# CHAPTER 12

# ATOMS

## Bohr's Theory and Atomic Physics

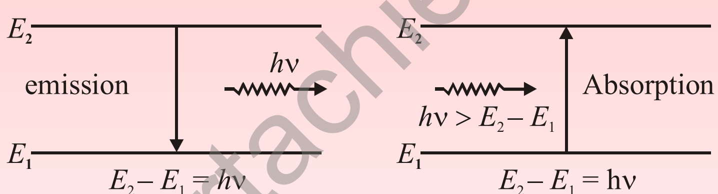
❖ **Bohr's model:**

**(a) Postulates:**

**(i)** The electrons move around the nucleus in closed orbits.

**(ii)** The orbits are stable called stationary orbits. They have special values of radii such that the angular momentum is quantized, *i.e.*, $mvr = n\hbar$ where $\hbar = \frac{h}{2\pi}$.

**(iii)** The energy is emitted when electrons make a transition from higher to lower orbit and is absorbed when electrons jump from lower to higher orbit.




**(b) Result:**

**(i)** The centripetal force is equal to electrostatic force for the radius of $n^{th}$ orbit $r_n = \frac{n^2 h^2 \epsilon_0}{\pi m z e^2}$.

**(ii)** Binding energy of $n^{th}$ orbit $E_n = \frac{m z^2 e^4}{8 \epsilon_0^2 h^2 n^2}$.

**(iii)** Velocity of electron in the $n^{th}$ orbit $v_n = \frac{2\pi z e^2}{4\pi \epsilon_0 n h} = \frac{C}{137}\frac{z}{n} = \frac{2.2 \times 10^6 z}{n}$.

**(iv)** $\alpha = \frac{2\pi e^2}{4\pi \epsilon_0 ch} = \frac{1}{137}$ is called fine structure constant.

**(v)** Angular frequency of electron $= \frac{8\pi^2 z^2 e^4 m}{(4\pi \epsilon_0)^2 n^3 h^3} = \frac{4.159 \times 10^6 z^2}{n^3}$ radian.

**(vi)** Magnetic induction produced in the $n^{\text{th}}$ orbit $B_n = \frac{\mu_0 I_n}{2r_n} = \frac{8\pi^4 z^3 e^7 mh2}{n^5 h^5 (4\pi \in_0)^3} = \frac{12.58 z^3}{n^5}$ Tesl.

**(vii)** Magnetic moment produced in the $n^{\text{th}}$ orbit $M_n = \frac{e\hbar n}{2m} = \frac{ehn}{4\pi m} = 9.26 \times 10^{-24} n \text{ Am}^2$

= n (Bohr magneton).

**(ix)** $KE$ of electron $= \frac{e^2 z^2}{8\pi \in_0 r_n} = \frac{13.6 z^2}{n^2}$ eV .

**(x)** $PE$ of electron $= -2KE = -\frac{e^2 z^2}{4\pi \in_0 r_n} = \frac{-27.2 z^2}{n^2}$.

**(xi)** $BE$ of electron $= KE + PE = E_n = -\frac{e^2 z^2}{8\pi \in_0 r_n} = \frac{-13.6 z^2}{n^2}$.

**(xii)** Ionization potential $= \frac{E_n}{e} = \frac{13.6 z^2}{n^2}$ V.

**(xiii)** Rydberg constant $R = \frac{me^4}{8 \in_0^2 Ch^3} = 1.09737 \times 10^7 m^{-1}$

❖ **De-Broglie's concept:**

The electrons revolve around the nucleus in stable circular orbits in the form of stationary waves. Only those circular orbits are possible whose circumference is integral multiple of de-Broglie's wavelength.

## Hydrogen Spectrum

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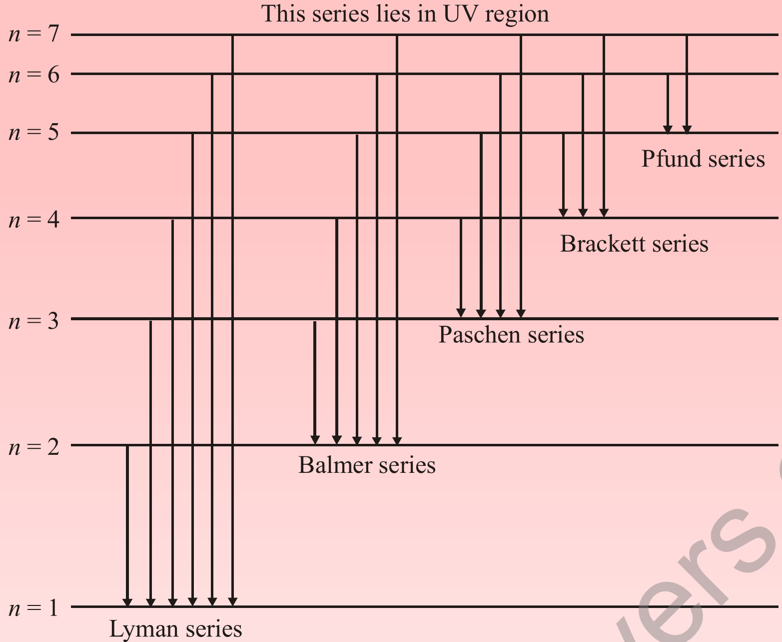
➢ $\frac{1}{\lambda} = R\left[\frac{1}{n^2} - \frac{1}{m^2}\right]$ [wave number $\nu = \frac{1}{\lambda}$ ].

