Atoms

Chapter 12

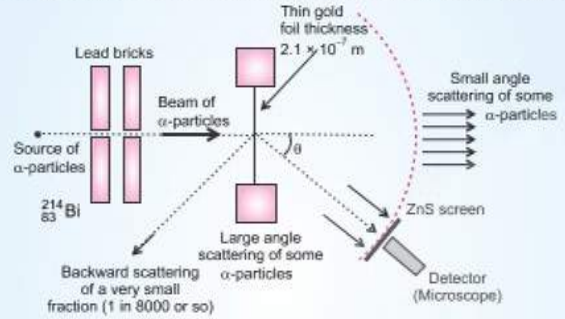
1 ATOMIC MODELS

Thomson's Model → Rutherford Model → Bohr's Model

Thomson's Model

Atom is a spherical cloud of positive charge with electrons embedded into it, like seeds in watermelon.

α-Particle Scattering Experiment and Rutherford nuclear model of atom



Conclusions

1. Only about 0.14% of incident α-particle scatter by more than 1°
2. About 1 in 8000 deflect by more than 90°
3. Size of nucleus to be about 10^{-15} m to 10^{-14} m
4. For large impact parameter the α-particle goes nearly undeviated.
5. In case of head on collision, the impact parameter is minimum and α-particle rebound back ($\theta \cong \pi$)

Rutherford's Model

According to Rutherford most of the mass of atom and all its positive charge are concentrated in a tiny space of the order of 10^{-14} m, called nucleus and electrons revolve around it. Centripetal force is obtained from electrostatic attraction between electron and nucleus.

Draw backs

(i) Stability of atom

(ii) Line spectrum of atoms

2 IMPACT PARAMETER

It is perpendicular distance of initial velocity vector of the α particle from the centre of nucleus.

$$b = \frac{Ze^2 \cot\left(\frac{\theta}{2}\right)}{4\pi\varepsilon_0 E}$$

Electron orbit

- radius $(r) = \dfrac{e^2}{4\pi\varepsilon_0 mv^2}$
- Kinetic energy $(K) = \dfrac{e^2}{8\pi\varepsilon_0 r}$
- Potential energy $(U) = -\dfrac{e^2}{4\pi\varepsilon_0 r}$
- Total energy $(E) = K + U = -\dfrac{e^2}{8\pi\varepsilon_0 r}$

Bohr's Model

Bohr combined classical and quantum concepts and gave the theory in terms of three postulates.

1. An electron can revolve in certain stable orbits without emission of radiant energy.
2. Electron can revolve only in those orbits in which angular momentum is integral multiple of $\left(\dfrac{h}{2\pi}\right)$

   $L = mv_n r_n = \dfrac{nh}{2\pi}$, $n = 1, 2, 3, \ldots$
3. When an electron makes a transition from one of the specified non radiatory orbit to another lower energy orbit then radiate energy equal to the difference of energy equal to final and initial state.

- Bohr's model is applicable for hydrogen and hydrogen like elements.

Limitations of Bohr's Model

- Bohr's model is applicable for single electron atom/ions.
- Bohr's model correctly predict the frequencies of the light emitted by hydrogenic (hydrogen like) atoms but unable to explain the relative intensities of light

3 DIFFERENT QUANTITIES FOR HYDROGEN LIKE ELEMENTS

- **Radius of the n^{th} orbit:**

$$r_n = \left(\frac{\varepsilon_0 h^2}{\pi me^2}\right)\frac{n^2}{Z} = 0.529\frac{n^2}{Z}\text{ Å}$$

$$\Rightarrow r_n \propto \frac{n^2}{Z}$$

- **Speed of electron in n^{th} orbit:**

$$v_n = \frac{e^2}{2h\varepsilon_0}\frac{Z}{n} = \frac{C}{137}\frac{Z}{n}$$

$$\Rightarrow v_n \propto \frac{Z}{n}$$

- **Energy of electron in n^{th} orbit**

$$E_n = -\left(\frac{me^4}{8\varepsilon_0^2 h^2}\right)\frac{Z^2}{n^2}\text{ J} = (2.18\times10^{-18})\frac{Z^2}{n^2}\text{ J}$$

