Unit - 19

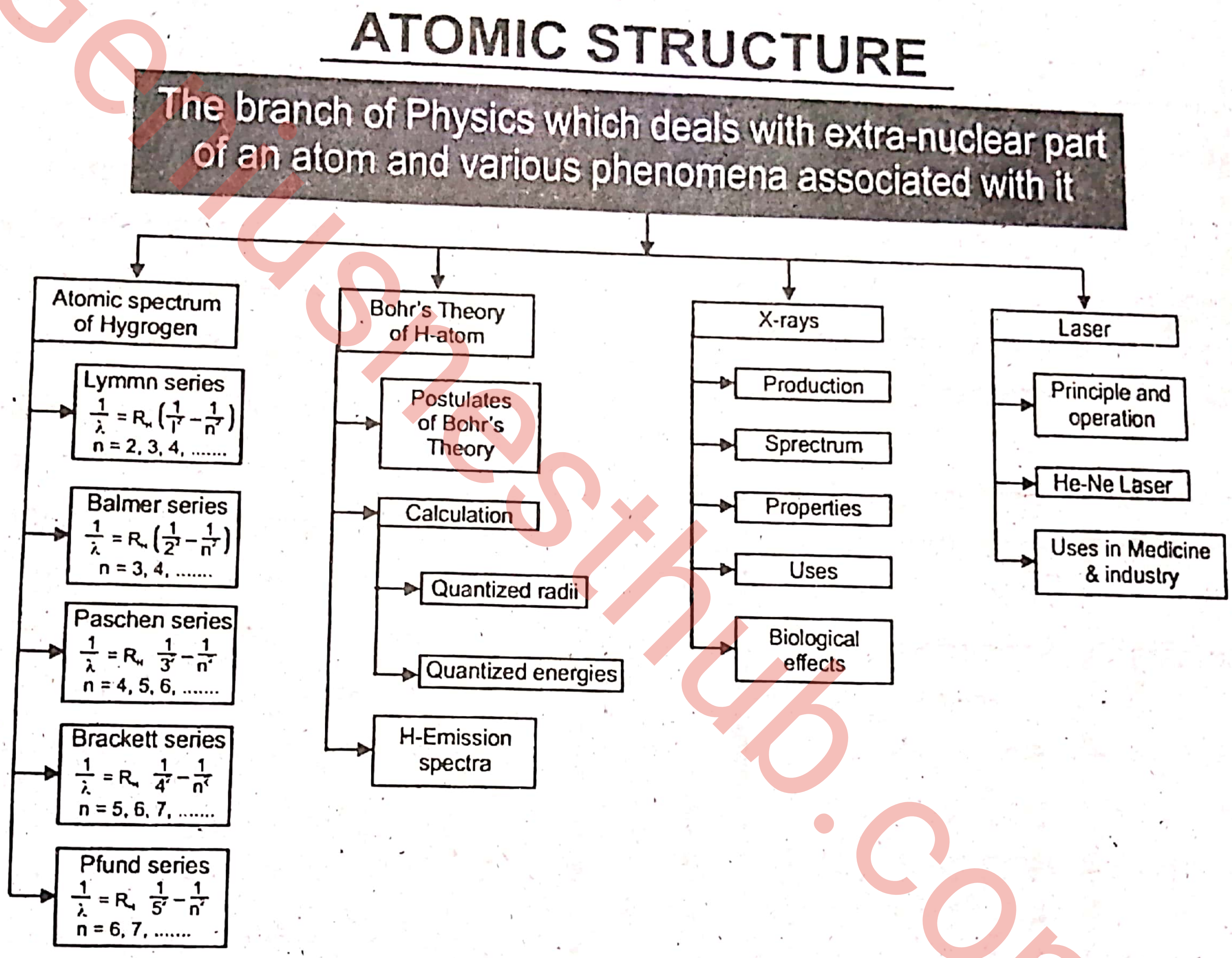
ATOMIC SPECTRA

Learning Objectives

After studying this chapter the students will be able to

- Describe and explain the origin of different types of optical spectra.
- Show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines.
- Explain how the uniqueness of the spectra of elements can be used to identify and element.
- Analyze the significance of the hydrogen spectrum in the development of Bohr's model of the atom.
- Explain hydrogen atom in terms of energy levels on the basis of Bohr Model.
- Determine the ionization energy and various excitation energies of an atom using an energy level diagram.
- Solve problems and analyze information using $1\lambda=R_H[1/p^2=1/n^2]$
- Understand that inner shell transitions in heavy elements result into emission of characteristic X-rays.
- Explain the terms spontaneous emission, stimulated emission, meta stable states, population inversion and laser action.
- Describe the structure and purpose of the main components of a He-Ne gas laser.

