CHAPTER 12

Atoms

Syllabus

- **Alpha Particle Scattering and Rutherford's Nucleus Model of Atom:** Alpha particle scattering Nucleus model of Atom; observation; conclusion; Alpha-particle Trajectory; Impact Parameter (b); Number of Scattered particles; Distance of closest Approach: Estimation of Nuclear size; Atomic Model from α-Particle Scattering Experiment; Rutherford's model; Failure of Rutherford's atomic model.
- **Hydrogen Spectrum:** Introduction; The Line Spectra of the hydrogen atom: Rydberg Formula, Atomic Spectra; Spectral Series.
- **Bohr Model of the Hydrogen Atom and Bohr Model of Hydrogen Like Atoms:** Bohr's atom model, Bohr's postulates; Limitation of Bohr's model; Drawback of Bohr's Model; Bohr's model of Hydrogen Atom.
- **Energy Level:** Introduction; Ionization energy and Potential; Excitation energy and Potential.
- **De-Broglie's Explanation of Bohr's second Postulate of Quantisation.**

MIND MAP

ATOMS

- Alpha Particle Scattering and Rutherford's Nucleus Model of Atom
- Hydrogen Spectrum
  - Rydberg Formula $\frac{1}{\lambda} = RZ^2\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$
  - Spectral Series
    - Lyman series
    - Balmer series
    - Paschen series
    - Brackett series
    - Pfund series
- Bohr's Model of Hydrogen Atom and Bohr's Model of Hydrogen Like Atom
- Energy Level
  - The definite amount of energies associated with the electrons in different orbits of an atom are called the energy levels
    - Ionization Energy and Potential $E_i = +(Rch)\frac{Z^2}{n^2}$ eV
    - Excitation Energy and Potential $E_e = -R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]Z^2ch$
- De-Broglie Explanation of Bohr's Second Postulate of Quantization (Electron orbiting in circular orbit can be considered as a particle wave) $2\pi r_n = n\lambda$

Mind Map 1: Atoms at a Glance

ALPHA PARTICLE SCATTERING AND RUTHERFORD'S NUCLEUS MODEL OF ATOM

- Alpha Particle Scattering Nucleus Model of Atom
  - Alpha-particle trajectory $b = \dfrac{Ze^2 \cot\frac{\theta}{2}}{4\pi\varepsilon_0 K_\alpha}$
  - Impact parameter $b = \dfrac{Ze^2 \cot(\frac{\theta}{2})}{4\pi\varepsilon_0 \left(\frac{1}{2}mv^2\right)}$
  - Number of scattered particles $N \propto \dfrac{1}{\sin^4\left(\frac{\theta}{2}\right)}$
- Rutherford's Model of an Atom
  The entire positive charge and most of the mass of the atom is concentrated in a small volume known as nucleus with electrons
  Rutherford's Scattering formula
  $$N(\theta) = \frac{N_i ntZ^2 e^4}{(8\pi\varepsilon_0)^2 r^2 K^2 \sin^4\left(\frac{\theta}{2}\right)}$$

Mind Map 2: Reflection of Light by Spherical Mirrors

BOHR'S MODEL OF HYDROGEN ATOM AND BOHR'S MODEL OF HYDROGEN LIKE ATOM

- Bohr's Model of Hydrogen Atom
  - Bohr's postulate
    - Stationary orbit $\dfrac{mv^2}{r} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Ze(e)}{r^2}$
    - Bohr's quantization condition $I\omega = mvr = \dfrac{n\hbar}{2\pi}$
    - Bohr's frequency condition $E_2 - E_1 = h\upsilon$
- Bohr's Model of Hydrogen Like Atom
  - Bohr postulated in his H-atom model
  - Circular Orbits
  - Radius of Orbit
  - Velocity of Electron in n^{th} Orbit
  - K.E. of Electron in n^{th} Orbit
  - P.E. of Electron in n^{th} Orbit
  - Total Energy of Electron in n^{th} Orbit
  - Frequency of Emitted Radiation

Mind Map 3: Bohr's Model of Hydrogen Atom and Bohr's Model of Hydrogen Like Atom

RECAP

Alpha Particle Scattering and Rutherford's Nucleus Model of Atom

Alpha particle Scattering Nucleus Model of Atom

- On Ernest Rutherford's suggestion, in 1911, Geiger and E. Marsden performed some experiments and studied scattering of α-particles by gold foil.
- They directed a beam of 5.5 MeV α-particles emitted from a $^{214}_{83}Bi$ radioactive source at a thin gold foil. The beam was allowed to fall on a thin foil of gold of thickness 2.1×10^{-7} m. Alpha particles emitted by radioactive source were collimated into a narrow beam by passing through lead bricks.
- The scattered α-particles were received by a rotatable detector with zinc sulphide screen and a microscope. Distribution of the number of scattered particles was studied as a function of angle of scattering by flashes or scintillations produced by striking a particle on the zinc sulphide screen.

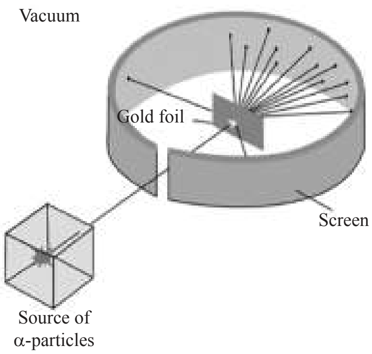


Figure: Geiger-Marsden scattering experiment

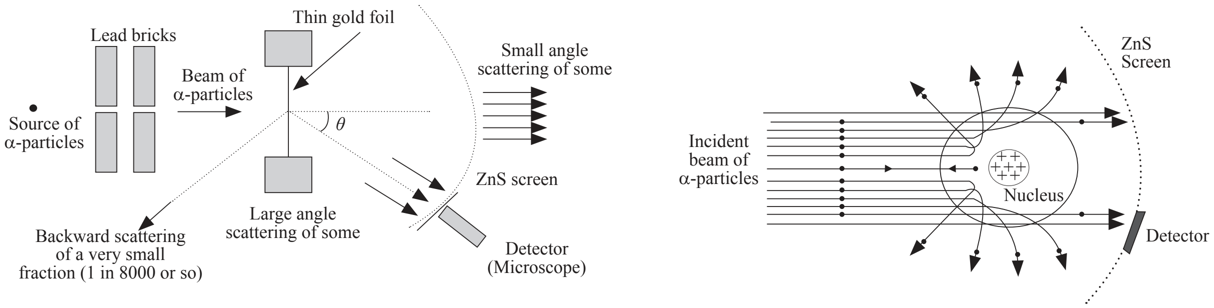
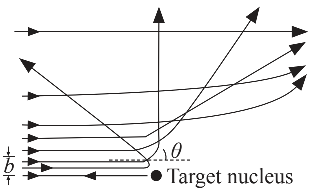


Figure: Schematic arrangement of the Geiger-Marsden experiment

- **Observation**
  - Most α-particles passed through foil without any deflection. Some of them deflected through small angles.
  - A few α-particles (1 in 1000) deflected through the angles more than 90°. Very few α-particles returned back i.e., deflected through 180°.
- **Conclusion**
  - Assumed that scattering occurs due to Coulomb interaction between positive charge of α-particle and positive charge in gold atom (located at center of atom). Since most α-particles passed undeviated, atom has lot of empty space. The α-particles passing at larger distance from positive charge in atom suffers small deviations due to small force of repulsion.
  - α-particles passing through atom nearer to positive charge experience large electrostatic force of repulsion, hence suffer large deviation. The α-particles which travel directly towards center of atom suffer deviation of 180° (due to maximum repulsive force by positive charge at center of atom).
- **Alpha-particle trajectory**
  - The trajectory traced by alpha particle depends on its impact parameter (b). Rutherford had analytically calculated the relation between the impact parameter (b) and the scattering angle θ, given by,

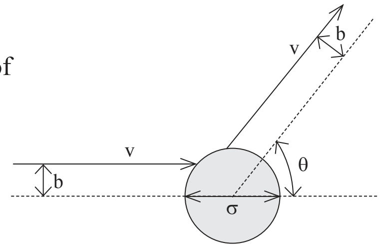


$$b=\frac{Ze^2\cot\frac{\theta}{2}}{4\pi\varepsilon_0 K_\alpha}$$

  - If $b=0$, then by above relation $\cot\frac{\theta}{2}=0$ or $\frac{\theta}{2}=90^\circ$ or $\theta=180^\circ$ i.e., in case of head on collision, the impact parameter is zero and the α-particle rebounds back.

- If $b=\infty$ then by above relation $\cot\frac{\theta}{2}=\infty$ or $\frac{\theta}{2}=0^{o}$ or $\theta=0°$ i.e., the alpha particle goes nearly undeviated for a large impact parameter.

- **Impact parameter (*b*)**
  - Perpendicular distance of velocity vector ($\vec{v}$) of α-particle from center of nucleus when it is far away from nucleus. It is given as,



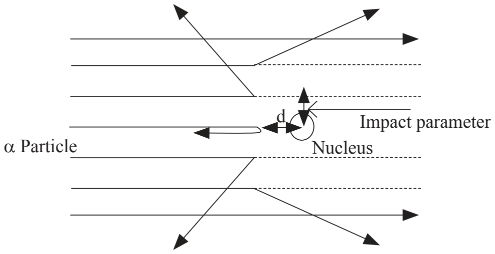
$$b=\frac{Ze^2\cot(\frac{\theta}{2})}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}$$

$$\Rightarrow b\propto\cot\left(\frac{\theta}{2}\right)$$

  - For large b, α-particles will go undeviated and for small b, α-particles will suffer large (scattering) deviation. For $b = 0$, i.e., if an α-particle has impact parameter zero, it will be scattered through 180°.

- **Number of scattered particles**
  - The relation between number of α-particle (N) scattered through an angle θ is given by,

$$N\propto\frac{1}{\sin^4\left(\frac{\theta}{2}\right)}$$



- **Distance of Closest Approach: Estimation of Nuclear Size**
  - Suppose α-particle of mass m and initial velocity v moves directly towards centre of nucleus of atom. As it approaches positive nucleus, it experiences Coulombic repulsion and its kinetic energy gets progressively converted into electrostatic potential energy.
  - At a certain distance r_0 from the nucleus, the α-particle stops for a moment and then begin to retrace its path. The distance r_0 is called the distance of closest approach.
  - Let, initial kinetic energy of α-particle, $K.B.=\frac{1}{2}mv^2$
  - Electrostatic potential energy of α-particle and nucleus at distance r_0,

$$U=\frac{q_1q_2}{4\pi\varepsilon_0r_0}=\frac{2eZe}{r_0}\frac{1}{4\pi\varepsilon_0}$$

  - At the distance r_0, $KE_\alpha = U$

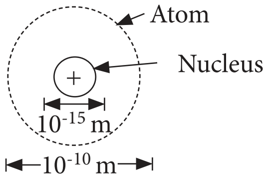
$$\frac{1}{2}mv^2=\frac{2eZe}{r_0}\frac{1}{4\pi\varepsilon_0}\Rightarrow r_0=\frac{Ze^2}{\pi\varepsilon_0mv^2}$$

  - Hence radius of nucleus must be smaller than r_0.

- **Atomic Model from α-Particle Scattering Experiment**
  - The whole positive charge of atom is concentrated in its nucleus, which is very small size compared to size of atom. Atom has a diameter of the order of 10^{-10} m, whereas nucleus has a diameter of the order of 10^{-14} m.
  - Electrons are situated in the large empty space around nucleus and are revolving, such that the centripetal force is provided by electrostatic force of attraction between electron and nucleus.
  - Atom is neutral, so the total positive charge on nucleus is equal to the total negative charge on electrons.

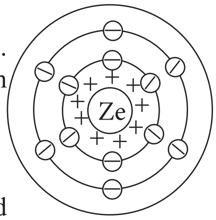
Rutherford's Model of an Atom

- On basis of results of the α-scattering experiment, Rutherford suggested following structure of the atom known as Rutherford's atomic model.
- An atom may be regarded as a sphere having a diameter of about 10^{-10} m. The entire positive charge and mass of the atom is confined to an extremely small central core called as nucleus.



Size of the nucleus = 1 Fermi = 10^{-15} m
Size of the atom = 1 Å = 10^{-10} m

- The charge on the nucleus is + Ze, where, Z is the atomic number of the element.
- The electrons (negatively charged particles) are distributed in the hollow space around the nucleus.
- Total negative charge of electrons is equal to positive charge of the nucleus. Thus, making atom electrically neutral.
- The electrons do not reside stationary around the nucleus but revolve in circular orbits,



  - Failure of Rutherford's atomic model
    - It fails to explain stability of atom. As per laws of electromagnetic theory, accelerated charge particle continuously subjected to centripetal acceleration $\frac{v^2}{r}$ should radiate energy continuously.
    - Due to this, electron loses its energy and follows spiral path, ultimately falls into nucleus. So, atomic structure should collapse but, atom is very stable entity.
    - According to this model, the spectrum of the atom must be continuous whereas practically it is a line spectrum. It could not explain the distribution of electrons outside the nucleus.

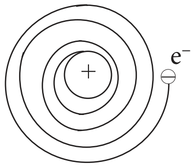


Figure: Instability of atom

Electromagnetic Spectrum

Hydrogen Spectrum

- Emission spectrum of atomic hydrogen is divided into number of **spectral series**, with wavelengths given by Rydberg formula. These observed spectral lines are due to electron transitioning between two energy levels. It is a result of Neil Bohr's description of a structure of atom and is highly relevant to even quantum theory.
- A **spectrum** is collective term for electromagnetic waves of different frequencies.