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

$$\Rightarrow E_n \propto \frac{Z^2}{n^2}$$

- **Time period of revolution of electron in n^{th} orbit.**

$$T = \left(\frac{4\varepsilon_0 h^3}{me^4}\right)\frac{n^3}{Z^2}$$

$$= \frac{n^3}{Z^2}(1.51\times10^{-16}\text{ s})$$

$$\Rightarrow T \propto \frac{n^3}{Z^2}$$

(4) HYDROGEN SPECTRUM

1. Lyman series

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

lies in U.V. region

2. Balmer series

$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right],\ n = 3, 4, 5 \ldots \infty$$

Mostly lies in visible region

3. Paschen series

$$\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n^2}\right],\ n = 4, 5, 6 \ldots \infty$$

lies in near infra red region

4. Bracket series

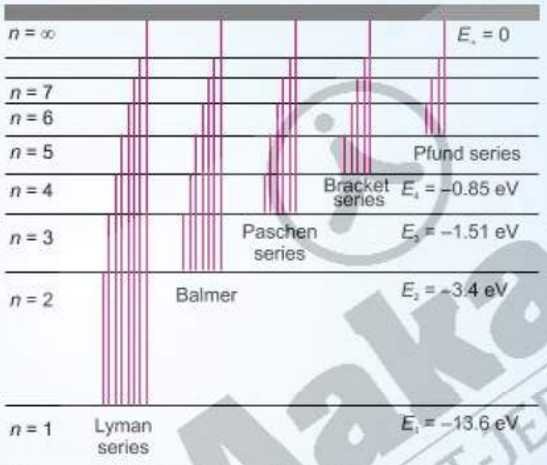
$$\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n^2}\right],\ n = 5, 6, 7 \ldots \infty$$

lies in infra red region

5. Pfund series

$$\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n^2}\right],\ n = 6, 7, 8 \ldots \infty$$

lies in far infra red region



(Line spectra originate in Transition between energy levels)

Rydberg constant

$$R = \frac{me^4}{8\varepsilon_0 h^3 c} = 1.03 \times 10^7\ \text{m}^{-1}$$ (By Bohr-model)

$R = 1.097 \times 10^7\ \text{m}^{-1}$ (from Balmer empirical formula)

(5) DE BROGLIE'S EXPLANATION OF BOHR'S SECOND POSTULATE OF QUANTISATION

de-Broglie explained second postulate of Bohr's atomic model by assuming an electron has wave nature.

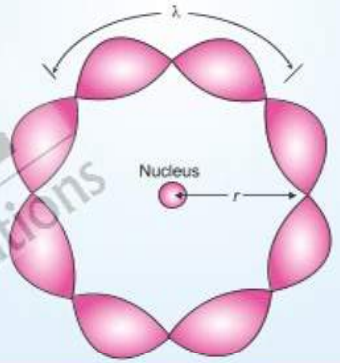
The circumference of orbit should be integer multiple of de-Broglie wavelength of electron in n^{th} orbit.

- $2\pi r_n = n\lambda,\ n = 1,2,3,\ldots$

  or

  $$mv_n r_n = \frac{nh}{2\pi}$$

- This is quantum condition proposed by Bohr for an angular momentum of an electron.



(6) LASER

Acronym: light amplification by stimulated emission of radiation.

- It involves population inversion.
- It is highly coherent
- Laser light is highly monochromatic
- Divergence of laser beam is very less
- If there are N atoms, each emitting light with intensity I, then net intensity produced by ordinary source is proportional to NI whereas in laser source, it is proportional to N^2I
- There are low power lasers with a power of 0.5 mW, called pencil lasers which serve as pointers. There lasers are used for delicate surgery of eye or glands in stomach.
- Laser can cut and weld steel.