(a) **Lyman series:** $\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$ $n = 1, 2, 3....$

This series lies in UV region




$\lambda_{max} = 1216 Å, \lambda_{min} = 912 Å$

It shows both emission and absorption spectrum.

(b) **Balmer series:** $\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$ $n = 3, 4, 5...$

$\lambda_{max} = 656.3\,nm, \lambda_{min} = 364.6\,nm.$

This series lies in visible region. It shows only emission spectrum.

(c) **Paschen series:** $\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n^2}\right]$ $n = 4, 5, 6...$

$\lambda_{max} = 1875.1nm$ and $\lambda_{min.} = 810.7nm.$

It lies in infrared region, and shows only emission spectrum.

(d) **Brackett series:** $\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n^2}\right]$

$\lambda_{max.} = 4047.7nm$ and $\lambda_{min.} = 1457.2$ nm.

It lies is infrared region, and shows only emission spectrum.

(v) **Pfund series:** $\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n^2}\right]$

$\lambda_{max} = 7451.5nm$ and $\lambda_{min.} = 2276.8nm.$

It lies in deep infrared region and shows only emission spectrum.

Number of spectral lines emitted $N = \frac{n(n-1)}{2}$ if the electron is in $n^{th}$ orbit.

The distance of closest approach $r_o = \frac{2ze^2}{4\pi \in_0 (KE)}$. The impact parameter $b = \frac{ze^2 \cot(\theta/2)}{4\pi \in_0 (KE)}$

.

***Example 1:*** **In a head-on collision between an α-particle and a gold nucleus, the distance of closest approach is 41.3 fermi. Calculate the energy of the particle.**

***Solution:*** Here $r_0 = 41.3\,\text{fm} = 41.3 \times 10^{-15}\,\text{m}, Z = 79, E = ?$

$$E = \frac{2kZe^2}{r_0} = \frac{2 \times 9 \times 10^9 \times 79 \times (1.6 \times 10^{-19})^2}{41.3 \times 10^{-15}}\,\text{J}$$

$$= 8.814 \times 10^{-13}\,\text{J} = \frac{8.814 \times 10^{-13}}{1.6 \times 10^{-13}}\,\text{MeV} = 5.51\,\text{MeV}.$$

***Example 2:*** **Calculate the impact parameter of a 5 MeV particle scattered by 90° when it approaches a gold nucleus.**

***Solution:*** Here $E = 5\,\text{MeV} = 5 \times 1.6 \times 10^{-13}\,\text{J}, \theta = 90°, Z = 79$

$$b = \frac{kZe^2 \cot\frac{\theta}{2}}{E} = \frac{9 \times 10^9 \times 79 \times (1.6 \times 10^{-19})^2 \cot 45°}{5 \times 1.6 \times 10^{-13}}\,\text{m} = 2.27 \times 10^{-14}\,\text{m}$$

***Example 3:*** **The wavelength of the first member of the Balmer series in hydrogen spectrum is 6563 Å. What is the wavelength of the first member of Lyman series?**

***Solution:*** Balmer series $\frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36}$

Lyman series $\frac{1}{\lambda'_1} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3R}{4}$; $\frac{\lambda'_1}{\lambda_1} = \frac{4}{3R} \times \frac{5R}{36} = \frac{20}{108} = \frac{5}{27}$

$$\lambda'_1 = \frac{5}{27} \times \lambda_1 = \frac{5}{27} \times 6563 = \mathbf{1215\ Å}$$

***Example 4:*** **The longest wavelength in the Lyman series for hydrogen is 1215Å. Calculate the Rydberg constant.**

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

For the Lyman series $n = 1$; the longest wavelength will correspond to the value $m = 2$.

$\frac{1}{1215\,Å} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$ or $R = \mathbf{1.097 \times 10^{-3}\ Å^{-1}}$

***Example 5:*** **(a) An X-ray tube produces a continuous spectrum of radiation with its short wavelength and at 0.66Å. What is the maximum energy of a photon in the radiation?**

**(b) From your answer to (a) guess what order of accelerating voltage (for electrons) is required in such a tube?**

***Solution:*** Here, $\lambda = 0.66\mathring{A} = 0.66\times10^{-10}\,\text{m}$

Now, $h = 6.62\times10^{-34}\,\text{Js}$ and $c = 3\times10^{8}\,\text{ms}^{-1}$

(a) The maximum energy of photon is given by

$$E = \frac{hc}{\lambda} = \frac{6.62\times10^{-34}\times3\times10^{8}}{0.66\times10^{-10}} = 3.01\times10^{-15}\,\text{J} \quad = \frac{3.01\times10^{-15}}{1.6\times10^{-16}} = 18.81\,keV$$

(b) To produce electrons of energy 18.81 keV, accelerating potential of 18.81 kV i.e., of the order of 20 kV is required.

## X-Rays

- X-rays were discovered by Roentgen in 1895. It is an electromagnetic radiation whose energy is greater than ultraviolet and less than the γ-rays.

Then wavelength is of the order of 1Å (0.1Å to 100Å). Their energies vary from 100eV to $10^4$ eV range.

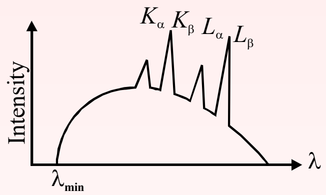
X-rays are produced in two ways:

(a) When a charged particle decelerates, em radiations are produced. (Bremsstrahlung radiations).

(b) If a particle knocks out an inner electron, then an outer electron comes to its place. The difference in the energy of the two levels is emitted in the form of X-ray. (Characteristic X-ray).