CONCEPT MAP


ATOMIC STRUCTURE
The branch of Physics which deals with extra-nuclear part of an atom and various phenomena associated with it
Atomic spectrum of Hygrogen
Lymmn series $\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$ n = 2, 3, 4, ...
Balmer series $\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ n = 3, 4, ...
Paschen series $\frac{1}{\lambda} = R_H \frac{1}{3^2} - \frac{1}{n^2}$ n = 4, 5, 6, ...
Brackett series $\frac{1}{\lambda} = R_H \frac{1}{4^2} - \frac{1}{n^2}$ n = 5, 6, 7, ...
Pfund series $\frac{1}{\lambda} = R_H \frac{1}{5^2} - \frac{1}{n^2}$ n = 6, 7, ...
Bohr's Theory of H-atom
Postulates of Bohr's Theory
Calculation
Quantized radii
Quantized energies
H-Emission spectra
X-rays
Production
Sprectrum
Properties
Uses
Biological effects
Laser
Principle and operation
He-Ne Laser
Uses in Medicine & industry

The beginning of the twentieth century saw the start of new branches of Physics-atomic structure and spectra which has a profound effect on revealing the inner mysteries of the structures of atoms.

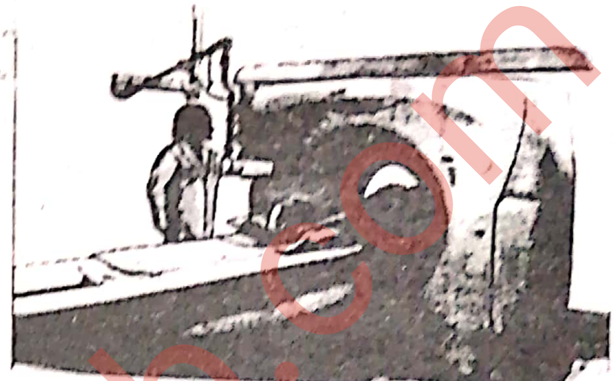
The existence of line emission spectra from atomic gases is used to infer a structure of an atom in terms of discrete energy levels in atoms. J.J.Balmer in 1885 succeeded to devise an empirical formula which could explain the existence of the spectra of atomic hydrogen.

In this chapter we sill study the line spectrum of hydrogen atom, the Bohr model of hydrogen atom, production of X-rays, working principle of CAT scanner and Laser.

The branch of physics which deals with the production, measurement, and interaction of electromagnetic radiation emitted or absorbed by atoms is called spectroscopy. So, it is the study of spectra produced by atoms.

For your Information

A CT scan stands for Computed Tomography scan. It is also known as a CAT (Computer Axial Tomography) scan. It is a medical imaging method that employs tomography. CT scanning is useful to get a very detailed 3-D image of certain parts of the body, such as soft tissues, the blood vessels, the lungs, the brain, abdomen, and bones.



Types of Emission Spectra:

In general, there are three types of spectra:

(i) Continuous spectrum
(ii) Band spectrum
(iii) Line or discrete spectrum

(i) Continuous Spectrum:

A radiation spectrum in which the frequencies of the radiations emitted by the atoms of a substance are so close to each other that they give continuous row of overlapping images is called a continuous spectrum.

Example:

Black body radiation spectrum is the example of continuous spectra.

(ii) Band Spectrum:

A spectrum that appears as a number of bands of emitted or absorption radiations is called band spectrum.

Example:

Molecular spectrum is the example of band spectrum.

(iii) Line or discrete spectrum:

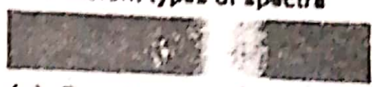
A spectrum consisting of discrete lines corresponding to single wavelengths of emitted radiation is called as line spectrum.

