^2 \quad \text{---(7)}$$

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

$$v = \frac{m_e e^4}{32\pi^3 \epsilon_0^2 \left(\frac{h}{2\pi}\right)^3 n^3}$$

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 ($\sim 10^{-10}$ 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.

Ans:

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

Mass of an electron, $m_e = 9.1 \times 10^{-31}$ kg

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

Let the given quantities be: $\left(\frac{e^2}{4\pi\epsilon_0 m_e c^2}\right)$

Where, ϵ_0 = Permittivity of free space

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

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

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

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

Mass of an electron, $m_e = 9.1 \times 10^{-31}$ kg

Planck's constant, $h = 6.63 \times 10^{-34}$ 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, $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$

The numerical value of the taken quantity will be:

$$4\pi\epsilon_0 \times \frac{\left(\frac{h}{2\pi}\right)^2}{m_e e^2} = \frac{1}{9 \times 10^9} \times \frac{\left(\frac{6.63 \times 10^{-34}}{2 \times 3.14}\right)^2}{9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2} = 0.53 \times 10^{-10} \text{ m}$$

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, $E = -4.3 \text{ eV}$

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

$$K = -E = -(-4.3) = +4.3 \text{ eV}$$

Hence, the kinetic energy of the electron in the given state is $+4.3 \text{ eV}$.

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

$$U = -2K = -2 \times 4.3 = -8.6 \text{ eV}$$

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.

The reference point of the potential energy is considered to be 0. The value of potential energy is dependent on the reference point. Therefore, any change in reference point will result in the change of potential energy which will bring changes in the total energy which is equal to the sum of potential energy and kinetic energy.

Q16: If Bohr's quantization postulate (angular momentum = $nh/2\pi$) 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 quantization of orbits of planets around the sun?

Ans:

The quantum level for a planetary motion is considered to be continuous. This is because the angular momentum associated with planetary motion is largely relative to the value of Planck's constant (h). $10^{70}h$ is the order of the angular momentum of the Earth in its orbit. As the values of n increase, the angular momenta decreases. So, the planetary motion is considered to be 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 $207m_e$ orbits around a proton].

Ans:

Mass of a negatively charged muon, $m_\mu = 207 m_e$

According to Bohr's model:

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

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

Also, energy of a ground state muonic hydrogen atom, $E_\mu = m_\mu$

We have the value of the first bohr orbit, $r_e = 0.53 \text{ \AA} = 0.53 \times 10^{-10} \text{ m}$

Let, r_μ be the radius of muonic hydrogen atom.

Following is the relation at equilibrium:

$$m_\mu r_\mu = m_e r_e$$

$$207 m_e \times r_\mu = m_e r_e$$

$$R_\mu = (0.53 \times 10^{-10}) / 207 = 2.56 \times 10^{-13} \text{ m}$$

Hence, for a muonic hydrogen atom $2.56 \times 10^{-13} \text{ m}$ is the value of first Bohr radius.

We have,

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

Considering the ratio of the energies we get:

$$\frac{E_e}{E_\mu} = \frac{m_e}{m_\mu} = \frac{m_e}{207 m_e}$$

$$E_\mu = 207 E_e = 207 \times (-13.6) = -2.81 \text{ keV}$$

-2.81 keV is the ground state energy of a muonic hydrogen atom.