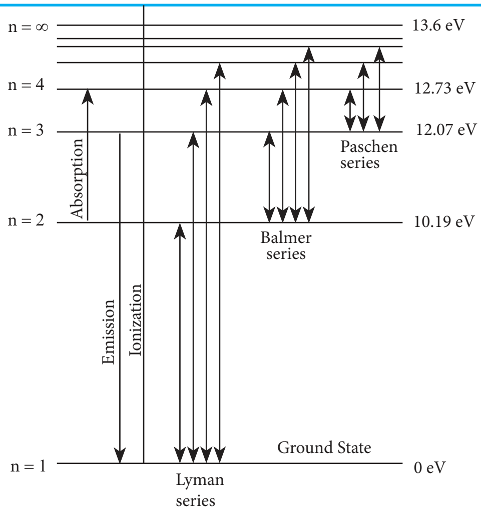


Figure: Hydrogen Spectrum

The Line Spectra of Hydrogen Atom

- Classification of series by Rydberg formula was important in quantum mechanics. The spectral series are important in astronomical spectroscopy for detecting presence of hydrogen and calculating red shifts.
- A hydrogen atom consists of an electron orbiting its nucleus. The electromagnetic force between the electron and the nuclear proton leads to a set of quantum states for the electron, each with its own energy. These states were visualized by the Bohr model of the hydrogen atom as being distinct orbits around the nucleus.

Rydberg Formula

- The energy differences between levels in the Bohr model, and hence the wavelengths of emitted/absorbed photons, is given by the Rydberg formula

$$\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

  Meaningful values are returned only when n is greater than n'. This equation is valid for all hydrogen-like species, i.e. atoms having only a single electron, and the particular case of hydrogen spectral lines are given by Z=1.

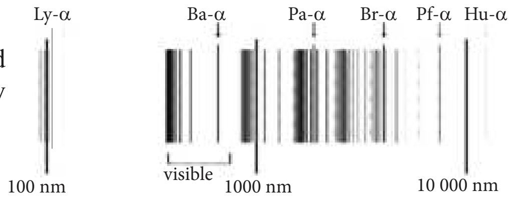


Figure: The Line Spectra of Hydrogen Atom

Atomic Spectra

- When electron jumps amongst energy levels, energy is emitted/absorbed as electromagnetic radiations and these radiations produce spectral line of frequencies (wavelength) associated

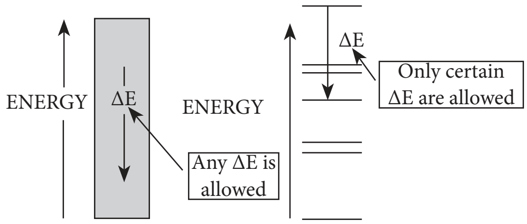


Figure: Continuous Spectraquantized Spectra with atom. **Spectroscopy** is learning and examination emission and absorption spectra associated with atom to determine its properties.

- **Spectral lines** are bright and dark line series that constitute spectrum associated with atom. An atom has a discrete spectrum (where exist a fixed specific lines of energy transition of electron with discrete energy gaps) also known as quantized spectra.
- Another type is continuous spectra (where there are no specific lines of energy transition of electrons) which is the reverse of discrete spectra.
  - **Emission spectra:**
    - Radiation spectrum produced due to absorption of energy by matter. When electron of atom, molecules or ions get to higher energy state than their ground (stable) state due to radiation absorption, they are excited.
    - Emission spectrum is produced when energy is supplied to a sample (through heating or irradiation) and the wavelength or frequency of radiation emitted by the sample is observed as a function of energy.
  - **Absorption spectra:**
    - It is just the opposite of emission spectra. Continuous radiation (energy) is directed through a sample which absorbs certain radiation of particular wavelengths and remaining spectrum is recorded. Absorbed wavelengths correspond to the dark spaces in the spectrum.
    - Whatever absent (showed by dark lines) in the emission spectrum of an atom is actually present (showed by bright lines) in the absorption spectrum of that atom.
  - **Continuous spectra:**
    - Formed when a ray of white light is passed through a prism (or water droplets) causing a continuous spectrum of visible light of different wavelength.
    - There are no discrete lines (separation) between any 2 adjacent wavelengths.
    - Speed of light changes with respect to the medium through which it passes, so as the medium changes, light with the longest wavelength (red)deviates the least and the light with the shortest wavelength (violet) deviates the most.

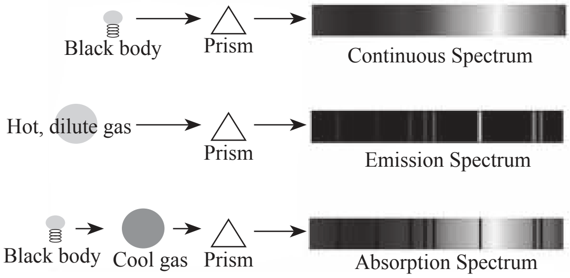
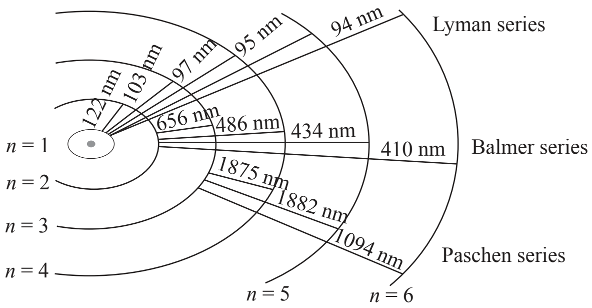


Figure: Emission Line Spectra

Spectral Series:



- On passing electric discharge through hydrogen gas, hydrogen molecules would dissociate giving rise to excited (highly energetic) hydrogen atoms that emit radiation of certain specified frequency while returning to its ground state.
- Hydrogen spectra is constituted of 5 series of spectrum named after their discoverer (Lyman, Balmer, Paschen, Bracket and Pfund series).
- **Balmer series**
  - First scientist to discover a spectral series of hydrogen atom. It consists of visible radiation spectrum.
  - Experimentally, he found that these spectral lines could be expressed mathematically in the form of wavelength as:

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

  - For maximum wavelength (λ_{max}) in the Balmer series, n = 3 (has to be minimum):

$$\frac{1}{\lambda_{max}}=R\left(\frac{1}{2^2}-\frac{1}{3^2}\right);\ \lambda_{max}=\frac{36}{5R}$$

  - For minimum wavelength (λ_{min}) in the Balmer series, $n=\infty$ (has to be minimum):

$$\frac{1}{\lambda_{min}}=R\left(\frac{1}{2^2}-\frac{1}{\infty^2}\right);\ \lambda_{min}=\frac{4}{R}$$

- **Lyman series**
  - Spectral series when radiation emitted is due to jumping of electron from higher energy to ground state.
  - Mathematically expressed as,

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

  - Here $n = 2, 3, 4\ldots$ For maximum wavelength in the Lyman series, $n = 2$ (has to be minimum):

$$\lambda_{max} = \frac{4}{3R}$$

  - For minimum wavelength in the Lyman series, $n = \infty$ (has to be minimum):

$$\lambda_{min} = \frac{1}{R}$$

  - Similarly, all other series could be expressed as:
- **Paschen Series**
  - Mathematically expressed as,

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

  - Here $n = 4, 5, 6\ldots$
- **Bracket series**
  - Mathematically expressed as,

$$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$$

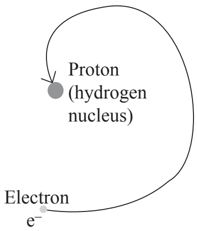
  - Here $n = 5, 6, 7\ldots$
- **Pfund series**
  - Mathematically expressed as,

$$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$$

  - Here $n = 6, 7, 8\ldots$

Bohr's Model of Hydrogen Atom and Bohr's Model of Hydrogen Like Atom

Bohr's Model of Hydrogen Atom



- Model by Rutherford assumes that atom, consisting of central nucleus and revolving electron is stable like sun-planet system. However, there are some differences between the two situations.
- While the planetary system is held by gravitational force, the nucleus-electron system being charged objects, interact by Coulomb's Law of force. We know that an object which moves in a circle is being constantly accelerated the acceleration being centripetal in nature.
- An accelerated atomic electron must spiral into the nucleus as it loses energy.
  - **Bohr's atom model**
    - In 1913, Niels Bohr modified Rutherford's atomic model on the basis of quantum theory of radiation. The new modified atomic model is called as Bohr's atomic model.
    - To explain Bohr's atomic model satisfactorily, Bohr came up with three important postulates.
  - **Bohr's postulates**
    - **Stationary orbits:**
      - The electrons, instead of revolving in any orbit around the nucleus revolve only in some specific non-radiating or stationary orbits. The mass of electrons revolving in these orbits remains constant.
      - When an electron revolves in a circular orbit, the force of attraction between an electron and the nucleus provides the necessary centripetal force for the motion of electron in circular path i.e.,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze(e)}{r^2}$$

- **Bohr's quantization condition:**
  - The electron can revolve round the nucleus only in those circular orbits in which the angular momentum of an electron is integral multiple of $\frac{\hbar}{2\neq}$ where, $\hbar$ is Planck's constant,

$$I\omega = mvr = \frac{n\hbar}{2\pi}$$

where, n = 1, 2, 3.... (an integer). The integer n is called as principle quantum number.

- **Bohr's frequency condition:**
  - The energy is radiated when an electron jumps from higher energy orbit to lower energy orbit and the energy is absorbed when it jumps from lower energy orbit to higher energy orbit.
  - If an electron suffers transition from the 2nd orbit to the 1st orbit (when $2 > 1$), the frequency υ of the radiation emitted is given as, $E_2 - E_1 = h\upsilon$, where, E_2 and E_1 are the energies of electron in the 2nd and 1st orbits respectively. This equation is called Bohr's frequency condition.

- **Limitations of Bohr's model:**
  - It failed to explain the spectra of multi-electron atoms. It could not explain the splitting of a spectral line into a number of spectra lines when the source is placed in a magnetic field and in an electric field.
  - This model is not concordant with dual nature of matter. It could not explain the binding of atoms into molecules. It could not explain the reason why atoms should combine to form chemical bonds and why molecules are more stable for such combinations.
  - No justification was given for the principle of quantization of angular momentum in Bohr's atomic model.
- **Drawback of Bohr's model:**
  - It was primarily for hydrogen atom. It couldn't elaborate spectra of multi-electron atoms.
  - Wave nature of electron was not justified by the model (inconsistent with the de Broglie's hypothesis of dual nature of matter). It didn't illustrate molecules making process of chemical reactions.
  - It violated Heisenberg's Principal ($\Delta x \times \Delta p \geq \frac{n\mathrm{h}}{2\pi}$) which said that it was impossible to evaluate the precise position and momentum of electron (and other microscopic particles) simultaneously. Only their probability could be estimated.
  - Zeeman effect (spectral lines variation due to external magnetic field) and Stark Effect (spectral lines variation due to external electric field) couldn't be described by the model.

Bohr's Model of Hydrogen Like Atom

- **Bohr postulated in his H-atom model.**
  - The electron is revolving around the nucleus in stationary orbits.
  - When an electron makes a transition from a higher orbit to a lower stable orbit, the difference in the energy of the electron is radiated as a photon of energy $h\upsilon$.
  - The angular momentum of the electron in the stationary orbits is quantised.

$$mvr = nh$$

where, $n = \frac{h}{2\pi}$

  - The Bohr model is applicable not only for hydrogen but all hydrogen-like atoms i.e., atoms which have been ionized to have a single electron revolving round the nucleus.
- **Circular Orbits**
  - The atom consists of central nucleus, containing the entire positive charge and almost all the mass of the atom. The electrons revolve around the nucleus in certain discrete circular orbits. The necessary centripetal force for circular orbits is provided by the Coulomb attraction between the electron and nucleus.
  - So, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze(e)}{r^2}$
- **Stationary Orbits**
  - The allowed orbits for the electrons are those in which the electron does not radiate energy.
- **Quantum Condition (Bohr's Quantisation Rule)**
  - The stationary orbits are those in which angular momentum of the electron is an integral multiple of,

$\frac{\hbar}{2\pi}(n)$; i.e., $mvr = n\left(\frac{\hbar}{2\pi}\right)$

n being integer or the principle quantum number.

- **Radius of Orbit**
  - Since, we have

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

And, $mvr = \frac{nh}{2\pi}$ ...(*ii*)

- Putting in (i), we get

$$r_n = \frac{n^2h^2\varepsilon_0}{\pi me^2 Z} = (0.53)\frac{n^2}{Z}\ \text{Å}$$

From(ii), $v = \frac{nh}{2\pi mr}$

So, for H-like atoms, $r_n \propto \frac{n^2}{Z}$

- **Velocity of electron in n^{th} Orbit**

Since, $v = \frac{nh}{2\pi mr}$; and $r = \frac{n^2h^2\varepsilon_0}{\pi me^2 Z}$

$$\Rightarrow v = \left(\frac{e^2}{2h\varepsilon_0}\right)\frac{Z}{n} = \left(\frac{e^2}{2h\varepsilon_0 c}\right)\left(\frac{cZ}{n}\right) = \alpha\left(\frac{cZ}{n}\right)$$

Where, $\alpha = \frac{e^2}{2h\varepsilon_0 c}$, is the Sommerfeld's fine structure constant (a pure number) whose value is $\frac{1}{137}$

$$\Rightarrow v = \left(\frac{1}{137}\right)\frac{cZ}{n}$$

i.e. velocity of electron in Bohr's first orbit is $\frac{c}{137}$ and in second orbit is and $\frac{c}{274}$ and so on.

- **Kinetic Energy (*K.E.*) Electron in n^{th} Orbits**
  - Since, we have,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2}$$

$$\Rightarrow K = \frac{1}{2}mv^2 = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

- **Potential Energy (*U*)Electron in n^{th} Orbits**

$$U = -\frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r} = -\frac{Ze^2}{4\pi\varepsilon_0 r}$$

- **Total Energy (*E*) Electron in n^{th} Orbits**
  - Total energy = K.E. + P.E.

$$\Rightarrow E = \frac{Ze^2}{8\pi\varepsilon_0 r} - \frac{Ze^2}{4\pi\varepsilon_0 r} = -\frac{Ze^2}{8\pi\varepsilon_0 r}$$

So, we conclude that total energy = −K.E.= $\frac{1}{2}$ (P.E)

Further, since

$$r = \frac{n^2h^2\varepsilon_0}{\pi me^2 z}$$

$$\Rightarrow \quad E = -\left(\frac{me^4}{8h^2\varepsilon_0^2}\right)\frac{Z^2}{n^2} = -(13.6)\frac{Z^2}{n^2}\ \text{eV}$$

$$\text{Also, } E = -\left(\frac{me^4}{8\varepsilon_0^2 ch^3}\right)ch\frac{Z^2}{n^2} = -(Rch)\frac{Z^2}{n^2}$$

$$R = \frac{me^4}{8\varepsilon_0^2 ch^3} = 1.097\times 10^7\ \text{m}^{-1}$$

$$\simeq 2.18\times 10^{-18}\ \text{J}$$

$\simeq$ 13.6 eV, is the electron energy in first orbit of H-atom.