### ❖ X-rays spectrum:

The continuous background is called bremsstrahlung radiations. The peaks represent $K_\alpha$, $K_\beta$, $L_\alpha$, $L_\beta$ lines and are termed as characteristic X-ray.




Penetrating power of x-rays depends upon the accelerating potential of electron (V) or the wavelength of X-rays. The penetrating power $\alpha \frac{1}{\lambda}$.

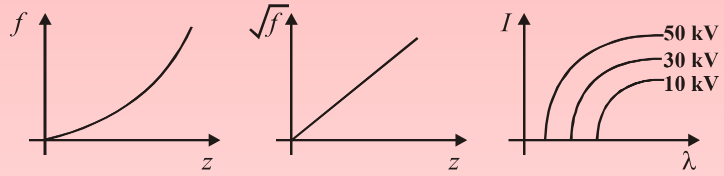
The intensity of X-rays will depend upon current through the X-rays tube or the number of electron incident per second.

- **Absorption of X-rays:**

  $I = I_0 e^{-\mu x}$ where μ is absorption coefficient $\mu \propto \lambda^2$, $\mu \propto Z^4$ where $Z$ is atomic number and λ is wavelength. Lead is the best absorber of X-rays.

- **Moseley's law:**

  $\sqrt{f} = a(z-b)$ where $f$ is frequency and $a$ and $b$ are constants.




Thus, according to Moseley's law, the basic properties of element and their place in the periodic table depends on their atomic numbers and not on atomic weights.

- **Applications of X-rays**

(a) Diagnostic tool for fracture.
(b) To treat cancer.
(c) As detectors etc.

- **Properties of X-Rays**

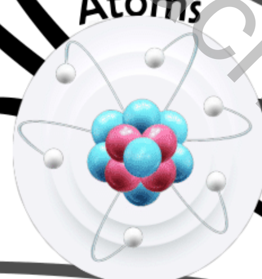
(i) X-rays being an electromagnetic wave travel with a speed equal to the speed of light.

(ii) X-rays are not responsive to electric or magnetic field.

(iii) X-rays when pass through gases, produce ionization.

(iv) X-rays can affect photographic plates and exhibit the phenomenon of fluorescence.

# Atoms



## Rutherford's Model

### Postulates
- Atoms have a central, massive, positively charged core called nucleus around which electrons revolve.
- Size of nucleus ≈ 1 fermi = $10^{-15}$ m

### Drawbacks
- Doesn't explain the stability of atom
- Doesn't explain the atomic spectra

## α – particle scattering experiment
- α- particle bombarded on thin gold foil
- Most of α– particles passed undeviated or with a small angle
- 1 out of 8000 α– particles were deflected by scattering angle

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

## Contribution
In 1898, J.J Thomson proposed the first model of atom known as plum-pudding model.
In 1911, Rutherford prepared planetary model of atom.
In 1913, Niels Bohr prepared a model of Hydrogen atom based on quantum theory.

## Energy Level
Energy of electron in each stationary orbits is

Given by $E_n = -13.6\dfrac{Z^2}{n^2}$ eV
Where $n = 1, 2, 3....$
$Z$ = atomic number of atom
- These stationary energy orbits are also called energy levels.
- When electron jumps from higher energy level to lower energy level, it releases energy.

$$\Delta E = E_f - E_i = 13.6\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]Z^2 \text{eV}$$

## Hydrogen Spectrum
- Hydrogen gas heated in a sealed tube emits radiation when passed through prism components of different wavelength appear.
- Wavelength in each series given by
  $\bar{v} = \dfrac{1}{\lambda} = R\left[\dfrac{1}{n_i^2} - \dfrac{1}{n_f^2}\right]$
  $n_f > n_i$
- Lyman series [U.V. region]
  $n_i = 1, n_f = 2, 3, 4....$
  $\lambda_{min} = 912$ Å, $\lambda_{max} = 1216$ Å
- Balmer series [visible region]
  $n_i = 2 \quad n_f = 3, 4, 5.....$
  $\lambda_{min} = 3648$ Å, $\lambda_{max} = 6563$ Å
- Paschan series [IR region]
  $n_i = 3 \quad n_f = 4, 5, 6.....$
  $\lambda_{min} = 8208$ Å, $\lambda_{max} = 18761$ Å
- Brackett series [IR region]
  $n_i = 4 \quad n_f = 5, 6, 7...$
  $\lambda_{min} = 14592$ Å $\quad \lambda_{max} = 40533$ Å
- P fund [IR region]
  $n_i = 5 \quad n_f = 6, 7, 8......$
  $\lambda_{min} = 23850$ Å $\quad \lambda_{max} = 74618$ Å

## Bohr Model

### Postulates
- Electron revolves around the nucleus in stationary orbits.
- Angular momentum of electron
  $mvr_n = n \times \dfrac{h}{2\pi}$ where, $n$ is an integer
  It is also known as principal Quantum Number.
- It explains spectrums of hydrogen or hydrogen like [$He^+$, $Li^{++}$] atoms.

### Limitations
- Fails to explain spectrum of complex atoms/ions of multi electron system.
- Doesn't explain Zeeman's and Stark's effect.