Sharpen Your Understanding

1. The thickness of gold foil used in α-particle scattering experiment was [NCERT Pg. 416]

(1) 2.1×10^{-7} m (2) 2.1×10^{-3} m

(3) 3.1×10^{-10} m (4) 2.1×10^{-12} m

2. In α-particle scattering experiment number of α-particles scatter by more than 1° is about [NCERT Pg. 416]

(1) 0.3%

(2) 0.24%

(3) 0.20%

(4) 0.14%

3. In α-particle scattering experiment, number of α-particles deflected by more than 90° is [NCERT Pg. 416]

(1) 1 in 8000

(2) 1 in 2000

(3) 1 in 1000

(4) 1 in 10,0000

4. Rutherford's experiments suggested that the size of nucleus is about [NCERT Pg. 417]

(1) 10^{-14} m to 10^{-11} m

(2) 10^{-16} m to 10^{-13} m

(3) 10^{-15} m to 10^{-14} m

(4) 10^{-15} m to 10^{-10} m

NCERT Based MCQs

5. In which of the following, will the radius of the first orbit ($n = 1$) be minimum? [NCERT Pg. 425]

(1) Doubly ionized lithium

(2) Singly ionized helium

(3) Deuterium atom

(4) Hydrogen atom

6. If 13.6 eV energy is required to separate a hydrogen atom into a proton and electron, then the velocity of revolving electron is [NCERT Pg. 425]

(1) 1.2×10^6 m/s (2) 2.2×10^6 m/s

(3) 3.2×10^6 m/s (4) 1.8×10^5 m/s

7. An electron in a hydrogen atom makes a transition from $n = n_1$ to $n = n_2$. The time period of revolution of the electron in the initial state is eight times that in final state. The possible value of n_1 and n_2 are [NCERT Pg. 429]

(1) $n_1 = 4, n_2 = 2$ (2) $n_1 = 8, n_2 = 2$

(3) $n_1 = 8, n_2 = 1$ (4) $n_1 = 6, n_2 = 2$

8. If muonic hydrogen atom is an atom in which a negatively charged muon (μ) of mass about $207m_e$ revolve around a proton, then first Bohr radius of this atom is (radius of electron orbit is 0.53 Å) [NCERT Pg. 437]

(1) 2.56×10^{-10} m (2) 2.56×10^{-11} m

(3) 2.56×10^{-12} m (4) 2.56×10^{-13} m

9. The minimum energy that must be given to a hydrogen atom in ground state so that it can emit an H_γ line in Balmer series. [NCERT Pg. 429]

(1) 12.4 eV

(2) 10.2 eV

(3) 13.06 eV

(4) 12.75 eV

10. A hydrogen atom initially in the ground state absorbs a photon and is excited to $n = 4$ level, then the wavelength of photon is nearly [NCERT Pg. 427]

(1) 790 Å

(2) 870 Å

(3) 970 Å

(4) 1070 Å

11. The wavelength of first line of Lyman series is 1215 Å, the wavelength of first line of Balmer series will be [NCERT Pg. 421]

(1) 4545 Å (2) 5295 Å

(3) 6563 Å (4) 6750 Å

12. The ratio of the speed of electron in the ground state of hydrogen atom to the speed of light in vacuum is [NCERT Pg. 425]

(1) $\frac{1}{2}$ (2) $\frac{2}{237}$

(3) $\frac{1}{137}$ (4) $\frac{1}{237}$

13. Ionization potential of hydrogen atom is 13.6 eV. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to Bohr's theory, the spectral lines emitted by hydrogen will be [NCERT Pg. 429]
(1) One
(2) Two
(3) Three
(4) Five

14. Bohr's basic idea of discrete energy levels in atoms and process of emission of photons from the higher levels to the lower levels was experimentally confirmed by experiments performed by [NCERT Pg. 428]
(1) Michelson-Morley
(2) Millikan
(3) Joule
(4) Franck and Hertz