- **Frequency of Emitted Radiation**
  - If electron makes transition (jumps) from final state n_f to initial state n_i then frequency of emitted radiation

    υ is given by

$$E_i - E_f = h\upsilon; \text{or } \upsilon = \frac{E_i - E_f}{h} = Z^2Rc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

  - If c is the speed of light and λ is the wavelength of emitted or absorbed radiation, then

$$\upsilon = \frac{c}{\lambda} = Z^2Rc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

So, wave number ($\bar{\upsilon}$) is given by

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

  - This relation holds for radiations emitted by hydrogen like atoms i.e. H (Z= 1), He^+ (Z= 2), Li^{++} (Z= 3) and Be^{+++} (Z=4). If the electron makes a transition from n = 1 to the higher states, it is absorption.

Energy Level

Introduction

- Definite amount of energies associated with electrons in different orbits of atom.
- The total energy of an electron revolving in an orbit is given by the relation,

$$E_n = -\frac{me^4Z^2}{8\varepsilon_0^2h^2n^2}$$

$$E_n = -\left[\frac{me^4}{8\varepsilon_0^2\text{ch}^3}\right]\frac{Z^2}{n^2}\text{ch}$$

$$E_n = -\text{Rch}\frac{Z^2}{n^2}$$

$$\Rightarrow E_n \propto \frac{1}{n^2}$$

Where,

$$R = \frac{me^4}{8\varepsilon_0^2\text{ch}^3} = 1.09\times 10^7/\text{m}$$

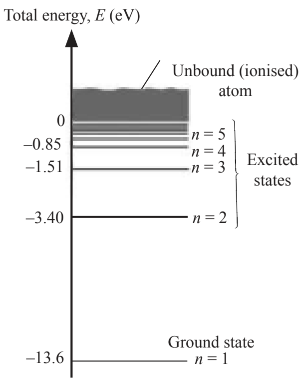


Figure : Energy level for hydrogen atom

- Energy level diagram for hydrogen atom. Electron in hydrogen atom at room temperature spends most of its time in ground state. To ionize hydrogen atom, electron from ground state, 13.6 eV of energy must be supplied. (The horizontal lines specify the presence of allowed energy states.)

Ionization Energy and Potential

- Knocking electron out of the atom is ionization. The energy required to ionize an atom is called ionization energy.
- It is the energy required to make an electron jump from the present orbit to the infinite orbit.
  Hence, ionisation energy (E_i) is,

$$E_i = E_\infty - E_n = 0 - \left(-Rch\frac{Z^2}{n^2}\right) = +(Rch)\frac{Z^2}{n^2}\ \text{eV}$$

- Ionization Potential (V_i) is potential needed to accelerate electron to acquire energy equal to ionisation energy

$$V_i = \frac{E_i}{e}$$

Excitation Energy and Potential

- **Excitation:** Absorption of energy by electron to raise from lower to higher energy level.
- **Excitation energy:** Energy required to excite an electron from its ground state to the upper state.
- The energy is given externally to the electron. The excitation energy (E_e) is,

$$E_e = E_{\text{final}} - E_{\text{inital}} = -R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]Z^2ch$$

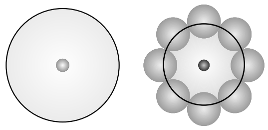
E_{initial} = Energy of electron in lower level (initial one)

- The potential difference through which electron in an atom has to be accelerated so as to just raise it from its ground state to the excited state is called excitation potential for that state.

De-Broglie Explanation of Bohr's Second Postulate of Quantization

- Electron orbiting in circular orbit can be considered as a particle wave.
- Only those waves propagate and survive which form nodes at terminal point with integer multiple of wavelength (resonant standing waves), thus, covering the whole circumferential distance of circular orbit,

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



- From de Broglie's hypothesis: $\lambda = \frac{h}{mv}$
- So, ultimately, we get: $mv_n r_n = \frac{nh}{2\pi}$
- This proved that wave-particle duality is the cause of quantized energy states.

PRACTICE TIME

Alpha Particle Scattering and Rutherford's Nucleus Model of Atom

1. Thomson's atom model could not explain ______ successfully.
(a) Ionization of particles
(b) α-particle scattering
(c) Photoelectric effect
(d) Thermionic emission

2. The first model of atom in 1898 was proposed by:
(a) Niels Bohr (b) J. J. Thomson
(c) Albert Einstein (d) Ernst Rutherford

3. According to classical theory, the path of an electron in Rutherford atomic model is:
(a) straight line
(b) parabolic
(c) circular
(d) spiral

4. Charge on an α-particle equals to:
(a) 2e (b) 4e
(c) e^4 (d) e^2

5. In Geiger-Marsden scattering experiment, the trajectory traced by an α-particle depends on:
(a) impact parameter
(b) number of scattered α-particles
(c) number of collisions
(d) none of these

6. Rutherford's atomic model was unstable because:
(a) electrons are repelled by the nucleus
(b) orbiting electrons radiate energy
(c) electrons do not remain in orbit
(d) nuclei will break down

7. To study the internal structure of the atom, Rutherford used _________.
(a) γ-rays (b) B-rays
(c) a-rays (d) cathode rays

8. In a Geiger-Marsden experiment. Find the distance of closest approach to the nucleus of a 7.7 MeV α-particle before it comes momentarily to rest and reverses its direction. (Z for gold nucleus = 79):
(a) 40 fm (b) 30 fm
(c) 20 fm (d) 10 fm

9. As one considers orbits with higher values of n in a hydrogen atom, the electric potential energy of the atom:
(a) increases (b) does not increase
(c) decreases (d) remains the same

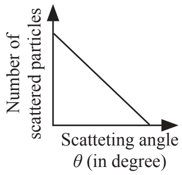
10. The α-particle scattering experiment suggests that :
(a) individual negative charge revolves around individual positive charge.
(b) positive charges are present in a dense core and the negative charges are present in the surrounding of that core.
(c) positive charge revolves around individual negative charge.
(d) positive charge and negative charge are present inside the atom in packets.

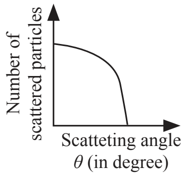
11. In the Geiger-Marsden scattering experiment, in case of head-on collision the impact parameter should be:
(a) zero (b) minimum
(c) infinite (d) maximum

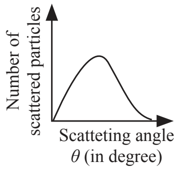
12. The significant result deduced from the Rutherford's scattering experiment is that:
(a) electrons are revolving around the nucleus
(b) electrons are embedded in the atom
(c) there are neutrons inside the nucleus
(d) whole of the positive charge is concentrated at the centre of atom

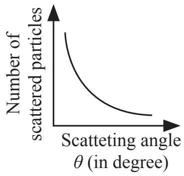
13. Rutherford's experiment on scattering of α-particles proved that:
(a) atom contains positrons
(b) number of positive charges is not equal to the number of negative charges
(c) positive charge is uniformly distributed in the atom
(d) atom is mostly empty

14. The graph of the total number of α-particles scattered at different angles in a given interval of time for α-particle scattering in the Geiger-Marsden experiment is given by:

(a)


(b)


(c)


(d)


15. Which of the following parameters is the same for all hydrogen-like atoms and ions in their ground states?
(a) Orbital angular momentum of the electron
(b) Energy of the atom
(c) Speed of the electron
(d) Radius of the orbit

16. Number of α-particles scattered in a particular direction is:
(a) inversely proportional to the square of the thickness of foil
(b) directly proportional to the square of the thickness of foil
(c) independent of the thickness of the foil
(d) directly proportional to the thickness of the foil

17. Rutherford's experiments suggested that the size of the nucleus is about :

(a) 10^{-15} m to 10^{-12} m

(b) 10^{-15} m to 10^{-13} m

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

(d) 10^{-14} m to 10^{-12} m

18. For the α-particle scattering experiment, which of the following is not true for the distance of closest approach:

(a) It specifies the nuclear dimensions

(b) At this distance, kinetic energy is greater than potential energy

(c) At this distance, entire initial kinetic energy is converted into potential energy

(d) It is proportional to the atomic number of the nucleus

19. In an atom the ratio of radius of orbit of electron to the radius of nucleus is:

(a) 10^6 (b) 10^5

(c) 10^4 (d) 10^3

20. The distance of the closest approach of an alpha particle fired at a nucleus with kinetic energy K is r_0. The distance of the closest approach when the α-particle is fired at the same nucleus with kinetic energy $2K$ will be:

(a) $2r_0$ (b) $4r_0$

(c) $\frac{r_0}{4}$ (d) $\frac{r_0}{2}$

21. The relation between the orbit radius and the electron velocity for a dynamically stable orbit in hydrogen atom is (where, all notations have their usual meanings):

(a) $r = \sqrt{\frac{ve^2}{4\pi\varepsilon_0 m}}$ (b) $v = \sqrt{\frac{e^2}{4\pi\varepsilon_0 mr}}$

(c) $v = \sqrt{\frac{4\pi\varepsilon_0}{me^2 r}}$ (d) $r = \sqrt{\frac{e^2}{4\pi\varepsilon_0 v}}$

22. When an α-particle of mass m moving with velocity v bombards on heavy nucleus of charge Ze its distance of closest approach from the nucleus depends on m as:

(a) m (b) $\frac{1}{\sqrt{m}}$

(c) $\frac{1}{m}$ (d) $\frac{1}{m^2}$

23. Rutherford proposed_________.

(a) the presence of electrons in fixed orbits around the nucleus

(b) the liquid drop model of the nucleus

(c) the planetary model of an atom

(d) the plum-pudding model of an atom

24. An α-particle of energy 5 MeV is scattered through 180° by gold nucleus. The distance of closest approach is the order of:

(a) 10^{-12} cm (b) 10^{-16} cm

(c) 10^{-10} cm (d) 10^{-14} cm

25. The volume occupied by an atom is greater than the volume of the nucleus by a factor of about:

(a) 10^{15} (b) 10^{10}

(c) 10^5 (d) 10^1

26. Rutherford's model of an atom is based on:

(a) Newton's law of gravitation

(b) study of α-particles scattering by a thin gold foil

(c) radioactivity

(d) study of spectral lines in hydrogen atom

27. Consider aiming a beam of free electrons towards free protons. When they scatter, an electron and a proton cannot combine to produce a H-atom, because of:

(a) angular momentum conservation

(b) momentum conservation

(c) simultaneously releasing energy in the form of radiation

(d) energy conservation

28. Rutherford's α-particle experiment showed that the atoms possess at the center:

(a) electrons (b) neutron

(c) nucleus (d) proton

Hydrogen Spectrum

29. The first spectral series was discovered by:

(a) Pfund (b) Paschen

(c) Lyman (d) Balmer

30. Which of the following models was successful in explaining the observed hydrogen spectrum?

(a) Classical model (b) Rutherford's model

(c) Bohr's model (d) Thomson's model

31. Which of the following spectral series falls within the visible range of electromagnetic radiation?

(a) Pfund series (b) Paschen series

(c) Balmer series (d) Lyman series

32. Information about energy levels within the atoms of a gas comes from the study of:

(a) photoelectric emission of gas
(b) fermi energy level of gas
(c) thermionic emission in gas
(d) spectrum of a gas

33. The shortest wavelength present in the Paschen series of spectral lines is:
(a) 820 nm (b) 800 nm
(c) 790 nm (d) 720 nm

34. Which of the following phenomena suggests the presence of electron energy levels in atoms?
(a) α-particle scattering
(b) Spectral lines
(c) Isotopes
(d) Radioactive decay

35. The shortest wavelength in the Balmer series is:
(a) 364.6 nm (b) 300 nm
(c) 256.8 nm (d) 200 nm

36. In hydrogen spectrum, as the energy of energy level increases, the spacing between them:
(a) increases
(b) decreases
(c) remains same
(d) cannot be predicted

37. When an electron jumps from the fourth orbit to the second orbit, one gets the:
(a) second line of Lyman series
(b) first line of Pfund series
(c) second line of Balmer series
(d) second line of Paschen series

38. If the mass of the electron is reduced to half, the Rydberg constant:
(a) becomes one fourth
(b) becomes half
(c) becomes double
(d) remains unchanged

39. The Balmer series for the H-atom can be observed:
(a) if we measure the frequencies of light emitted when an excited atom falls to the ground state
(b) if we measure the frequencies of light emitted due to transitions between excited states and the first excited state
(c) in any transition in a H-atom
(d) none of these

40. Which of the statements is correct as regards to hydrogen spectrum?
(a) There are infinite lines in ultraviolet region.
(b) There are sixteen visible lines in Balmer region.
(c) There are finite lines in Balmer series.
(d) There are finite lines in Lyman series.