### Radius of $n^{th}$ Bohr's orbit
$$R_n = \frac{\varepsilon_0 h^2}{\pi me^2}\left(\frac{n^2}{Z}\right) = 0.53\frac{n^2}{Z} \text{Å}$$

### Velocity of electron in $n^{th}$ Bohr's orbit
$$v_n = \frac{e^2}{2\varepsilon_0 h}\left(\frac{Z}{n}\right) = 2.2 \times 10^6 \frac{Z}{n} \text{ m/s}$$

### Potential Energy
$$U_n = -\frac{KZe^2}{r_n} = \frac{-me^4}{4\varepsilon_0^2 h^2}\left(\frac{Z^2}{n^2}\right) = \frac{-27.2Z^2}{n^2} \text{eV}$$

### Kinetic Energy
$$E_k = \frac{KZe^2}{2r_n} = \frac{me^4}{8\varepsilon_0^2 h^2}\frac{Z^2}{n^2} = \frac{13.6}{n^2}Z^2 \text{eV}$$

### Total Energy
$$E = U_n + E_k = -\frac{KZe^2}{2r_n} = \frac{-13.6Z^2}{n^2} \text{eV} = \frac{U_n}{2} = -E_K$$

Trace the Mind Map
- First Level
- Second Level
- Third Level

# PRACTICE QUESTIONS

**1.** An electron collides with a hydrogen atom in its ground state and excites it to $n$=4. The energy given to hydrogen atom in this inelastic collision is (neglect the recoiling of hydrogen atom)

a) 10.2 eV  b) 12.75 eV  c) 12.5 eV  d) None of these

**2.** Excitation energy of a hydrogen like atom in its first excitation state is 54.4eV. Energy needed to remove the electron from the ion in ground state is

a) 40.8 eV  b) 27.2 eV  c) 54.4 eV  d) 13.6 eV

3. What is the relationship between the distance of closest approach for an alpha nucleus and the energy of the nucleus when it collides with a heavy nuclear target of charge Ze?

$a)\ v^2$  b) 1/m  c) $1/v^4$  d) $1/Ze$

4. The ratio of minimum to maximum wavelength in Paschen series is

a) 7:16  b) 5:36  c) 1:144  d) 3:4

5. What is the excitation energy of a hydrogen atom when its electron transitions from the ground state (-13.6 eV) to the first excited state?

a) 3.4 eV  b) 6.8 eV  c) 10.2 eV  d) zero

6. What is the energy required to remove one electron from the Balmer series of the hydrogen spectrum?

a) 13.6 eV  b) 10.2 eV  c) 3.4 eV  d) $-1.12$ eV

7. If an electron is revolving around the hydrogen nucleus at a distance of 0.2 nm, what would be its speed?

a) $2.188\times10^{6}$ ms^-1  b) $1.094 \times 10^{6}$ ms^-1  c) $4.376 \times 10^{6}$ ms^-1  d) $1.59\times 10^{6}$ ms$^{-1}$

8. What is the longest wavelength in the Lyman series of the hydrogen spectrum if the shortest wavelength is 91.2 nm?

a) 121.6 nm  b) 182.4 nm  c) 234.4 nm  d) 364.8 nm

9. If $\lambda$ is the wavelength of hydrogen atom from the transition $n$ =2 to $n$=1, then what is the wavelength for doubly ionised lithium ion for same transition?

a) $\frac{\lambda}{2}$  b) $2\lambda$  c) $\frac{\lambda}{4}$  d) $4\lambda$

10. What is the energy difference between the first and third Bohr orbits for an electron in $Li^+$ ion?

a) 36.3 eV  b) 108.8 eV  c) 122.4 eV  d) 12.1eV

11. What is the spectrum produced when white light is passed through a dilute solution of potassium permanganate?
a) Band emission spectrum
b) Line emission spectrum
c) Band absorption spectrum
d) Line absorption spectrum

12. In a hypothetical Bohr hydrogen atom, the mass of the electron is halved. The energy $E_o$ and energy $r_o$ of the first orbit will be ($a_o$ is the Bohr radius)
a) $E_o = -6.8\text{eV}; r_o = 2a_o$
b) $E_o = -27.2\text{eV}; r_o = a_o/2$
c) $E_o = -13.6\text{eV}; r_o = a_o/2$
d) $E_o = -13.6\text{eV}; r_o = a_o$

13. What is the speed of the electron in the ground state orbit of a hydrogen atom, according to the Bohr model, considering the radius of the orbit (a_0), the mass of the electron (m), the charge on the electron (e), and the vacuum permittivity (ε_0)?
a) 0
b) $\frac{e}{\sqrt{\varepsilon_0 a_0 m}}$
c) $\frac{e}{\sqrt{4\pi\varepsilon_0 a_0 m}}$
d) $\sqrt{\frac{4\pi\varepsilon_0 a_0 m}{e}}$

14. The figure indicates the energy levels of a certain atom. When the system moves from $3E$ level to $E$, a photon of wavelength $\lambda$ is emitted. The wavelength of photon produced during its transition from $\frac{2E}{3}$ level to $E$ is
a) $\frac{\lambda}{3}$
b) $\frac{3\lambda}{4}$
c) $\frac{4\lambda}{3}$
d) $3\lambda$

15. The series limit wavelength of the Balmer series for the hydrogen atom is given by
a) $1/R$
b) $R/4$
c) R/9
d) $16/R$

16. The energy of electron in the $n$th orbit of hydrogen atom is expressed as En $= \frac{-13.6}{n^2}$ eV. The amount of energy needed to transfer electron from first orbit to third orbit is

a) 12.09eV
b) 14.6eV
c) 13.6eV
d) None of these

17. In a hydrogen atom, the electron is making $3.3 \times 10^{15}\text{revs}^{-1}$ around the nucleus in an orbit of radius 0.528 Å.The magnetic moment ($\text{Am}^2$) will be
a) $5 \times 10^{-15}$
b) $5 \times 10^{-10}$
c) $5 \times 10^{-24}$
d) $5 \times 10^{-27}$