Example:

Atomic spectra are examples of discrete or line spectra.

For Your Information

Different types of spectra



(a) Continuous spectrum

(b) Line spectrum

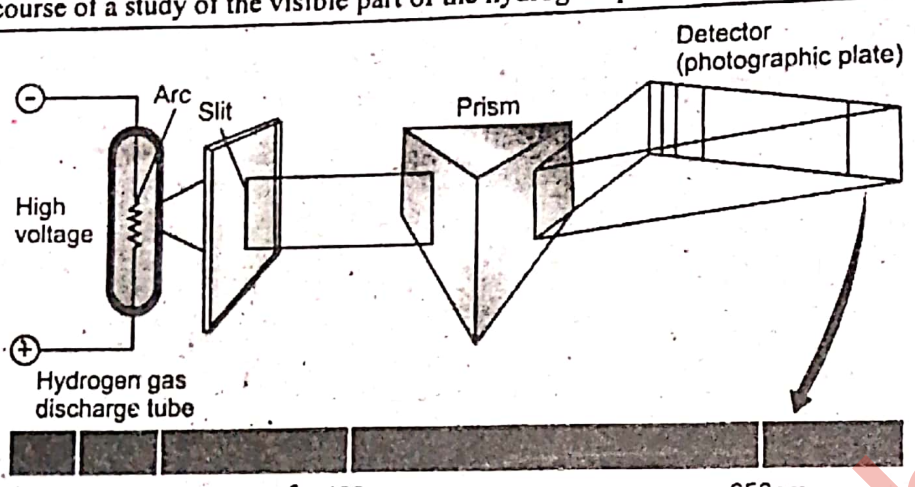
(c) Band spectrum

Q.1 What is Atomic Spectrum? Discuss Different Series in Visible Region of Electromagnetic Spectrum?

Atomic Spectra

When a substance is heated, its atoms absorb energy and are excited, i.e., some of its electrons jump to higher energy states. The electron stays there for a short duration (10^{-8} s) and fall back to its lower energy state. In this process it emits a radiation called photon which is supposed to be a discrete packet of light energy. A photon is a particle of light having wave characteristics, i.e. It has frequency and wavelength.

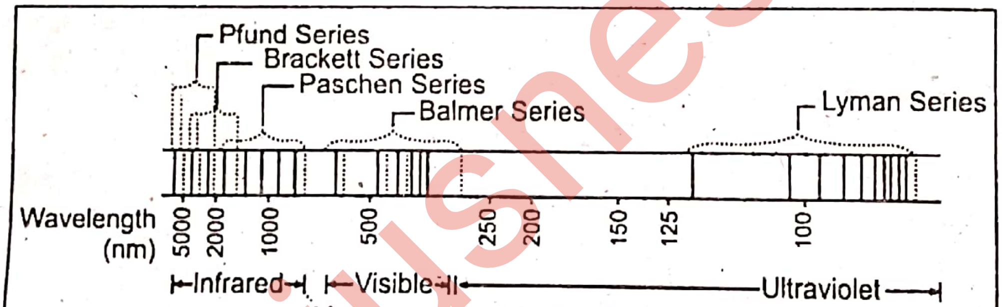
Suppose an evacuated glass tube is filled with a gas such as neon, helium, or argon. If a potential difference between electrodes in the tube produces an electric current in the gas, the tube will emit light whose color is **characteristic of the gas**. If the emitted light is analyzed by passing it through a narrow slit and then through a spectroscope, a series of discrete lines is observed, each line corresponding to a different wavelength or colour. We refer to such a series of lines as a **line spectrum**. The wavelengths contained in a given line spectrum are characteristic of the elements emitting light. Because no two elements emit the same line spectrum, this phenomenon represents a practical technique for identifying elements in chemical substance. The first such spectral series was found by J.J.Balmer in 1885 in the course of a study of the visible part of the hydrogen spectrum.



Line spectrum

The Spectrum of Hydrogen Atom

Consider hydrogen gas is filled in a discharge tube, and a discharge is caused in it by means of high voltage across the tube, the gas becomes luminous and gives off a bluish-red light, Figure. This light can be analyzed by passing it through a dispersing device such as a prism or a grating. The spectrum of hydrogen atoms consists of a series of lines. Each line represents a wavelength of light given off by the light source.