15. If E is the energy of n^{th} orbit of hydrogen atom, the energy of n^{th} orbit of He^+ ion will be [NCERT Pg. 425]
(1) E (2) $2E$
(3) $3E$ (4) $4E$

16. The shortest wavelength present in, the Paschen series of spectral lines is nearly [NCERT Pg. 429]
(1) 720 nm (2) 790 nm
(3) 800 nm (4) 820 nm

17. If there are N atoms in a source of Laser light and each atom is emitting light with intensity I, then the total intensity produced by it is [NCERT Pg. 432]
(1) NI (2) N^2I
(3) N^3I (4) N^4I

18. Which of the following statements is true for hydrogen atom? (n is principal quantum number of orbit) [NCERT Pg. 425]
(1) Angular momentum $\propto \frac{1}{n}$
(2) Radius of orbit $\propto \frac{1}{n}$
(3) Magnitude of linear momentum of electron in any orbit $\propto \frac{1}{n}$
(4) Energy of electron in any orbit $\propto \frac{1}{n^3}$

19. The first spectral series of hydrogen atom was discovered by [NCERT Pg. 421]
(1) Balmer (2) Lyman
(3) Paschen (4) Bohr

20. In a hydrogen atom, total energy of electron is [NCERT Pg. 420]
(1) $\frac{e^2}{4\pi\varepsilon_0 r}$ (2) $\frac{-e^2}{4\pi\varepsilon_0 r}$
(3) $\frac{-e^2}{8\pi\varepsilon_0 r}$ (4) $\frac{e^2}{8\pi\varepsilon_0 r}$

Thinking in Context

1. The source of α-particles in Rutherford experiment is _____. [NCERT Pg. 416]

2. Emission line spectrum consists of _____ lines on a _____ background. [NCERT Pg. 421]

3. _____ the impact parameter, α-particle goes nearly undeviated [NCERT Pg. 418]

4. At room temperature most of hydrogen atoms are in _____ state. [NCERT Pg. 427]

5. According to Thomson model, the entire mass and charge of an atom are _____ distributed throughout the volume of atom. [NCERT Pg. 414]

6. Total energy of electron in inner orbits is _____ than in outer orbits [NCERT Pg. 425]

7. Orbital velocity of electrons in inner orbits _____ as compared to outer orbits. [NCERT Pg. 425]

8. Total energy of electron in any orbit of atom is _____. This indicates that electron is bound to nucleus. [NCERT Pg. 425]

9. According to Bohr, _____ momentum of revolving electron in hydrogen atom is quantised. [NCERT Pg. 424]

10. Lyman series lies in _____ region of hydrogen spectrum. [NCERT Pg. 429]
11. In Bohr model, contrary to ordinary classical expectation, the frequency of revolution of an electron in its orbit is not connected to _____ of spectral lines. [NCERT Pg. 423]
12. According to classical electromagnetic theory _____ charge particles emits radiation in the form of electromagnetic wave. [NCERT Pg. 423]
13. According to Quantum theory when an electron makes a transition from one of the specified orbit to lower energy orbit a _____ is emitted having energy equal to the _____ of two levels. [NCERT Pg. 424]
14. Bohr model is valid for only _____atom/ions. [NCERT Pg. 426]
15. If there are N atoms in a source, each emitting light with intensity I, then the total intensity produced by an ordinary source is proportional to _____ where as in laser source it is proportional to _____ [NCERT Pg. 432]
16. An electron can have any total energy above $E = 0$ eV. In such situations the electron is _____. [NCERT Pg. 427]
17. In Balmer series, the line with _____ colour is called H_β line. [NCERT Pg. 421]
18. Thomson's model is unstable electrostatically, while Rutherford model is unstable _____. [NCERT Pg. 434]
19. With the increase in principal quantum number in the stationary states, the difference of energy from ground state _____. [NCERT Pg. 427]
20. According to _____ postulate of Bohr's, an electron in an atom could revolve in certain stable orbits without the emission of radiant energy. [NCERT Pg. 423]

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