18. What is the ratio of the time taken by two electrons, moving in circular orbits of radii R and 9R respectively, to complete one revolution around the nucleus in an atom?
a) 1/3
b) 9/1
c) 27/1
d) 1/27

19. What is the change in kinetic energy (K) and potential energy (U) as the electron in a hydrogen atom Bohr orbit transitions from state n=2 to n=1?
a) $K$ two-fold, $U$ four-fold
b) $K$ four-fold, $U$ two-fold
c) $K$ four-fold, $U$ also four-fold
d) $K$ two-fold, $U$ also two-fold

20. The ionization energy of hydrogen atom is 13.6eV. Following Bohr's theory, the energy corresponding to a transition between 2nd and 3rd orbit is
a) 3.40 eV
b) 1.51 eV
c) 0.85 eV
d) 1.89 eV

21. In a hydrogen atom, the electron moves around the nucleus in a circular orbit of radius $2 \times 10^{-11}$m. Its time period is $10^{-16}$ .The current associated with the electron motion is (charge of electron is $1.6 \times 10^{-16}$ C)

a) 1.00 A b) $1.066 \times 10^{-3}$ A c) $1.81 \times 10^{-3}$ A d) $1.66 \times 10^{-3}$ A

22. What is the angle of α particle scattering in the Rutherford scattering experiment when the impact parameter is zero?

a) 90° b) 270° c) 0° d) 180°

23. An α −particle of energy 2MeV is scattered through 180° by a fixed uranium nucleus. The distance of closest approach is of the order of

a) 1 A° b) $10^{-10}$ cm c) $10^{-12}$cm d) $10^{-15}$cm

24. The ionization energy of 5time ionized sodium atom is

a) $\frac{13.6}{11}$ eV b) $\frac{0.37}{112}$ eV c) $0.37 \times (11)^2$eV d) 13.6 eV

25. What will be observed by the detector when a photon with an energy of 5.1 eV collides inelastically with a stationary hydrogen atom in its ground state, followed by another inelastic collision of a photon with an energy of 15n eV within a microsecond time interval?

a) 2 photons of energy 10.2 eV.
b) 2 photons of energy of 1.4 eV.
c) One photon of energy 10.2 eV and an electron of energy 1.4 eV
d) One photon of energy 10.2 eV and another photon of energy 1.4 eV

26. For light of wavelength 3000 Å, photon energy is nearly 1.5 eV. For $X$-rays of wavelength 1 Å, the photon energy will be close to

a)[1.5 ÷ 3000]eV b) $[1.5 \div (3000)^2]$eV c) [1.5 × 3000]eV d) $[1.5 \times (3000)^2]$eV

27. What is an example of a spectrum that can be observed from an oil flame?

a) Line emission spectrum b) Continuous emission spectrum
c) Line absorption spectrum d) Band emission spectrum

28. The ratio of the wavelengths for 4 → 1 transition in $Li^{2+}$, $He^{+}$ and H is

a) 1:1:1 b) $\frac{1}{9}:\frac{1}{4}:\frac{1}{1}$ c) 1:4:1 d) 3:2:1

29. What is the expression for the rotational energy of a diatomic molecule, composed of two masses m1 and m2 separated by a distance r, according to Bohr's rule of angular momentum quantization?

(a) $\frac{n^2h^2}{2(m_1+m_2)r^2}$ (b) $\frac{2n^2h^2}{(m_1+m_2)r^2}$

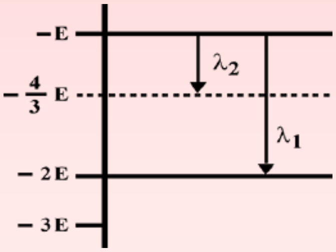
(c) $\frac{(m_1+m_2)n^2h^2}{2m_1m_2r^2}$ (d) $\frac{(m_1+m_2)^2n^2h^2}{2m_1^2m_2^2r^2}$

30. What is the ratio of the orbital speeds of electrons in different energy levels (n1 and n2) when they emit 2 and 6 spectral lines respectively?
  a) 4:3 b) 3:4 c) 2:1 d) 1:2

31. If scattering particles are 28 for 90° then at an angle 60°, it will be
  a) 112 b) 256 c) 98 d) 108

32. In the Bohr model, for an electron attracted towards the origin by a force of k/r, where k is a constant and r is the distance from the origin, the radius of the nth orbital is denoted as r_n and the kinetic energy of the electron as T_n. Which of the following statements accurately describes the relationship between r_n and T_n?
  a) $T_n \propto \frac{1}{n^2}, r_n \propto n^2$ b) $T_n$ independent of $n, r_n \propto n$
  c) $T_n \propto \frac{1}{n}, r_n \propto n$ d) $T_n \propto \frac{1}{n}, r_n \propto n^2$

33. In the given figure depicting the energy levels of a molecule, the ratio of the wavelengths (r) is defined as r = λ1 / λ2. What is the expression or value of this ratio?




a) r=4/3
b) r=2/3
c) r=3/4
d) r=1/3

34. When an electron jumps from the orbit $n = 2$ to $n = 4$, then wavelength of the radiations absorbed will be ($R$ is Rydberg's constant)
  a) $\frac{3R}{16}$ b) $\frac{5R}{16}$ c) $\frac{16}{5R}$ d) $\frac{16}{3R}$