Line spectrum of hydrogen atom

1. **Lyman Series:** Lyman series lie in **ultraviolet** region and its wave lengths are given by,

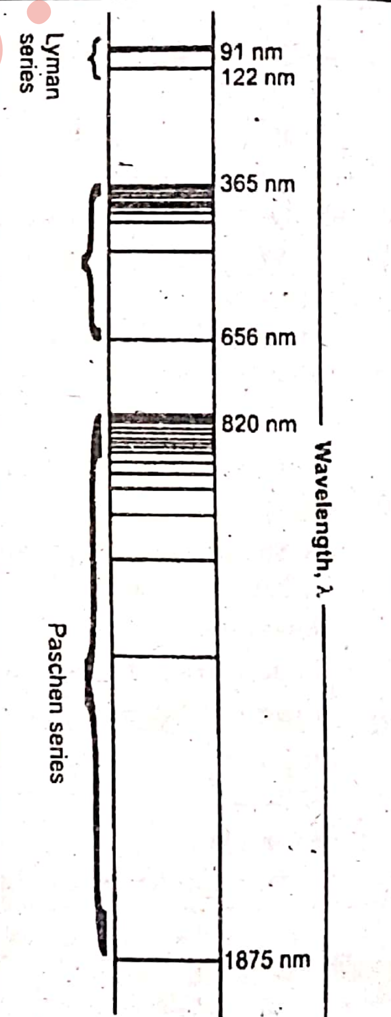
$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

where n = 2, 3, 4,……

2. **Balmer Series**

In 1885, the first spectral series for hydrogen was identified by J.J Balmer. The mathematical results were based on his study in the **visible** region of electromagnetic spectrum. In 1896, Rydberg expressed the results obtained by Balmer in mathematical form as,

For Your Information



Line spectrum of atomic hydrogen. Only the Balmer series lies in the visible region of the electromagnetic spectrum.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad \text{where } n = 3, 4, 5, \ldots\ldots\ldots$$

R_H is the Rydberg's constant and its value is $1.0974 \times 10^7 m^{-1}$

3. **Paschen Series**

Paschen series lies in the **infrared** region and its wave length is given by,

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

where n = 4, 5, 6,……

Bracket Series

Paschen series lies in the **infrared** region and its wave length is given by,

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

where n = 5, 6, 7,……

Pfund Series

Pfund series lies also in the **infrared** region and its wave length is given by,

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

where n = 6, 7, 8,……

General Formula

From above formulas, we can write

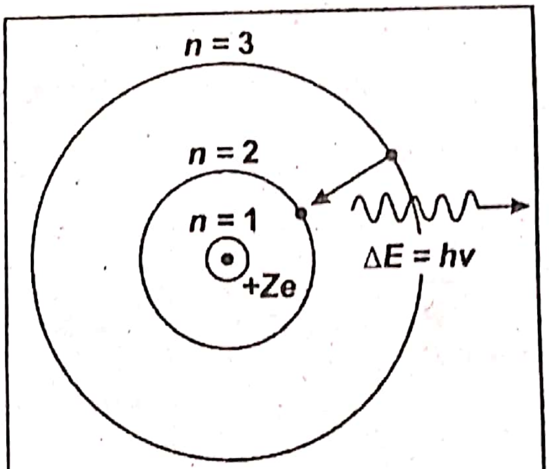
$$\frac{1}{\lambda} = R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right) \quad n > p$$

Where n = p + 1, p + 2, p + 3, …. and R_H is Rydberg constant whose value is equals to 1.097×10^7 m^{-1}.

Q.2 Give the Postulates of Bohr's Atomic model. *RWP 2017, GRW 2017, FEDERAL 2016, SGD 2016*

Bohr Model of The Hydrogen Atom

In 1913, the Danish scientist Neil Bohr (1885-1963) proposed a theory of the hydrogen atom which contained a combination of ideas from classical physics, Planck's original quantum theory, Einstein's photon theory of light, and Rutherford's model of the atom. Bohr's model of the hydrogen atom contains some classical features as well as some revolutionary postulates that could not be justified within the frame work of classical physics. The Bohr model can be applied quite successfully to such hydrogen-like ions as single ionized helium and doubly ionized lithium. However, the theory does not properly describe the spectra of more complex atoms and ions.