41. When an atomic gas or vapour is excited at low pressure, by passing an electric current through it then:
(a) emission spectrum is observed
(b) absorption spectrum is observed
(c) band spectrum is observed
(d) both (b) and (c)

42. Which of the following is true for number of spectral lines in going from Lyman series to Pfund series?
(a) Increases
(b) Decreases
(c) May decrease or increase
(d) Unchanged

43. In Balmer series of emission spectrum of hydrogen, first four lines with different wavelength H_α, H_β, H_γ and H_δ are obtained. Which line has maximum frequency out of these?
(a) H_δ (b) H_γ
(c) H_β (d) H_α

44. Which of the following spectral series of hydrogen atom is lies in visible range of electromagnetic wave?
(a) Balmer series (b) Lyman series
(c) Pfund series (d) Paschen series

45. Hydrogen atom emits light when it changes from $n = 5$ energy level to $n = 2$ energy level. Which color of light would the atom emit?
(a) green (b) violet
(c) yellow (d) red
[*Hint: Using Lyman Series of Hydrogen Spectrum.*]

46. Which of the following is true?
(a) The spectral series formula can be derived from the Rutherford model of the hydrogen atom.
(b) Balmer series is a line spectrum in the ultraviolet.
(c) Paschen series is a line spectrum in the infrared.
(d) Lyman series is a continuous spectrum.

47. The wavelength of the first line of Lyman series is 1215 Å, the wavelength of first line of Balmer series will be:
(a) 6750 Å (b) 6561 Å
(c) 5295 Å (d) 4545 Å

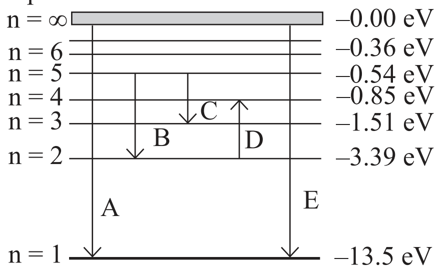
48. Which of the following transition will have highest emission wavelength?
(a) $n = 5$ to $n = 2$ (b) $n = 2$ to $n = 5$
(c) $n = 1$ to $n = 2$ (d) $n = 2$ to $n = 1$

49. The wavelength of radiation emitted is λ_0 when an electron jumps from the third to second orbit of hydrogen atom. For the electron jumping from the fourth to the second orbit of the hydrogen atom, the wavelength of radiation emitted will be:
(a) $\frac{25}{16}\lambda_0$ (b) $\frac{27}{20}\lambda_0$
(c) $\frac{20}{27}\lambda_0$ (d) $\frac{16}{25}\lambda_0$

50. Which of the following transitions in a hydrogen atom emits photon of the highest frequency?
(a) $n = 6$ to $n = 2$ (b) $n = 2$ to $n = 6$
(c) $n = 2$ to $n = 1$ (d) $n = 1$ to $n = 2$

51. The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for a hydrogen like ion. The atomic number Z of hydrogen like ion is:
(a) 2 (b) 1
(c) 4 (d) 3

52. The energy levels of the hydrogen spectrum are shown in the figure. There are some transitions *A, B, C, D* and *E*. Transition *A, B* and *C* respectively represent:



(a) Ionization potential of hydrogen, second spectral line of Balmer series and third spectral line of Paschen series.
(b) First member of Lyman series, third spectral line of Balmer series and the second spectral line of Paschen series.
(c) Series limit of Lyman series, third spectral line of Balmer series and second spectral line of Paschen series.
(d) Series limit of Lyman series, second spectral line of Balmer series and third spectral line of Paschen series.

53. Match column I (Emission Series) and column II (Make transitions from higher levels to following levels) and choose the correct combination from the given options:

	Column I		Column II
A	Balmer series	(i)	$n = 1$
B	Paschen series	(ii)	$n = 2$
C	Lyman series	(iii)	$n = 3$
D	Brackett series	(iv)	$n = 4$

(a) A-(ii), B-(iii), C-(i), D-(iv)
(b) A-(iii), B-(i), C-(iv), D-(ii)
(c) A-(i), B-(iv), C-(iii), D-(ii)
(d) A-(iv), B-(ii), C-(i), D-(iii)

54. In the following atoms and molecules for the transition from $n = 2$ to $n = 1$, the spectral line of minimum wavelength will be produced by:
(a) di-ionized lithium
(b) uni-ionized helium
(c) deuterium atom
(d) hydrogen atom

Bohr Model of the Hydrogen Atom and Bohr Model of Hydrogen Like Atoms

55. Which of the following postulates of the Bohr model led to the quantization of energy of the hydrogen atom?
(a) Quantization of energy is itself a postulate of the Bohr model.
(b) The magnitude of the linear momentum of the electron is quantized.
(c) The angular momentum of the electron can only be an integral multiple of $\frac{\hbar}{2\neq}$.
(d) The electron goes around the nucleus in circular orbits.

56. The atomic model based on quantum theory was first proposed by:
(a) Plank (b) Sommer field
(c) Bohr (d) Thomson

57. The Bohr model of atoms:
(a) predicts the same emission spectra for all types of atoms
(b) predicts continuous emission spectra for atoms
(c) uses Einstein's photoelectric equation
(d) assumes that the angular momentum of electrons is quantized

58. The fact that photons carry energy was established by:
(a) Diffraction of light (b) Bohr's theory
(c) Compton's effect (d) Doppler's effect

59. In the Bohr model of the hydrogen atom, the lowest orbit corresponds to:
(a) zero energy (b) minimum energy
(c) maximum energy (d) infinite energy

60. Bohr's atom model assumes:
(a) mass of electron remains constant
(b) electrons in a quantized orbit will not radiate energy
(c) the nucleus is of infinite mass and is at rest
(d) all the above conditions

61. Energy is absorbed in the hydrogen atom giving absorption spectra when transition takes place from:
(a) $n = 1 \to n'$ where $n' > 1$
(b) $n = 2 \to 1$
(c) $n' \to n$
(d) $n \to n' = \infty$

62. In Bohr's model of hydrogen atom, which of the following pairs of quantities are quantized?

(a) Energy but not the angular momentum
(b) Energy and angular momentum
(c) Linear and angular momentum
(d) Energy and linear momentum

63. Which of the following is not correct about Bohr model of the hydrogen atom?

(a) Bohr model is applicable to all atoms.
(b) Electron revolves around the nucleus only in those orbits for which angular momentum $L_n = \frac{n\hbar}{2\pi}$.
(c) When electron make a transition from one of its stable orbits to lower orbit then a photon emitted with energy $h\upsilon = E_f - E_i$.
(d) An electron in an atom could revolve in certain stable orbits without the emission of radiant energy.

64. The concept of stationary orbits was proposed by:

(a) Niels Bohr (b) Rutherford
(c) J.J. Thomson (d) I. Newton

65. In which of the following systems will the radius of the first orbit ($n = 1$) be minimum?

(a) hydrogen atom
(b) deuterium atom
(c) singly ionized helium
(d) doubly ionized lithium

66. The Bohr model of atom:

(a) assumes that the angular momentum of electrons is quantized
(b) uses Einstein's photo-electric equation
(c) predicts continuous emission spectra for atoms
(d) predicts the same emission spectra for all types of atoms

67. Let $E_n = \frac{-me^4}{8\varepsilon_0^2 n^2 h^2}$ be the energy of the n^{th} level of H-atom. If all the H-atoms are in the ground state and radiation of frequency $\frac{E_2 - E_1}{h}$ on it, then:

(a) all atoms will make a transition to the $n = 3$ state
(b) all atoms will be excited to the $n = 2$ state
(c) some of atoms will move to the first excited state
(d) it will not be absorbed at all

68. The ratio of the velocity of the electron in the first orbit to that in the second orbit is:

(a) 1:1 (b) 2:1
(c) 4:1 (d) 8:1

69. From quantization of angular momentum, one gets for hydrogen atom, the radius of the n^{th} orbit as

$$r_n = \left(\frac{n^2}{m_e}\right)\left(\frac{h}{2\pi}\right)^2\left(\frac{4\pi^2\varepsilon_0}{e^2}\right)$$

For a hydrogen like atom of atomic number Z:

(a) the radius of the first orbit will be the same
(b) r_n will be greater for larger Z values
(c) r_n will be smaller for larger Z values
(d) none of these

70. In Bohr's model of hydrogen atom, the period of revolution of the electron in any orbit is proportional to:

(a) cube of the quantum number
(b) square root of the quantum number
(c) square of the quantum number
(d) the quantum numbers

71. In the Bohr model of the hydrogen atom, let R, V and E represent the radius of the orbit, speed of the electron and the total energy of the electron respectively. Which of the following quantities are proportional to the quantum number?

(a) $\frac{R}{E}$ (b) RE
(c) VR (d) none of these

72. Energy of electron in an orbit of H-atom is:

(a) zero (b) positive
(c) negative (d) nothing can be said

73. In which of the following Bohr's orbit (n) a hydrogen atom emits the photons of lowest frequency?

(a) $n = 4$ to $n = 3$ (b) $n = 4$ to $n = 2$
(c) $n = 4$ to $n = 1$ (d) $n = 2$ to $n = 1$

74. When a hydrogen atom is raised from the ground state to an excited state:

(a) Potential energy increases and Kinetic energy decreases
(b) Potential energy decreases and Kinetic energy increases
(c) Both Kinetic energy and Potential energy increase
(d) Both Kinetic energy and Potential energy decrease

75. The energy required to excite an electron in hydrogen atom to its first excited state is:

(a) 13.6 eV (b) 12.7 eV
(c) 10.2 eV (d) 8.5 eV

76. In Bohr model of the hydrogen atom, the lowest orbit (nearest to nucleus) corresponds to:

(a) zero energy
(b) the minimum energy
(c) the maximum energy
(d) infinite energy

77. A triply ionized beryllium (Be^{3+}) has the same orbital radius as the ground state of hydrogen. Then the quantum state n of Be^{3+} is:
(a) $n = 4$ (b) $n = 3$
(c) $n = 2$ (d) $n = 1$

78. If an electron jumps from 1st orbital to 3rd orbital, then it will:
(a) lose –13.6 eV energy
(b) possess same energy
(c) release energy
(d) absorb energy

Energy Level

79. The relationship between kinetic energy (K) and potential energy (U) of electron moving in an orbit around the nucleus is:
(a) $U = -\frac{1}{2}K$ (b) $U = -3K$
(c) $U = -2K$ (d) $U = -K$

80. With the increase in principal quantum number, the energy difference between the two successive energy levels:
(a) sometimes increases and sometimes decreases
(b) remains constant
(c) decreases
(d) increases

81. The value of ionization energy of the hydrogen atom is:
(a) 13.6 eV (b) 12.09 eV
(c) 10.4 eV (d) 3.4 eV

82. The ratio of the energies of the hydrogen atom in its first to second excited state is:
(a) 4 (b) $\frac{9}{4}$
(c) $\frac{4}{9}$ (d) $\frac{1}{4}$

83. When an electron falls from a higher energy to a lower energy level the difference in the energies appears in the form of:
(a) both electromagnetic and thermal radiations
(b) thermal radiation only
(c) electromagnetic radiation only
(d) none of these

84. What is the energy of the ionization energy of 10 times ionized sodium atom is?
(a) 13.6×11^2 eV (b) $\frac{13.6}{11}$ eV
(c) 13.6×11 eV (d) 13.6 eV

85. An ionized H-molecule consists of an electron and two protons. The protons are separated by a small distance of the order of angstrom. In the ground state:
(a) the molecule will soon decay in to a proton and a H-atom
(b) the electron would not move in circular orbits
(c) the energy would be 2^4 times that of a H-atom
(d) none of these

86. What is the energy of the electron revolving in third orbit expressed in eV:
(a) 4 eV (b) 4.53 eV
(c) 3.4 eV (d) 1.51 eV

87. The ground state energy of hydrogen atom is –13.6 eV. The kinetic energy of the electron in this state is:
(a) 2.18×10^{-19} J (b) 2.18×10^{-18} J
(c) 2.18×10^{-16} J (d) 2.18×10^{-14} J

88. The energy of hydrogen atom in its ground state is −13.6 eV. The energy of the level corresponding to the quantum number n equals to 5 is:
(a) −0.54 eV (b) −0.85 eV
(c) −2.72 eV (d) −5.40 eV

89. The ground state energy of hydrogen atom is –13.6 eV. Find the potential energy of electron (in Joule) in the given state:
(a) -4.36×10^{-18} J (b) -4.36×10^{-17} J
(c) -4.36×10^{-16} J (d) -4.36×10^{-14} J

90. The minimum energy required to excite a hydrogen atom from its ground state is:
(a) 10.2 eV (b) 3.4 eV
(c) –13.6eV (d) 13.6 eV

91. The ratio of the speed of the electron in the ground state of hydrogen atom to the speed of light in vacuum is:
(a) $\frac{1}{237}$ (b) $\frac{1}{137}$
(c) $\frac{2}{237}$ (d) $\frac{1}{2}$

92. A hydrogen atom (ionization potential 13.6 eV) makes a transition from third excited state to first excited state. The energy of the photon emitted in the process is:
(a) 12.75 eV (b) 12.09 eV
(c) 2.55 eV (d) 1.89 eV

93. An electron is in an excited state in a hydrogen like atom. It has a total energy of -3.4 eV. The kinetic energy of the electron is E and its de Broglie wavelength is λ. Then:

(a) $E = 6.8$ eV, $\lambda = 6.6 \times 10^{-10}$ m

(b) $E = 3.4$ eV, $\lambda = 6.6 \times 10^{-10}$ m

(c) $E = 3.4$ eV, $\lambda = 6.6 \times 10^{-11}$ m

(d) $E = 6.8$ eV, $\lambda = 6.6 \times 10^{-10}$ m

94. As per Bohr model, the minimum energy (in eV) required to remove an electron from the ground state of doubly ionized Li atom ($Z = 3$) is:
(a) 122.4 (b) 40.8
(c) 13.6 (d) 1.51

95. The binding energy of an electron in the ground state of He is equal to 24.6 eV. The energy required to remove both the electrons is:
(a) 108.8 eV (b) 79 eV
(c) 54.4 eV (d) 49.2 eV

96. Minimum excitation potential of Bohr's first orbit in hydrogen atom is:
(a) 3.6 eV (b) 10.2 eV
(c) 3.4 eV (d) 13.6 eV

97. The ionization energy of Li^{++} is equal to:
(a) hcR (b) $2\ hcR$
(c) $6\ hcR$ (d) $9\ hcR$

98. In hydrogen atom if the difference in the energy of the electron in $n = 2$ and $n = 3$ orbits is E, the ionization energy of hydrogen atom is:
(a) $3.2\ E$ (b) $5.6\ E$
(c) $7.2\ E$ (d) $13.2\ E$