35. Assuming the mass of earth as $6.64 \times 10^{24}$ kg and the average mass of the atoms that makes up earth as 40 u (atomic mass unit), the number of atoms in the earth is approximately
  a) $10^{30}$ b) $10^{40}$ c) $10^{50}$ d) $10^{60}$

36. The shortest wavelength which can be obtained in hydrogen spectrum is ($R = 10^7\ m^{-1}$)
$a$) 1000 Å b) 800 Å c) 1300 Å d) 2100 Å

37. The $K_\alpha$ line of singly ionised calcium has a wavelength of 393.3nm as measured on earth. In the spectrum of one of the observed galaxies, the spectral line is located at 401.8 nm. The speed with which this galaxy is moving away from us, will be
$a$) 7400 $ms^{-1}$ b) $32.4 \times 10^2$ $ms^{-1}$ c) 6480$kms^{-1}$ d) None of these

38. The binding energy of the electron in the lowest orbit of the hydrogen atom is 13.6 eV. The energies required in eV to remove an electron from the three lowest orbits of the hydrogen atom are
a) 13.6, 6.8, 8.4 b) 13.6, 10.2, 3.4 c) 13.6, 27.2, 40.8 d) 13.6, 3.4, 1.5

39. What is the radius of Iodine atom? (Atomic no.53, mass no.126)
$a$) $2.5 \times 10^{-11}$m b) $2.5 \times 10^{-9}$m c) $7 \times 10^{-9}$m d) $7 \times 10^{-11}$m

40. The spectrum of an oil flame is an example for
a) Line emission spectrum b) Continuous emission spectrum
b) Line absorption spectrum d) Band emission spectrum

------------------------ANSWER KEY---------------------------

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1) | b | 2) | c | 3) | b | 4) | a |
| 5) | c | 6) | c | 7) | d | 8) | a |
| 9) | c | 10) | b | 11) | c | 12) | a |
| 13) | c | 14) | d | 15) | b | 16) | a |
| 17) | c | 18) | d | 19) | c | 20) | d |
| 21) | d | 22) | d | 23) | c | 24) | c |
| 25) | c | 26) | c | 27) | b | 28) | a |
| 29) | c | 30) | d | 31) | a | 32) | a |
| 33) | d | 34) | d | 35) | c | 36) | a |
| 37) | c | 38) | d | 39) | a | 40) | b |

# HINTS AND SOLUTIONS

**1. (b)**

The energy taken by hydrogen atom corresponds to its transition from
n =1 to n =4 state.
$\Delta E$ (given to hydrogen atom)

$= 13.6\left(1-\frac{1}{16}\right)$

$= 13.6 \times \frac{8}{9} = 12.75\text{eV}$

**2. (c)**

The excitation energy in the first excited state is

$E = RhcZ^2\left(\frac{1}{1^2}-\frac{1}{2^2}\right) = (13.6\text{ eV}) \times Z^2 \times \frac{3}{4}$

$\therefore \quad 40.8 = 13.6 \times Z^2 \times \frac{3}{4}$

$\Rightarrow \quad Z = 2$

So, the ion in problem is $He^+$. The energy of the ion in the ground state is

$E = \frac{RhcZ^2}{1^2} = 13.6 \times 4 = 54.4\text{ eV}$

Hence, 54.4 eV is required to remove the electron from the ion.

**3. (b)**

When the target is stationary, the relative velocity between two particles at the closest approach distance is v. At this point, the alpha particle comes to an instantaneous rest. Let required distance is r, then from work energy-theorem.

$$0-\frac{mv^2}{2} = -\frac{1}{4\pi\varepsilon_0}\frac{Z_e \times Z_e}{r}$$

$$r \propto \frac{1}{m}$$
$$\propto \frac{1}{v^2}$$
$$\propto Ze^2$$

**4. (a)**

For maximum wavelength of Balmer series

$$\frac{1}{\lambda_{max}} = R\left(\frac{1}{3^2}-\frac{1}{4^2}\right) = \frac{R \times 7}{144}$$

…(i)

For minimum wavelength of Balmer series,

$$\frac{1}{\lambda_{min}} = R\left(\frac{1}{3^2}-\frac{1}{\infty}\right) = \frac{R}{9} \qquad \text{…(ii)}$$

From Eqs. (i)and (ii), we have

$$\therefore \quad \frac{\lambda_{min}}{\lambda_{max}} = \frac{R \times 7}{144} \times \frac{9}{R} = \frac{7}{16}$$

**5. (c)**

Given, ground state energy of hydrogen atom

$E_1 = -13.6\text{ eV}$

Energy of electron in first excited state ($ie$, $n$=2)

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

Therefore, excitation energy

$\Delta E = E_2 - E_1$

$= -\frac{13.6}{4} - (-13.6)$

$= -3.4 + 13.6 = 10.2\text{ eV}$

**6. (c)**

In Balmer series, $n = 2$

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

**7. (d)**

Electrostatic force = centripetal force

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

$$\therefore \quad v = \sqrt{\left(\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{mr}\right)}$$

$$= \sqrt{\frac{9\times10^9 \times (1.6\times10^{-19})^2}{(9.1\times10^{-31})\times(0.2\times10^{-9})}}$$

$$= 1.12 \times 10^6\text{ms}^{-1}$$

**8. (a)**

The wavelength ($\lambda$) of lines is given by

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

For Lyman series, the shortest wavelength is for $n$=∞ and longest is for $n$=2.