Energy radiation due to jumping of electron from higher to lower orbit.

The basic postulates of the Bohr model of the hydrogen atom are as follows:

1. The electron revolve in circular orbits around the nucleus under the influence of the coulomb force of attraction between the electron and the positively charged nucleus.

$$\frac{mv^2}{r} = \frac{ke^2}{r^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $\frac{mv^2}{r}$ and $\frac{ke^2}{r^2}$ Are centripetal and coulomb forces respectively.

2. Only those stationary orbits are allowed for which orbital angular momentum is equal to an integral multiple of $\frac{h}{2\pi}$

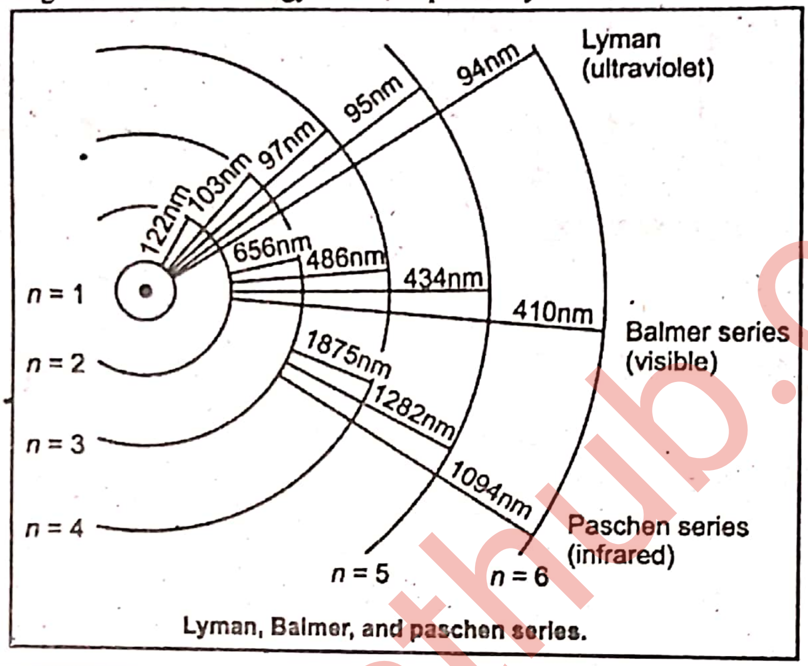
$$mvr = n\frac{h}{2\pi} \qquad \text{... (2)}$$

Where "h" is Plank's constant and its value is $h = 6.6256 \times 10^{-34}$ j s.

3. The electron in stable orbit does not radiate energy as in the classical theory.
4. The atom radiates energy only when the electron jumps from one allowed stationary orbit to another. The frequency of the radiation obeys the condition.

$$hf = E_n - E_p \qquad \text{.... (3)}$$

Where E_n and E_p are higher and lower energy states respectively.

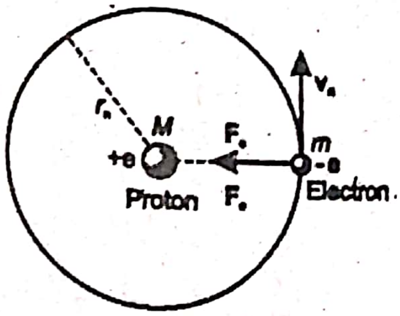


Lyman, Balmer, and paschen series.

Q.3 Derive an expression for the quantized radii of the orbits and speed of electron in hydrogen atom.

The Radii of The Quantized Orbit

Consider a hydrogen atom in which electron moving with velocity v_n in a circular orbit of radius r_n.



Coulomb's force between electron and a proton may be expressed as,

$$F_e = k\frac{e.e}{r_n^2}$$

Or
$$F_e = \frac{ke^2}{r_n^2}$$

Where k is the coulomb's constant and e is the charge on electron as well as proton.