99. When an electron in hydrogen atom is excited from its 4^{th} to 5^{th} stationary orbit, the change in angular momentum of electron is:
(a) 2.08×10^{-34} Js (b) 1.05×10^{-34} Js
(c) 3.32×10^{-34} Js (d) 4.16×10^{-34} Js

[***Hint:*** *Planck's Constant,* $h = 6.6 \times 10^{-34}$ Js]

De-Broglie's Explanation of Bohr's second Postulate of Quantisation

100. The number of De-Broglie wavelengths contained in the second Bohr orbit of Hydrogen atom is:
(a) 4 (b) 3
(c) 2 (d) 1

101. The acronym Laser stands for:
(a) Light Amplification by Stimulated Emission of Radio-wave
(b) Light Amplification by Strong Emission of Radiation
(c) Light Amplitude by Stimulated Emission of Radiation
(d) Light Amplification by Stimulated Emission of Radiation

HIGH-ORDER THINKING SKILL

Alpha Particle Scattering and Rutherford's Nucleus Model of Atom

1. For scattering by an inverse-square field (such as that produced by a charged nucleus in Rutherford's model) the relation between impact parameter b and the scattering angle θ is given by,

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

The scattering angle for $b = 0$ is:
(a) 120° (b) 45°
(c) 90° (d) 180°

Hydrogen Spectrum

2. The radiation corresponding to 3→2 transition of hydrogen atoms falls on a metal surface to produce photoelectrons. These electrons are made to enter a magnetic field of 3×10^{-4} T. If the radius of the largest circular path followed by these electrons is 10.0 mm, work function of the metal is close to:
(a) 1.8 eV (b) 0.8 eV
(c) 1.1 eV (d) 1.6 eV

Bohr Model of the Hydrogen Atom and Bohr Model of Hydrogen Like Atoms

3. In the Auger process an atom makes a transition to a lower state without emitting a photon. The excess energy is transferred to an outer electron which may be ejected by the atom. (This is called an Auger electron). Assuming the nucleus to be massive, the kinetic energy (in keV) of an $n = 4$ Auger electron emitted by Chromium by absorbing the energy from a $n = 2$ to $n = 1$ transition is:
(a) 3.36 (b) 5.38
(c) 7.5 (d) 4.6

4. An electron in an atom jumping from 3rd orbit to 2nd orbit emits radiation of wavelength λ_1) and when it jumps from 2nd orbit to 1st orbit emits radiation of wavelength λ_2. The wavelength of radiation emitted when it jumps from 3rd orbit to 1st orbit is:
(a) $\lambda_1 + \lambda_2$
(b) $\frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$
(c) $\frac{\lambda_1 + \lambda_2}{2}$
(d) $\sqrt{\lambda_1\lambda_2}$

5. The Bohr model for the H-atom relies on the Coulombs law of electrostatics. Coulomb's law has not directly been verified for very short distances of the order of angstroms. Supposing Coulomb's law between two opposite charge $+q_1, -q_2$ is modified to:

$$|\vec{F}| = \frac{q_1q_2}{(4\pi\varepsilon_0)}\frac{1}{r^2}, r \geq R_0$$
$$= \frac{q_1q_2}{4\pi\varepsilon_0}\frac{1}{R_0^2}\left(\frac{R_0}{r}\right)^{\varepsilon}, r \leq R_0$$

Calculate in such a case, the ground state energy (in eV) of a H-atom, if $\varepsilon = 0.1$, $R_0 = 0.1\ \overset{\circ}{A}$.
(a) –23.2 eV
(b) –5.9 eV
(c) –11.4 eV
(d) –17.3 eV

Energy Level

6. If a proton had a radius R and the charge was uniformly distributed, the ground state energy (in eV) of a H-atom for $R = 0.1\ \overset{\circ}{A}$ is:
(a) –30.8
(b) –3.4
(c) –27.2
(d) –13.6

7. The half-life of a radioactive substance is 30 minutes. The time (in minutes) taken between 40% decay and 85% decay of the same radioactive substance is:
(a) 45
(b) 30
(c) 15
(d) 60

NCERT EXEMPLAR PROBLEMS

1. Taking the Bohr radius as $a_0 = 53$ pm, the radius of Li^{++} ion in its ground state, on the basis of Bohr's model, will be about:
(a) 53 pm
(b) 27 pm
(c) 18 pm
(d) 13 pm

2. The binding energy of a H-atom, considering an electron moving around a fixed nuclei (proton), is $B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ (m = electron mass). If one decides to work in a frame of reference where the electron is at rest, the proton would be moving around it. By similar arguments, the binding energy would be $B = -\frac{Me^4}{8n^2\varepsilon_0^2h^2}$ (M = proton mass). This last expression is not correct because:
(a) n would not be integral
(b) Bohr-quantisation applies only to electron
(c) the frame in which the electron is at rest is not inertial
(d) the motion of the proton would not be in circular orbits, even approximately

3. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because:
(a) of the electrons not being subject to a central force.
(b) of the electrons colliding with each other.
(c) of screening effects.
(d) the force between the nucleus and an electron will no longer be given by Coulomb's law.

4. For the ground state, the electron in the H-atom has an angular momentum = h, according to the simple Bohr model. Angular momentum is a vector and hence there will be infinitely many orbits with the vector pointing in all possible directions. In actuality, this is not true:
(a) because Bohr model gives incorrect values of angular momentum.
(b) because only one of these would have a minimum energy.
(c) angular momentum must be in the direction of spin of electron.
(d) because electrons go around only in horizontal orbits.

5. O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms:
(a) is not important because nuclear forces are short-ranged
(b) is as important as electrostatic force for binding the two atoms
(c) cancels the repulsive electrostatic force between the nuclei
(d) is not important because oxygen nucleus have equal number of neutrons and protons

6. Two H atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is:
(a) 10.20 eV (b) 20.40 eV
(c) 13.6 eV (d) 27.2 eV

7. A set of atoms in an excited state decay:
(a) in general, to any of the states with lower energy.
(b) into a lower state only when excited by an external electric field.
(c) all together simultaneously into a lower state.
(d) to emit photons only when they collide.

ASSERTION AND REASONS

Directions: In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:
(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

Alpha Particle Scattering and Rutherford's Nucleus Model of Atom

1. **Assertion:** According to electromagnetic theory an accelerated particle continuously emits radiation.
Reason: According to classical theory, the proposed path of an electron in Rutherford atom model will be parabolic.
2. **Assertion:** According to classical theory, the proposed path of an electron in Rutherford atom model will be parabolic.
Reason: According to electromagnetic theory an accelerated particle continuously emits radiation.
3. **Assertion:** In alpha particle scattering number of alpha particles undergoing head on collision is small.
Reason: Small fraction of the number of incident particles rebound back.
4. **Assertion:** Amongst alpha, beta and gamma rays, α-particle has maximum penetrating power.
Reason: The alpha particle is heavier than beta and gamma rays.
5. **Assertion:** Atoms of each element are stable and emit characteristic spectrum.
Reason: The spectrum provides useful information about the atomic structure.
6. **Assertion:** Amongst alpha, beta and gamma rays, α-particle has maximum penetrating power.
Reason: The alpha particle is heavier than beta and gamma rays.
7. **Assertion:** Most of the mass of the atom is concentrated in its nucleus.
Reason: All alpha particles striking a gold sheet are scattered in different directions.

Hydrogen Spectrum

8. **Assertion:** Hydrogen atom consists of only one electron but its emission spectrum has many lines.
Reason: Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.
9. **Assertion:** Balmer series lies in the visible region of electromagnetic spectrum.
Reason: Wavelength emission observed in Balmer region lies between 500 Å to 1000 Å.
10. **Assertion:** It is essential that all the lines available in the emission spectrum will also be available in the absorption spectrum.
Reason: The spectrum of hydrogen atom is only absorption spectrum.
11. **Assertion:** It is essential that all the lines available in the emission spectrum will also be available in the absorption spectrum.
Reason: The spectrum of hydrogen atom is only absorption spectrum.

Bohr Model of the Hydrogen Atom and Bohr Model of Hydrogen Like Atoms

12. **Assertion:** Bohr's postulate states that the electrons in stationary orbits around the nucleus do not radiate.
Reason: According to classical physics, all moving electrons radiate.
13. **Assertion:** Bohr postulated that the electrons in stationary orbits around the nucleus do not radiate energy.
Reason: According to classical physics all moving electrons radiate energy.

Energy Level

14. **Assertion:** The electron in the hydrogen atom passes from energy level n=4 to the n=1 level. The maximum and minimum number of photons that can be emitted are six and one respectively.

Reason: The photons are emitted when electron make a transition from the higher energy state to the lower energy state.

ANSWER KEYS

Practice Time

1 (b)	2 (b)	3 (c)	4 (a)	5 (a)	6 (b)	7 (c)	8 (b)	9 (a)	10 (b)
11 (b)	12 (d)	13 (d)	14 (d)	15 (a)	16 (d)	17 (c)	18 (c)	19 (b)	20 (d)
21 (b)	22 (c)	23 (c)	24 (a)	25 (a)	26 (b)	27 (d)	28 (c)	29 (d)	30 (c)
31 (c)	32 (d)	33 (a)	34 (b)	35 (a)	36 (b)	37 (c)	38 (b)	39 (b)	40 (a)
41 (a)	42 (b)	43 (a)	44 (a)	45 (b)	46 (c)	47 (b)	48 (a)	49 (c)	50 (c)
51 (a)	52 (c)	53 (a)	54 (a)	55 (c)	56 (c)	57 (d)	58 (b)	59 (b)	60 (d)
61 (a)	62 (b)	63 (a)	64 (a)	65 (d)	66 (a)	67 (c)	68 (b)	69 (c)	70 (a)
71 (c)	72 (c)	73 (d)	74 (a)	75 (c)	76 (b)	77 (c)	78 (d)	79 (c)	80 (c)
81 (a)	82 (b)	83 (c)	84 (a)	85 (b)	86 (d)	87 (b)	88 (a)	89 (a)	90 (a)
91 (b)	92 (c)	93 (b)	94 (a)	95 (b)	96 (b)	97 (d)	98 (c)	99 (b)	100 (c)
101 (d)									

High-Order Thinking Skill

1 (d)	2 (c)	3 (b)	4 (b)	5 (c)	6 (d)	7 (d)

NCERT Exemplar Problems

1 (c)	2 (c)	3 (a)	4 (a)	5 (a)	6 (a)	7 (a)

Assertion and Reason

1 (c)	2 (d)	3 (b)	4 (d)	5 (c)	6 (d)	7 (b)	8 (b)	9 (c)	10 (d)
11 (d)	12 (c)	13 (b)	14 (b)						

HINTS AND EXPLANATIONS

Practice Time

1 (b) Thomson's atomic model failed to explain how the positive charge holds on the electrons inside the atom. It also failed to explain an atom's stability. The theory did not mention anything about the nucleus of an atom. It was unable to explain the alpha particle scattering experiment of Rutherford.

2 (b) Sir J. J. Thomson proposed the first model of atom called plum pudding model of atom. According to this model, the positive charge of the atom is uniformly distributed throughout the volume of the atom and the negatively charged electrons are embedded in it like seeds in a watermelon.

3 (c) The Rutherford model shows that an atom is mostly empty space with electrons orbiting in a fixed, predictable paths. Prior to Rutherford, the popular model of the atom was the plum pudding model, popularized by J.J. Thomson. In Atoms nucleus is surrounded by negatively charged particles called electrons. The electrons revolve around the nucleus in a fixed circular path at very high speed. These fixed circular paths were termed as orbits.

4 (a) Charge on alpha particle = 2e. An alpha particle is a helium nucleus consisting of two protons and two neutrons so its charge is +2e ($e=1.602\times10^{-19}$ C).

5 (a) Trajectory of an α-particle depends on impact parameter which is the perpendicular distance of the initial velocity vector of the α-particle from the centre of the nucleus. For small impact parameter α-particle close to the nucleus suffers larger scattering.

6 (b) Rutherford's model of atom was unstable because he said that every electron revolving around a nucleus radiate energy, since every radiating energy has an acceleration, the electron would have felt inside nucleus, which results in the unstability of atom.

7 (c) Rutherford overturned Thomson's model in 1911 with his well-known gold foil experiment in which he demonstrated that the atom has a tiny and heavy nucleus. Rutherford designed an experiment to use the alpha particles emitted by a radioactive element as probes to the unseen world of atomic structure. To study the internal structure of the atom, Rutherford used alpha rays.

8 (b) Let d be the distance of closest approach.

Then by the conservation of energy.

Initial kinetic energy of incoming α-particle K = Final electric potential energy U of the system as,

$$K=\frac{1}{4\pi\varepsilon_0}\times\frac{(2e)(Ze)}{d}$$

$$\therefore \quad d=\frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{K}\ldots\text{(i)}$$

Here, $\frac{1}{4\pi\varepsilon_0}=9\times10^9\ \text{Nm}^2\text{C}^{-2}$

$Z=79$

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

$K=7.7$ MeV

$=7.7\times10^6\times1.6\times10^{-19}$ J

$=1.2\times10^{-12}$ J

Substituting these values in (i)

$$d=\frac{2\times9\times10^9\times\left(1.6\times10^{-19}\right)^2\times79}{1.2\times10^{-12}}$$

$d=3\times10^{-14}$ m

$=30$ fm $\ldots\left(\because 1\text{ fm}=10^{-15}\text{ m}\right)$

9 (a) According to the Bohr's Model orbits with higher values of n in a hydrogen atom, the electric potential energy of the atom increases.

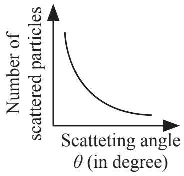
10 (b) Rutherford's alpha particle scattering experiment shows the presence of nucleus in the atom. It also gives the following important information about the nucleus of an atom. Nucleus of an atom is positively charged. Nucleus of an atom is very dense and hard. Nucleus of an atom is very small as compared to the size of the atom as a whole. Rutherford model of atom is also called Nuclear model of atom.