$$\therefore \quad \frac{1}{\lambda_s} = R\left(\frac{1}{1^2}\right) \qquad \text{... (i)}$$

$$\frac{1}{\lambda_L} = R\left(\frac{1}{1}-\frac{1}{2^2}\right) = \frac{3}{4}R \qquad \text{…(ii)}$$

Dividing Eq.(ii) by Eq. (i) , we get

$$\frac{\lambda_L}{\lambda_s} = \frac{4}{3}$$

Given $\lambda_s$=91.2 nm

$\Rightarrow$ $\lambda_L = 91.2 \times \frac{4}{3} = 121.6\text{nm}$

**9. (c)**

For wavelength

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

Here, transition is same

So, $\lambda \propto \frac{1}{Z^2}$

$$\frac{\lambda_H}{\lambda_{Li}} = \frac{(Z_{Li})^2}{(Z_H)^2} = \frac{4}{(1)^2} = 4$$

$$\lambda_{Li} = \frac{\lambda_H}{4} = \frac{\lambda}{4}$$

**10. (b)**

$$\Delta E = 13.6Z^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

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

=108.8 eV

11. (c)

when light is passed through the solution then some part of the complete electromagnetic spectrum will be absorbed by the solution. So, the emitted spectrum will have some missing E.M. waves of frequency corresponding to what has been absorbed by the solution. So, the emergent light produced will be Band Absorption Spectrum

**12. (a)**

As $r \propto \frac{1}{m}$

$$\therefore r_0 = \frac{2}{1}a_0$$

As $E \propto m$

$$\therefore E_0 = \frac{(-13.6)}{2}$$

$= -6.8$ eV

**13. c)**

Centripetal force=force of attraction of nucleus on electron

$$\frac{mv^2}{a_0} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a_0^2}$$

$$v = \frac{e}{\sqrt{4\pi\varepsilon_0 m a_0}}$$

**14. (d)**

In the first case, energy emitted,

$E_1 = 3E - E = 2E$

In the second case, energy emitted

$$E_2 = \frac{5E}{3} - E = \frac{2E}{3}$$

As $E_3$ is $\frac{1}{3}$rd, $\lambda_2$must be 3 times, ie, $3\lambda$

**15. (b)**

For Balmer series, $n_1 = 2, n_2 = \infty$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right) = \frac{R}{4}$$

**16. (a)**

Using $E = -13.6/n^2$

For n = 1, E1=−13.6

=−13.6eV

and

for n = 3, E3=−13.6/9

=−1.51eV

So required energy

=E3−E1=

−1.51−(−13.6) =12.09eV

**17. (c)**

Current, $I = 3.3 \times 10^{15} \times 1.6 \times 10^{-19}$

$= 5.28 \times 10^{-4}$ A

Area $A = \pi R^2 = 3.142 \times (0.528)^2 \times 10^{-20}\ m^2$

So, magnetic moment $M = IA = 5.28 \times 10^{-4} \times 3.142 \times (0.528)^2 \times 10^{-20}$

$= 4.6 \times 10^{-24}$ units

**18. (d)**

$$\frac{R_1}{R_2}=\frac{n_1^2}{n_2^2}=\frac{1}{9}\therefore\frac{n_1}{n_2}=\frac{1}{3}$$

$$\frac{T_1}{T_2}=\left(\frac{n_1}{n_2}\right)^3=\left(\frac{1}{3}\right)^3=\frac{1}{27}$$

**19. (c)**

As $U=2E, K=-E$

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

Hence, $K$ and $U$ change as four-fold each.

**20. (d)**

$E=E_3-E_2$

$$=-\frac{13.6}{3^2}-\left(-\frac{13.6}{2^2}\right)=-1.51+3.4$$

$$=1.89\text{ eV}$$

21. *(d)*

*The charge of electron=*

$$q=1.6\times10^{-19}\text{ C}$$

time period t = $10^{-16}$

i= q/t

current = $1.6\times10^{-19}/10^{-16}$

*= 1.6 mA*

**22. (d)**

Impact parameter b $\propto\cot\frac{\theta}{2}$

Here $b$=0, hence, $\theta=180^0$

**23. (c)**

$$r_0=\frac{(Ze)(2e)}{4\pi\varepsilon_0(E)}$$

$$=\frac{2\times92(1.6\times10^{-19})^2\times9\times10^9}{2\times1.6\times10^{-13}}$$

$$=1.32\times10^{-14}\text{m}\approx10^{-12}\text{cm}$$

**24. (c)**

The energy of $n$th orbit of hydrogen like atom is,

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

Here, $Z=11$ for Na atom. 5 electrons are removed already. For the last electron to be removed $n$=6.

$$\therefore E_n=\frac{-13.6\times(11)^2}{(6)^2}\text{ eV}$$

$$=-0.37\times(11)^2\text{ eV}$$

**25. (c)**

The first photon will excite the hydrogen atom (in ground state) in first excited state (as $E_2-E_1-5.1$ eV). Hence, during de-excitation a photon of 10.2 eV will be released. The second photon of energy 15 eV can ionize the atom. Hence the balance energy *ie*,
$(15-13.6)$ eV = 1.4 eV is retained by the electron.
Therefore, by the second photon an electron of energy 1.4 eV will be released.

**26. (c)**

As energy $\propto\frac{1}{\lambda}$,

Therefore, energy corresponding to 1 Å = 1.5 × 3000 eV

**27. (b)**

Since spectrum of an oil flame consists of continuously varying wavelength in a definite

**28. (a)**

From Bohr's formula, the wave number $\left(\frac{1}{\lambda}\right)$ is given by

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

where $Z$ is atomic number, $R$ the Rydberg's constant and $n$ the quantum number.