11 (b) At minimum impact parameter α particle rebound back ($\theta\approx\pi$) and suffers large scattering.

12 (d) In the Rutherford's scattering experiment A very small fraction of α-particles were deflected by very large angles, indicating that all the positive charge and mass of the gold atom were concentrated in a very small volume within the atom.

13 (d) Rutherford's alpha particle scattering experiment proved that the atom was mainly empty space, which cannot be allowed by the Thompson mode. Thomson's model stated that atoms are positive spheres with electrons studded in them.

14 (d) When Geiger and Marsden shot alpha particles at their metal foils, they noticed only a tiny fraction of the alpha particles were deflected by more than 90°. Most flew straight through the foil. This suggested that those tiny spheres of intense positive charge were separated by vast gulfs of empty space.



15 (a) Orbital angular momentum of the electron parameters is the same for all hydrogen-like atoms and ions in their ground states.

16 (d) Rutherford concluded that there was only one way to explain these results. He assumed that the positive charge and the mass of an atom are concentrated in a small fraction of the total volume and then derived mathematical equations for the scattering that would occur. These equations predicted that the number of α-particles scattered through a given angle should be proportional to the thickness of the foil and the square of the charge on the nucleus and inversely proportional to the velocity with which the α-particles moved raised to the fourth power.

17 (c) Rutherford's experiments suggested that the size of the nucleus is about 10^{-15} m to 10^{-14} m.

18 (c) In Rutherford's scattering experiments, alpha particles (charge = +2e) were fired at a gold foil. The alpha particle will come to rest when all its initial kinetic energy has been converted to electrical potential energy. All of the particle's initial kinetic energy is converted into electrical potential energy.

19 (b) The radius of orbit of electrons = 10^{-10} m
radius of nucleus $=10^{-15}$ m

$$\text{Ratio } = \frac{10^{-10}}{10^{-15}} = 10^5$$

Hence the radius of electron orbit is 10^5 times larger than the radius of nucleus.

20 (d) When a particle is fired towards positive target nucleus with kinetic energy K, its kinetic energy keeps on decreasing and potential energy keeps on increasing. At closest approach kinetic energy becomes zero and potential energy becomes maximum.

Let U be the potential energy at distance of closest approach r_0

$$U = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{r_0}$$

But, $K = U$

$$\text{thus, } K \propto \frac{1}{r_0}$$

$$\frac{K}{K'} = \frac{1/r_0}{1/r_0'}$$

$$\Rightarrow \frac{K}{K'} = \frac{r_0'}{r_0}$$

$$\Rightarrow \frac{r_0'}{r_0} = \frac{K}{2K} \qquad ...(\because K' = 2K)$$

$$r_0' = \frac{r_0}{2}$$

21 (b) In hydrogen atom electrostatic force of attraction (F_e) between the revolving electrons and the nucleus provides the requisite centripetal force (F_c) to keep them in their orbits. Thus,

$$F_e = F_c$$

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$\text{or, } v^2 = \frac{e^2}{4\pi\varepsilon_0 mr}$$

$$\Rightarrow v = \sqrt{\frac{e^2}{4\pi\varepsilon_0 mr}}$$

22 (c) As we know that,

$$(K.E.)_{\text{initial}} = (P.E)_{\text{closest approach}}$$

$$\frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\varepsilon_0 r_0}$$

$$\Rightarrow r_0 \propto \frac{1}{m}$$

23 (c) Rutherford proposed that electrons revolving around the nucleus are just like planets revolving around the sun.

24 (a) As we know that,

$$r_0 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E}$$

For $E = 5$ MeV

$$= 5\times10^6\times1.6\times10^{-19} \text{ J}$$

For gold, $Z = 79$

$$r_0 = \frac{9\times10^9\times2\times79\times\left(1.6\times10^{-19}\right)^2}{5\times10^6\times1.6\times10^{-19}}$$

$$= 4.55\times10^{-14} \text{ m}$$

$$= 4.55\times10^{-12} \text{ cm}$$

25 (a) According to the question

$$\frac{\text{Volume of atom}}{\text{Volume of nucleus}} = \frac{\frac{4}{3}\pi\left(10^{-10}\right)^3}{\frac{4}{3}\pi\left(10^{-15}\right)^3}$$

$$= 10^{15}$$

26 (b) Rutherford's model of an atom is based on study of α-particles scattering by a thin gold foil.

27 (d) When a beam of free electron is aimed towards free protons, the electrons get scattered on account of energy conservation.

28 (c) Rutherford concluded that since alpha particles are positively charged, for them to be deflected back, they needed a large repelling force. He then suggested the nuclear model of an atom wherein the entire positive charge and most of the mass of the atom is concentrated in the nucleus.

29 (d) In 1885, the first spectral series were observed by a Swedish school teacher Johann Jakob Balmer. This series is called the Balmer series.

30 (c) Niel Bohr proposed a model for the hydrogen atom that explained the spectrum of the hydrogen atom. The Bohr model was based on the following assumptions. The electron in a hydrogen atom travels around the nucleus in a circular orbit. The energy of the electron in an orbit is proportional to its distance from the nucleus.

31 (c) Spectral line series, any of the related sequences of wavelengths characterizing the light and other electromagnetic radiation emitted by energized atoms. Hydrogen displays five of these series in various parts of the spectrum, the best-known being the Balmer series in the visible region.

32 (d) The emission spectra are produced by thin gases in which the atoms do not experience many collisions (because of the low density). The emission lines correspond to photons of discrete energies that are emitted when excited atomic states in the gas make transitions back to lower-lying levels.

33 (a) The wavelength for Paschen series,

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

For shortest wavelength, $n=\infty$

$$\frac{1}{\lambda}=R\left[\frac{1}{9}-\frac{1}{\infty^2}\right]$$

$$=\frac{R}{9}$$

$$\lambda=\frac{9}{R}$$

$$=\frac{9}{1.097\times10^7}$$

$$=8.20\times10^{-7}\text{ m}$$

$$=820\text{ nm}$$

34 (b) Bohr's model explains the spectral lines of the hydrogen atomic emission spectrum. When the atom absorbs one or more quanta of energy, the electron moves from the ground state orbit to an excited state orbit that is further away. Energy levels are designated with the variable

35 (a) Wavelength for Balmer series is,

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

At $n=\infty$ the limit of the series observed

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

$$\frac{1}{\lambda}=\frac{R}{4}$$

$$\text{or }\lambda=\frac{4}{R}$$

Here, Rydberg's constant,

$$R=1.097\times10^7\text{ m}^{-1}$$

$$\lambda=\frac{4}{1.097\times10^7}$$

$$=364.6\times10^{-9}\text{ m}$$

$$=364.6\text{ nm}$$

36 (b) In hydrogen spectrum, as the energy of energy level increases, the spacing between them decreases.

37 (c) Jump to second orbit leads to Balmer series. When an electron jumps from 4th orbit to 2nd orbit shall give rise to second line of Balmer series.

38 (b) $R\propto m$. Thus, if mass reduces to half, then Rydberg constant also becomes half

39 (b) Balmer series for hydrogen atom can be observed by measuring the frequencies of light emitted due to the transitions between excited states and the first excited state ($n=2$).

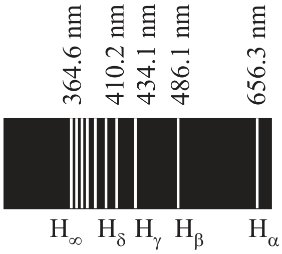
Here the sequence of frequencies with higher frequencies get closely packed.

40 (a) In Hydrogen Spectrum the Lyman series lies in the Ultraviolet region. Four of the Balmer lines are in the technically visible part of the spectrum, with wavelengths longer than 400 nm and shorter than 700 nm. Parts of the Balmer series can be seen in the solar spectrum. H-alpha is an important line used in astronomy to detect the presence of hydrogen.

41 (a) When an atomic gas or vapour is excited under low pressure by passing an electric current through it, the spectrum of the emitted radiation has specific wavelengths. It is important to note that, such a spectrum consists of bright lines on a dark background. This is an emission line spectrum.

42 (b) Maximum number of spectral lines are observed in Lyman series.

43 (a) Since out of the given four lines H_δ line has smallest wavelength. Hence the frequency of this line will be maximum.



44 (a) The radiation from excited hydrogen atoms forms a set of very regular patterns over a broad range of the electromagnetic spectrum. The sequence of spectral lines that lie in the visible range are members of the Balmer series.

45 (b) As we know that,

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

$$=R\left[\frac{1}{4}-\frac{1}{25}\right]$$

$$=\frac{21R}{100}$$

$$\lambda=\frac{100}{21R}$$

$$= \frac{100}{21 \times 1.1 \times 10^7}$$

$$= \frac{100}{23.1} \times 10^{-7} \text{ m}$$

$= 4346$ Å

46 (c) Paschen series lies in the infrared region. While Lyman and Balmer series lie in ultraviolet and visible regions respectively.

47 (b) Here, $\lambda_L = 1215$ Å

For the first line of Lyman series,

$$\frac{1}{\lambda_L} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$$

$$= R\left[1 - \frac{1}{4}\right]$$

$$= \frac{3R}{4}$$

$$\lambda_L = \frac{4}{3R} \quad ...(i)$$

For first line of Balmer series,

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

$$= R\left[\frac{1}{4} - \frac{1}{9}\right]$$

$$\frac{1}{\lambda_B} = R\left[\frac{5}{36}\right]$$

$$\lambda_B = \frac{36}{5R} \quad ...(ii)$$

From (i) and (ii) we get,

$$\frac{\lambda_B}{\lambda_L} = \frac{\frac{36}{5R}}{\frac{4}{3R}}$$

$$= \frac{36 \times 3}{4 \times 5}$$

$$\lambda_B = \frac{108}{20} \times \lambda_L$$

$$= \frac{108}{20} \times 1215$$

$= 6561$ Å

48 (a) To obtain an emission wavelength electron must transit from higher energy state to lower.

For transition from $n = 2$ to $n = 1$, energy change be E_{21} and from $n = 5$ to $n = 2$ be E_{52}

As $E_{52} < E_{21}$

and $E \propto \frac{1}{\lambda}$

$\Rightarrow \lambda_{52} > \lambda_{21}$

Hence, option (a) is correct.

49 (c)
$$\frac{\lambda}{\lambda_0} = \frac{\left[\frac{1}{2^2} - \frac{1}{3^2}\right]}{\left[\frac{1}{2^2} - \frac{1}{4^2}\right]}$$

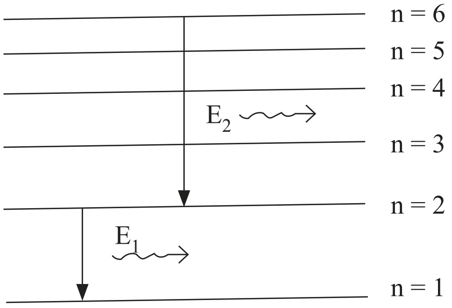
$$= \frac{5}{36} \times \frac{16}{3}$$

$$= \frac{20}{27}$$

$$\text{or } \lambda = \frac{20}{27}\lambda_0$$

50 (c) According to the Hydrogen atom,

$\therefore E_1 > E_2 \Rightarrow v_1 > v_2$



i.e., photons of higher frequency will be emitted if transition takes place from $n = 2$ to 1

51 (a) The wavelength of the first line of Lyman series for hydrogen atom is,

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

The wavelength of the second line of Balmer series for hydrogen like ion is,

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

According to question,

$$\lambda = \lambda' \quad \frac{1}{\lambda} = \frac{1}{\lambda'}$$

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

$$\text{or, } \frac{3}{4} = \frac{3Z^2}{16}$$

$$\text{or, } Z^2 = 4$$

$$\text{or, } Z = 2$$

52 (c) Transition A ($n = \infty$ to 1): Series limit of Lyman series.

Transition B ($n = 5$ to $n = 2$): Third spectral line of Balmer series.

Transition C ($n = 5$ to $n = 3$): Second spectral line of Paschen series.

53 (a) (A)→(ii), (B)→(iii), (C)→(i), (D)→(iv)

54 (a) According to the question,

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

For di-ionised lithium, the values of Z and R ($\propto me^4$) maximum.

55 (c) Bohr's quantization condition of angular momentum i.e., $L = n\frac{\hbar}{2\pi}$ led to the quantization of energy.

56 (c) The atomic model based on quantum theory was first proposed by Bohr. The Bohr model of an atom was based upon Planck's quantum theory of radiation.

57 (d) Bohr made a hypothesis that there is certain special state of motion called stationary states, in which the electron may exist without radiating electromagnetic energy. In these states, according to Bohr, the angular momentum of electrons takes values that are integer multiples of $\hbar$. In stationary states, the angular momentum of the electron may have magnitude $\hbar$, $2\hbar$, $3\hbar$ ..., but never such as 2.5 $\hbar$ or 3.1 $\hbar$. This is called the quantization of angular momentum.

58 (b) The fact that photons carry energy was established by Bohr's theory.

59 (b) In hydrogen atom, the lowest orbit corresponds to minimum energy.

60 (d) Bohr's atom model assumption is that the nucleus is of infinite mass and is at rest Electrons in a quantized orbit will not radiate energy and mass of electron remains constant.

61 (a) Absorption is from the ground state $n = 1$ to n' where $n' > 1$.

62 (b) According to Bohr's model of an atom. The total energy of electron is quantized. Angular momentum of electron is quantized. Both energy and angular momentum are observables that correspond to so-called eigenvalues.

63 (a) The three options (b) (c) and (d) are Bohr's postulates of atomic model whereas option (a) is not correct as Bohr's model is applicable to hydrogen atom only.

64 (a) Atoms absorb or emit radiation only when the electrons abruptly jump between allowed, or stationary, states. In the Bohr model of the atom, electrons travel in defined circular orbits around the nucleus. The orbits are labelled by an integer, the quantum number n.