⇒ $\lambda \propto \frac{1}{Z^2}$

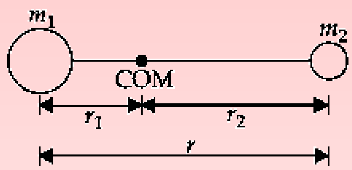
Atomic number of lithium is 3, of helium is 2 and of hydrogen is 1.

∴ $\lambda_{Li^{2+}} : \lambda_{He^{+}} : \lambda_{H} = \frac{1}{(4)^2} : \frac{1}{(4)^2} : 1/(4)^2$

$= 1:1:1$

**29. (c)**

A diatomic molecule consists of two atoms of masses m1 and m2 at a distance r apart. Let r1 and r2 be the distances of the atoms from the centre of mass.




The moment of inertia of this molecule about an axis passing through its centre of mass and perpendicular to a line joining the atoms is

$$I = m_1 r_1^2 + m_2 r_2^2$$

As $m_1 r_1 = m_2 r_2$ or $r_1 = \frac{m_2}{m_1} r_2$

$\because \quad r_1 + r_2 = r$

$\therefore \quad r_1 = \frac{m_2}{m_1}(r - r_1)$

On rearranging, we get

$$r_1 = \frac{m_2 r}{m_1 + m_2}$$

Similarly, $r_2 = \frac{m_1 r}{m_1 + m_2}$

Therefore, the moment of inertia can be written as

**1. (d)**

**30. (a)**

Number of emitted spectral lines

$$N = \frac{n(n-1)}{2}$$

Case I

$$N = 3$$

∴ $3 = \frac{n_1(n_1 - 1)}{2}$

⇒ $n_1^2 - n_1 - 6 = 0$

$(n_1 - 3)(n_1 + 2) = 0$

$n_1 = 3$

Case II

$$N = 6$$

$6 = \frac{n_2(n_2 - 1)}{2}$

$n_2^2 - n_2 - 12 = 0$

⇒ $(n_2 - 4)(n_2 + 3) = 0$

$n_2 = 4\,, n_2 = -3$

Again, as $n_2$ is always positive

∴ $n_2 = 4$

Velocity of electron $v = \frac{Ze^2}{2\varepsilon_0 hn}$

∴ $\frac{v_1}{v_2} = \frac{n_2}{n_1}$

⇒ $\frac{v_1}{v_2} = \frac{4}{3}$

**31. (a)**

Radius of orbit

$$r_n = \frac{n^2h^2}{4\pi^2 k^2 m_e^2}$$

$$r_n \propto n^2$$

Energy $E = -Rch\frac{Z^2}{n^2}$

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

**32. (d)**

$E = hc/\lambda$

$\Rightarrow \lambda = hc/E$

$\Rightarrow \lambda \propto 1/E$

From Figure,

Energy of photon of wavelength λ2

$\triangle E2 = -E - (-4E/3)$

$\triangle E2 = E/3$

Energy of photon of wavelength λ1

$\triangle E1 = -E - (-2E)$

$\triangle E1 = E$

$\therefore \lambda 1/\lambda 2 = \triangle E2/\triangle E1 = (E/3/E$

$r = 1/3$

**33. (d)**

$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

$n_1=2,\ n_2=4$

$\frac{1}{\lambda} = R\left[\frac{1}{4} - \frac{1}{16}\right]$

$= R\left[\frac{4-1}{16}\right] = \frac{3R}{16}$

$\lambda = \frac{16}{3R}$

**34. (c)**

1amu (or 1 u)=$1.6 \times 10^{-27}$ kg

40 u=$40 \times 1.6 \times 10^{-27}$ kg

Number of atoms in earth

$= \frac{6.64 \times 10^{24}}{40 \times 1.6 \times 10^{-27}} = 10^{50}$

**35. (a)**

For minimum wavelength $n_2 = \infty, n_1 = n$.

So $\lambda_{min} = \frac{n^2}{R} = \frac{1}{10^7} = 1000$ Å

**36. (c)**

From Hubble 's law

$Z \propto r$

Where Z → red shift, r →distance of the galaxy

Also, $Z = \frac{d\lambda}{\lambda} = \frac{v}{c} = \frac{\text{speed of galaxy}}{\text{speed of light}}$

Given $d\lambda = 401.8 - 393.3 = 8.5$ nm,

$\lambda = 393.3$ nm,

$Z = \frac{8.5}{393.3} = 0.0216$

Also $v = cZ$

$= 3 \times 10^8 \times 0.0216$

$= 64.8 \times 10^5 ms^{-1}$

Since 1km = $10^3$m , therefore

$v = 6480\ kms^{-1}$

**37. (d)**

Lowest orbit is n = 1. Three lower orbits correspond to n = 1. 2. 3

$\therefore E_1 = \frac{13.6}{1^2} = 13.6$ eV ,

$E_2 = \frac{13.6}{2^2} = 3.4$ eV, $E_3 = \frac{13.6}{3^2} = 1.5$ Ev

**38. (a)**

$\therefore n = 5$

$r_n = (0.53 \times 10^{-10})\frac{n^2}{Z}$

$= \frac{0.53 \times 10^{-10} \times 5^2}{53} = 2.5 \times 10^{-11}$m

40. (b)

Since spectrum of an oil flame consists of continuously varying wavelength in a definite wavelength range, it is an example for continuous emission spectrum.