65 (d) Radius of first orbit,

$$r \propto \frac{1}{Z}$$

For doubly ionized lithium, Z (= 3) will be maximum, hence for doubly ionized lithium, r will be minimum.

66 (a) The Bohr atom in the Bohr model postulated that electrons orbited the nucleus like planets orbiting the Sun. He managed to fit the data for hydrogen by postulating that electrons orbited the nucleus in circular orbits, and that angular momentum is quantized such that,

$$L = \frac{nh}{2\pi}, \text{ For } n = 1, 2, 3\ldots.$$

67 (c) The given energy of n^{th} level of hydrogen atom is,

$$E_n = \frac{-me^4}{8\varepsilon_0^2 n^2 h^2}$$

Since all the H-atom are in ground state (n = 1) then the radiation of given frequency $\frac{E_2 - E_1}{h}$ falling on it may be absorbed by some of the atoms and move them to the first excited state (n = 2).

68 (b) As we know that,

$$v \propto \frac{1}{n}$$

$$\frac{v_1}{v_2} = \frac{n_2}{n_1} = \frac{2}{1}$$

69 (c) For an atom with a single electron, Bohr atom model is applicable.
As the value of attraction between a proton and electron is proportional to e^2 for an ion with a single electron

$$\frac{e^2}{4\pi\varepsilon_0} \text{ is replaced by } \frac{Ze^2}{4\pi\varepsilon_0} \text{ i.e. } r_n \propto \frac{n^2}{Z}.$$

70 (a) According to the Bohr's Model of Hydrogen Atom,

$$v = \frac{2\pi r}{T}$$

$$\Rightarrow T = \frac{2\pi r}{v}$$

But, $r \propto n^2$

and $v \propto \frac{1}{n}$

$$T \propto \frac{r}{v} \propto \frac{n^2}{\left(\frac{1}{n}\right)}$$

71 (c) According to the question,

$R \propto n^2$

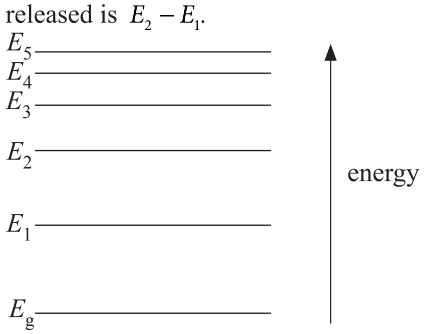
$V \propto n^{-1}$

$E \propto n^2$

72 (c) The electron in the orbit is bound to nucleus. Hence, its total energy is taken negative.

73 (d) The energy level diagram schematically looks like this. As we move to higher and higher levels, the energy increases, but the energy gap between any two levels decreases. Hence in the transition from $n = 4$ to $n = 3$, energy released will be $E_4 - E_3$.

And in the transition from n = 2 to n = 1, energy released is $E_2 - E_1$.



74 (a) For Hydrogen atom in ground State,

$$P.E. \propto -\frac{1}{r}$$

And, $K.E. \propto \frac{1}{r}$

As r increases, Kinetic energy decreases but Potential energy increases.

75 (c) As we know that,

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

In ground state energy,

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

In first excited state energy,

$$E_2 = -\frac{13.6}{2^2}$$
$$= -3.4 \text{ eV}$$

Then the required energy,

$$= E_2 - E_1$$
$$= -3.4 \text{ eV} - (-13.6 \text{ eV})$$
$$= 10.2 \text{ eV}$$

76 (b) In hydrogen atom, the lowest orbit (n = 1) corresponds to minimum energy (–13.6 eV).

77 (c) Radius of n^{th} orbit in hydrogen like atoms is,

$$r_n = \frac{a_0 n^2}{Z}$$

where a_0 is the Bohr's radius

For hydrogen atom, $Z = 1$

$\therefore\ r_1 = a_0$ ...($\because\ n = 1$ for ground state)

For Be^{3+},

$Z = 4$

$$\therefore\ r_n = \frac{a_0 n^2}{4}$$

According to given problem,

$r_1 = r_n$

$$\Rightarrow a_0 = \frac{n^2 a_0}{4}$$

$\Rightarrow\ n = 2$

78 (d) When an electron jumps from the orbit of lower energy ($n = 1$) to the orbit of higher energy ($n = 3$), energy is absorbed.

79 (c) We know that, Kinetic energy,

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r}$$

and, Potential Energy,

$$U = -\frac{e^2}{4\pi\varepsilon_0 r}$$

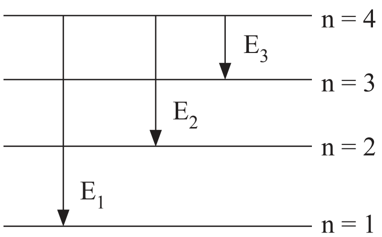
Then,

$$K = \frac{1}{2}mv^2$$
$$= \frac{e^2}{8\pi\varepsilon_0 r}$$

$\Rightarrow U = -2K$

80 (c) According to the Energy Levels,

$E_1 > E_2 > E_3$



81 (a) The minimum energy required to free the electron from the ground state of the hydrogen atom is called the ionisation energy. For hydrogen atom, its value is 13.6 eV.

82 (b) First excited state i.e., second orbit ($n = 2$)

Second excited state i.e., third orbit ($n = 3$)

$$E \propto \frac{1}{n^2}$$

$$\Rightarrow \frac{E_2}{E_3} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$$

83 (c) When an electron falls from a higher energy to a lower energy level the difference in the energies appears in the form of electromagnetic radiation only this is because electrons interact only electro-magnetically.

84 (a) According to the Ionization Energy,

$$(E_i)_{Na} = Z^2 (E_i)_H$$
$$= (11)^2 13.6 \text{ eV}$$

85 (b) An ionized H-molecule consists of an electron and two protons. The protons are separated by a small distance of the order of angstrom. In the ground state the electron would not move in circular orbits.

86 (d) As we know that,

$$E_n = -\frac{13.6}{n^2} \text{eV}$$
$$= -\frac{13.6}{(3)^2}$$
$$= -1.51 \text{ eV}$$

87 (b) Here the ground state energy,

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

Since, Kinetic energy of the electron,

$$= -E$$
$$= 13.6 \text{ eV}$$
$$= 13.6 \times 1.6 \times 10^{-19} \text{ J}$$
$$= 21.76 \times 10^{-19} \text{ J}$$
$$= 2.18 \times 10^{-18} \text{ J}$$

88 (a) As we know that the energy of Hydrogen atom is,

$$E_n = \frac{-13.6}{n^2} \text{ eV}$$
$$\Rightarrow E_5 = \frac{-13.6}{5^2}$$
$$= \frac{-13.6}{25}$$
$$= -0.54 \text{ eV}$$

89 (a) As we know that,

$$P.E. = -2K.E$$

Here, $K.E. = -E = 13.6 \text{ eV}$

$$= 13.6 \times 1.6 \times 10^{-19} \text{ J}$$
$$= 2.18 \times 10^{-18} \text{ J}$$

Hence, $P.E. = -2 \times 2.18 \times 10^{-18} \text{ J}$

$$= -4.36 \times 10^{-18} \text{ J}$$

90 (a) Minimum energy required to excite from ground state,

$$= 13.6\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$$
$$= 10.2 \text{ eV}$$

91 (b) Speed of the electron in the ground state of hydrogen atom is,

$$v = \frac{2\pi e^2}{4\pi\varepsilon_0 h}$$
$$= \frac{c}{137}$$
$$= c\alpha$$

where, c = speed of light in vacuum,

$$\alpha = \frac{e^2}{2\varepsilon_0 hc}$$

is the fine structure constant. It is a pure number whose value is, $\frac{1}{137}$

$$\therefore \frac{v}{c} = \frac{1}{137}$$

92 (c) Energy Released,

$$= 13.6\left[\frac{1}{(2)^2} - \frac{1}{(4)^2}\right]$$
$$= 2.55 \text{ eV}$$

93 (b) The potential energy = − 2 × kinetic energy = $-2E$.

Total energy = $-2E+E = -E$ = − 3.4 eV or E = 3.4 eV.

Let p = momentum and m = mass of the electron.

$$\therefore E = \frac{p^2}{2m}$$
$$\text{or } p = \sqrt{2mE}$$

De-Broglie wavelength,

$$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$

On substituting the values, we get

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$
$$= 6.6 \times 10^{-10} \text{ m}$$

94 (a) According to the Bohr's Model,

$$E = Z^2 \times (-13.6 \text{ eV})$$
$$= -9 \times 13.6 \text{ eV}$$
$$= -122.4 \text{ eV}$$

So, Ionization energy = + 122.4 eV.

95 (b) The energy needed to remove one electron from the ground state of He = 24.6 eV.

As the He^+ is now hydrogen like, ionisation energy

$$E = |-13.6| \frac{2^2}{1^2} \text{ eV}$$

$$E = 54.4 \text{ eV}$$

$\therefore$ To remove both the electrons, energy needed

$$= (54.4 + 24.6) \text{ eV}$$

$$= 79 \text{ eV}$$

96 (b) According to Bohr's spectrum for hydrogen Atom,

$$\text{Excitation potential} = \frac{\text{Excitation Energy}}{\text{e}}$$

Minimum excitation energy corresponds to excitation from $n = 1$ to $n = 2$

Minimum excitation energy in hydrogen atom $-3.4 - (-13.6) = +10.2$eV

So, Minimum excitation potential = 10.2 eV.

97 (d) Ionisation energy of $Li^{++} = 9\ hcR$

Ionisation energy $= RchZ^2 = 9\ hcR$ (as Z = 3 for Li^{++})

98 (c) Energy,

$$\mathbf{E} = K\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Where, (K = constant)

$$n_1 = 2$$

$$\text{and } n_2 = 3$$

$$\text{So, } E = K\left[\frac{1}{2^2} - \frac{1}{3^2}\right]$$

$$= K\left[\frac{5}{36}\right]$$

$$\therefore K = \frac{36E}{5}$$

For removing an electron $n_1 = 1$ to $n_2 = \infty$

Energy,

$$E_1 = K[1] = \frac{36}{5} E = 7.2\ E$$

Ionization energy = 7.2 E

99 (b) Change in the angular momentum,

$$\Delta L = L_2 - L_1$$

$$= \frac{n_2 \hbar}{2\pi} - \frac{n_1 \hbar}{2\pi}$$

$$\therefore \Delta L = \frac{\hbar}{2\pi}(n_2 - n_1)$$

$$= \frac{6.6 \times 10^{-34}}{2 \times 3.14}(5 - 4)$$

$$= 1.05 \times 10^{-34} \text{ Js}$$

100 (c) The second Bohr orbit of Hydrogen Atom is,

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

$$n = 2$$

$$2\pi r_2 = 2\lambda$$

$$= 2 \times \text{de Broglie wavelength}$$

101 (d) A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term laser originated as an acronym for light amplification by stimulated emission of radiation.

High-Order Thinking Skill

1 (d) Given $b = 0$

$$\frac{Ze^2 \cot\frac{\theta}{2}}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)} = 0$$

$$\text{or, } \cot\frac{\theta}{2} = 0$$

...[$\therefore$ All other quantities are finite]

$$\because \frac{\theta}{2} = 90^\circ$$

$$\text{or } \theta = 180^\circ$$

Which is the value expected physically for a head-on collision.

2 (c) Using,

$$r = \frac{mv}{qB}$$

$$\text{and } \frac{1}{2}mv^2 = eV_0$$

$$\Rightarrow r = \frac{\sqrt{2meV_0}}{eB}$$

$$\Rightarrow r = \frac{1}{B}\sqrt{\frac{2m}{e}V_0}$$

$$\Rightarrow V_0 = \frac{B^2r^2e}{2m}$$

$$= \frac{\left(3\times10^{-4}\right)^2 \times \left(10\times10^{-3}\right)^2 \times 1.6\times10^{-19}}{2\times9.1\times10^{-31}}$$

$$= 0.8 \text{ eV}$$

For transition between 3 to 2,

$$E = 13.6\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$= \frac{13.6\times5}{36}$$

$$= 1.88 \text{ eV}$$

Work function,

$$= 1.88 \text{ eV} - 0.8 \text{ eV}$$

$$= 1.08 \text{ eV}$$

$$\approx 1.1 \text{ eV}$$

3 (b) As the nucleus is massive, recoil momentum of the atom can be ignored. We can assume that the entire energy of transition is transferred to the Auger electron. As there is a single valence electron in chromium (Z=24), the energy states maybe thought of as given by Bohr model. The energy of the state is,

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

Where R is Rydberg constant.
In the transition from n = 2 to n = 1, energy released

$$\Delta E = -RhcZ^2\left(\frac{1}{4} - 1\right)$$

$$= \frac{3}{4}RhcZ^2$$

The energy required to eject $n = 4$ electron,

$$= RhcZ^2\left(\frac{1}{4}\right)^2$$

$$= \frac{RhcZ^2}{16}$$

$\therefore$ KE of Auger electron,

$$= \frac{3RhcZ^2}{4} - \frac{RhcZ^2}{16}$$

$$\text{K.E} = RhcZ^2\left(\frac{3}{4} - \frac{1}{16}\right)$$

$$= \frac{11}{16}\text{RhcZ}^2$$

$$= \frac{11}{16}(13.6 \text{ eV})\times24\times24 \quad ...(\because Rhc = 13.6 \text{ eV})$$

5385.6 eV

$$= 5.38 \text{ keV}$$

4 (b) According to the question,

$$\frac{1}{\lambda_1} = \left[\frac{1}{2^2} - \frac{1}{3^2}\right]RZ^2$$

$$= \frac{5}{36}RZ^2$$

$$\Rightarrow \lambda_1 = \frac{36}{5}x$$

Let $RZ^2 = x$

$$\frac{1}{\lambda_2} = \left[\frac{1}{1^2} - \frac{1}{2^2}\right]RZ^2$$

$$= \frac{3}{4}RZ^2$$

$$\Rightarrow \lambda_2 = \frac{4}{3}x$$

$$\frac{1}{\lambda_3} = \left[\frac{1}{1^2} - \frac{1}{3^2}\right]RZ^2$$

$$= \frac{8}{9}RZ^2$$

$$\Rightarrow \lambda_3 = \frac{9}{8}x$$

Comparing with given combinations

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

$$= \frac{\frac{36x}{5}\times\frac{4}{3}x}{\frac{36}{5}x + \frac{4}{3}x}$$

$$= \frac{\frac{48}{5}x^2}{\frac{(108+20)x}{15}}$$

$$= \frac{48}{5}x^2 \times \frac{15}{128x}$$

$$= \frac{36}{32}x$$

$$= \frac{9}{8}x$$

5 (c) Given, $\varepsilon = 0.1$, $R_0 = 0.1$Å
Let $\varepsilon = 2 + \delta$

$$\frac{q_1q_2}{4\pi\varepsilon_0} = \left(1.6\times10^{-19}\right)^2\left(9\times10^9\right)$$

$$= 2.3\times10^{-28} \text{ Nm}^2$$

$$\left(\frac{1}{R_0^2}\right)\left(\frac{R_0}{r}\right)^{\varepsilon} = \left(\frac{1}{R_0^2}\right)\left(\frac{R_0}{r}\right)^{2+\delta}$$

$$= \frac{R_0^\delta}{r^{2+\delta}} \quad ...(\because x = \frac{q_1q_2}{4\pi\varepsilon_0})$$

$$\text{Thus, } F = \frac{xR_0^\delta}{r^{2+\delta}}$$

$$\text{As, } F = \frac{mv^2}{r}$$

$$\Rightarrow \frac{mv^2}{r} = \frac{xR_0^\delta}{r^{2+\delta}}$$

$$\text{or } v^2 = \frac{xR_0^\delta}{mr^{1+\delta}} \quad \text{...(i)}$$

(i) As we know that,

$$\text{As } mvr = n\hbar$$

$$\Rightarrow \quad r = \frac{n\hbar}{mv}$$

$$\text{using equation (i), } r = \frac{n\hbar}{m}\left[\frac{m}{xR_0^\delta}\right]^{1/2} r^{\frac{1+\delta}{2}}$$

$$\text{or, } r^{(1-\delta)/2} = \left(\frac{n^2\hbar^2}{mxR_0^\delta}\right)^{1/2}$$

$$\ldots\left(\therefore\ r = \left(\frac{n^2\hbar^2}{mxR_0^\delta}\right)^{1/(1-\delta)}\right)$$

For $n = 1$,

$$r_1 = \left(\frac{\hbar^2}{mxR_0^\delta}\right)^{1/(1-\delta)}$$

$$= \left[\frac{\left(1.05\times10^{-34}\right)^2}{\left(9.1\times10^{-31}\right)\left(2.3\times10^{-28}\right)\left(10^{19}\right)}\right]^{\frac{1}{29}}$$

$$= 8\times10^{-11}\ \text{m}$$

$$= 0.8\ \text{Å}$$

(ii) We know,

$$\text{From } v_n = \frac{n\hbar}{mr_n}$$

$$= n\hbar\left(\frac{xR_0^\delta}{n^2\hbar^2}\right)^{\frac{1}{1-\delta}}$$

For, $n = 1$,

$$v_1 = \frac{\hbar}{mr_1}$$

$$= 1.44\times10^6\ \text{ms}^{-1}$$

(iii) Kinetic Energy is,

$$\text{K.E.} = \frac{1}{2}mv_1^2$$

$$= 9.43\times10^{-19}\ \text{J}$$

$$= 5.9\ \text{eV}$$

(iv) Potential Energy of electron from ∞ to R_0

$$U_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{R_0}\right)$$

$$= \frac{-x}{R_0}$$

Potential Energy. of electron from R_0 to r

$$U_2 = -\int_{R_0}^{r} F dr$$

$$= xR_0^\delta \int_{R_0}^{r}\frac{dr}{r^{2+\delta}}$$

$$= \frac{xR_0^\delta}{r^{(1+\delta)}}\left|\frac{1}{r^{1+\delta}}\right|_{R_0}^{r}$$

$$= \frac{-x}{(1+\delta)}\left[\frac{R_0^\delta}{r^{1+\delta}} - \frac{1}{R_0}\right]$$

Total Potential Energy of electron, P E.

$$= -\frac{x}{1+\delta}\left[\frac{R_0^\delta}{r^{1+\delta}} - \frac{1}{R_0} + \frac{1+\delta}{R_0}\right]$$

$$= \frac{-2.3\times10^{-28}}{0.9}\left[\frac{R_0^\delta}{r^{1+\delta}} - \frac{\delta}{R_0}\right]$$

$$= \frac{-2.3\times10^{-28}}{0.9}\left[\frac{R_0^{-1.9}}{r^{-0.9}} - \frac{1.9}{R_0}\right]$$

$$= \frac{-2.3\times10^{-28}}{-0.9}\left[\frac{(0.8)^{0.9}}{10^{-10\times(-1.9)}} - \frac{1.9}{10^{-10}}\right]$$

$$= \frac{2.3\times10^{-28}}{0.9\times10^{-10}}\left[(0.8)^{0.9} - 1.9\right]$$

$$= -17.3\ \text{eV}$$

Total energy, E = K E+ P E

$$= 5.9\ \text{eV} - 17.3\ \text{eV}$$

$$= -11.4\ \text{eV}$$

6 (d) In a H-atom in ground state, electron revolves round the point-size proton in a circular orbit of radius r_B (Bohr's radius).

$$mvr_B = \hbar$$

$$\text{and } \frac{mv^2}{r_B} = \frac{-1\times e\times e}{4\pi\varepsilon_0 r_B^2}$$

$$\frac{m}{r_B}\left(\frac{-\hbar^2}{m^2r_B^2}\right) = \frac{e^2}{4\pi\varepsilon_0 r_B^2}$$

$$r_B = \frac{4\pi\varepsilon_0}{e^2}\frac{\hbar^2}{m}$$

$$= 0.53\ \mathring{A}$$

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

$$= \left(\frac{m}{2}\right)\left(\frac{\hbar}{mr_B}\right)^2$$

$$= \frac{\hbar^2}{2mr_B^2}$$
$$= 13.6 \text{ eV}$$

PE of the electron and proton

$$U = \frac{1}{4\pi\varepsilon_0}\frac{e(-e)}{r_B}$$
$$= -\frac{e^2}{4\pi\varepsilon_0 r_B}$$
$$= -27.2 \text{ eV}$$

Total energy of the electron, i.e.,

$$E = \text{K.E.} + U$$
$$= +13.6 \text{ eV} - 27.2 \text{ eV}$$
$$= -13.6 \text{ eV}$$

and $R = 0.1\ \text{Å} : R < r_B$ ...(as $r_B = 0.51$ Å)

the ground state energy is the same as obtained earlier for point-size proton. i.e., −13.6 eV.

7 (d) As we know that,

$$t = \frac{T}{\log_e(2)}\left[\log_e\left(\frac{N_0}{N}\right)\right]$$
$$\therefore \quad t_1 = \frac{T}{\log_e(2)}\left[\log_e\left(\frac{N_0}{N_1}\right)\right]$$
$$t_2 = \frac{T}{\log_e(2)}\left[\log_e\left(\frac{N_0}{N_2}\right)\right]$$
$$t_2 - t_1 = \frac{T}{\log_e(2)}\left[\log_e\left(\frac{N_1}{N_2}\right)\right]$$

For 40% decay, $N_1 = 60$

For 85% decay, $N_2 = 15$

$$t_2 - t_1 = \frac{30}{\log_e(2)}\left[\log_e\left(\frac{60}{15}\right)\right]$$
$$= \frac{30}{\log_e(2)} \times \log_e(4)$$
$$= 30 \times 2$$
$$= 60 \text{ min}$$

NCERT Exemplar Problems

1 (c) As we know that,

$$r = \frac{n^2h^2}{4\pi^2 mkze^2}$$
$$= a_0\frac{n^2}{z}$$

Here z=3 and n=1 for ground state

$$r = \frac{53 \times 1^2}{3}$$
$$= 18 \text{ pm}$$

2 (c) In a hydrogen atom, electron revolving around a fixed proton nucleus have some centripetal acceleration. Therefore, its frame of reference is non- inertial. If the frame of reference, where the electron is at rest, the given expression is not true as it forms the non-inertial frame of reference.

3 (a) The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons because when we derive the formula for radius/energy levels etc, we make the assumption that centripetal force is provided only by electrostatic force of attraction by the nucleus. Hence, this will only work for single electron atoms. In multi-electron atoms, there will also be repulsion due to other electrons. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons.

4 (a) Bohr's model gives only the magnitude of angular momentum, which is a vector. Hence it does not give correct values of angular momentum of revolving electron.

5 (a) Key concept: Forces that keep the nucleons bound in the nucleus are called nuclear forces.

(i) Nuclear forces are short range forces. These do not exist at large distances greater than 10 ~ 15 m.

(ii) Nuclear forces are the strongest forces in nature.

(iii) These are attractive force and causes stability of the nucleus.

(iv) These forces are charge independent.

(v) Nuclear forces arc non-central force.

The nuclear binding force has to dominate over the Coulomb repulsive force between protons inside the nucleus. The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres.

In O_2 molecule which consists of two oxygen atoms molecules, nuclear force between the nuclei of the two atoms is not important because nuclear forces are short-ranged and act inside the nucleus only.

6 (a) Initial K.E of two hydrogen atoms in ground state 13.6 eV

K.E of both H atoms before collision $= 2 \times 13.6 = 27.2$ V

Since the collision is inelastic, linear momentum is conserved, but some K.E is lost.
If one H atom goes to first excited state and the other remain in the ground state, then their combined K.E after collision $\frac{13.6}{2^2} + \frac{13.6}{12} = 17.0$ eV

Reduction in combined,
$K.E = 27.2 - 17.0$ eV
$= 10.2$ eV

7 (a) When hydrogen atom is excited, it returns to its normal unexcited (or ground state) state by emitting the energy it had absorbed earlier. this energy is given out by the atom in the form of radiations of different wavelengths as the electron jumps down from a higher to a lower orbit. Transition from different orbits cause different wavelengths, these constitute spectral series which are characteristics of the atom emitting them. A set of atoms in an excited state decays in general to any of the states with lower energy.

Assertion and Reasons

1 (c) According to classical electromagnetic theory, an accelerated charge continuously emits radiation. As electrons revolving in circular paths are constantly experiencing centripetal acceleration, hence they will be losing their energy continuously and the orbital radius will go on decreasing and form spiral and finally the electron will fall on the nucleus.

2 (d) According to classical electromagnetic theory, an accelerated charge continuously emits radiation. As electrons revolving in circular paths are constantly experiencing centripetal acceleration, hence they will be losing their energy continuously and the orbital radius will go on decreasing and form spiral and finally the electron will fall on the nucleus.

3 (b) The number of alpha particles undergoing head on collision is small. This in turn, implies that the mass of the atom is concentrated in a small volume.

4 (d) The penetrating power is maximum in case of gamma rays because gamma rays are an electromagnetic radiation of very small wavelength.

5 (c) Sir J. J. Thomson proposed the first model of atom called plum pudding model of atom. According to this model, the positive charge of the atom is uniformly distributed throughout the volume of the atom and the negatively charged electrons are embedded in it like seeds in a watermelon.

6 (d) The penetrating power is maximum in case of gamma rays because gamma rays are an electromagnetic radiation of very small wavelength.

7 (b) At minimum impact parameter α-particles rebound back ($\theta \approx \pi$) and suffers large scattering.

8 (b) Every atom has certain definite energy level. In the normal state, the electron in the hydrogen atom stays in lowest energy level When the atom gets appropriate energy from outside, then this electron rises to some higher energy level i.e. atom is excited. Within nearly 10^{-8} s, the electron leaves the higher energy level. Now, it can return either directly to the lowest energy level (or the ground state) or come to the ground state after passing through other lower energy levels. Since there are a large number of atoms in a light source (hydrogen lamp), all possible transitions take place in the source and many lines are seen in the spectrum. The slit gives the shape of the spectrum and large number of lines are obtained because a large number of atoms are getting excited and de-excited to different energy levels.

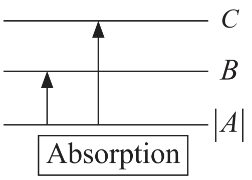
9 (c) For Balmer series,

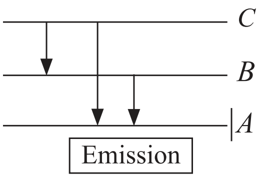
$$\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right] \quad \text{...(where, } n = 3, 4, 5.....)$$

$\lambda_{min} \approx 3646$ Å

and $\lambda_{max} \approx 6563$ Å

10 (d) Emission transitions can take place between any higher energy level and any energy level below it while absorption transitions start from the lowest energy level only and may end at any higher energy level. Hence number of absorptions transitions between two given energy levels is always less than the number of emission transitions between same two levels.





11 (d) Emission is the ability of a substance to give off light, when it interacts with heat.
Absorption is the opposite of emission, where energy, light or radiation is absorbed by the electrons of a particular matter. This produces an absorption spectrum, which has dark lines in the same position as the bright lines in the emission spectrum of an element. Atoms of individual elements emit light at only specific wavelengths, producing a line spectrum rather than the continuous spectrum of all wavelengths produced by a hot object.

12 (b) Bohr postulated that electron instead of revolving in any orbit around the nucleus, revolve only in some specific orbits. These orbits are called the non-radiating orbits or the stationary orbits. The electrons revolving in these orbits do not radiate any energy. They radiate only when they go from one orbit to the next lower orbit.

13 (b) Bohr postulated that electrons in stationary orbits around the nucleus do not radiate.
This is the one of Bohr's postulate. According to this the moving electrons radiate only when they go from one orbit to the next lower orbit.

14 (b) Maximum number of photons is given by all the transitions possible $4_{C_2} = 6$ Minimum number of transitions = 1, that is directly jump from 4 to 1.