As electron is revolving around the nucleus, so the centripetal force acting on it, is given by

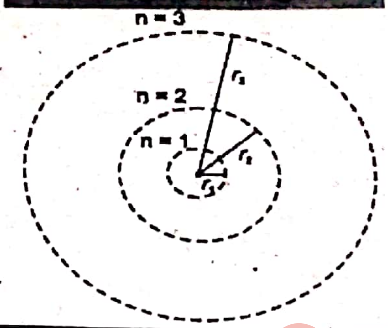
$$F_c = \frac{mv_n^2}{r_n}$$

Coulomb's force provides the necessary centripetal force to revolve the electron around the nucleus. So

$$F_c = F_e$$

$$\frac{mv_n^2}{r_n} = \frac{ke^2}{r_n^2}$$

For Your Information



The first Bohr orbit in the hydrogen Atom has a radius r = 5.3 × 10m. The second and third Bohr orbits have radii $r_2 = 4r_1$ and $r_3 = 9r_1$ respectively.

or $$mv_n^2 = \frac{ke^2}{r_n} \quad \text{———} (1)$$

According to second postulate of Bohr model,

$$mv_nr_n = \frac{nh}{2\pi} \quad \text{———} (2)$$

or $$v_n = \frac{nh}{2\pi m r_n}$$

So equation (1) becomes

$$m\left(\frac{nh}{2\pi m r_n}\right)^2 = \frac{ke^2}{r_n}$$

$$m\frac{n^2h^2}{4\pi^2m^2r_n^2} = \frac{ke^2}{r_n}$$

or $$r_n = \frac{n^2h^2}{4\pi^2ke^2m}$$

$$r_n = n^2\left(\frac{h^2}{4\pi^2ke^2m}\right) \quad \text{———} (3)$$

This is the radius of nth allowed orbit

Since $$\frac{h^2}{4\pi^2ke^2m} = \frac{(6.625\times10^{-34})^2}{4(3.14)^2(9\times10^9)(1.6\times10^{-19})^2(9.11\times10^{-31})}$$

$$= 0.053 \times 10^{-9}\ m$$

$$= 0.053nm$$

So, equation (3) becomes

$$r_n = n^2 \times 0.053nm \quad \text{———} (4)$$

Radius of first Bohr orbit

Now for first orbit, $n = 1$

Thus $r_1 = (1)^2 \times 0.053$

$r_1 = 0.053\ nm$

Hence, equation (4) becomes

$$r_n = n^2r_1 \quad \text{———} (5)$$

Radii of different Bohr's stationary orbits

The radii of different Bohr's stationary orbits are given by

$$r_n = r_1, 4r_1, 9r_1, 16r_1, \ldots\ldots$$

Speed of Electron

The speed of election in nth orbit can be obtained by putting the value of r_n from equation (3) in (2),we get

$$mv_nr_n = \frac{nh}{2\pi}$$

$$v_n = \frac{nh}{2\pi m r_n}$$

$$v_n = \frac{nh}{2\pi m\left(\frac{n^2h^2}{4\pi^2ke^2m}\right)}$$

$$v_n = \frac{2\pi k e^2}{nh} \quad \text{———} (6)$$

Q.4 Derive an expression for the energy of electron revolving in nth orbit of H- atom.

Energy of Electron in Quantized Orbit

Let us calculate the total energy E_n of an electron orbiting in Bohr orbit (i.e., first orbit).

The total energy of an electron (E_n) in an orbit is equal to the sum of its kinetic energy (K.E.) and potential energy (U) i.e.,

$$E_n = K.E. + U$$

Kinetic Energy

As K.E may be expressed as

$$K.E. = \frac{1}{2}mv_n^2 \qquad [\because \text{ from equation (1)}, mv_n^2 = \frac{ke^2}{r_n}]$$

$$K.E. = \frac{ke^2}{2r_n} \quad \text{------ (1)}$$

Potential Energy

The potential energy may be expressed as the work done for displacing the electron through r_n from nucleus.

As $U = -qV$

$= -eV$

Putting $V = k\frac{e}{r_n}$

$$= -e\left\{\frac{ke}{r_n}\right\}$$

So, P.E. becomes $U = -\frac{ke^2}{r_n}$ ------ (2)

> **FOR YOUR INFORMATION**
> nth excited state means (n + 1)th orbit.

Total Energy

Total energy may be expressed as,

$$E_n = U + K.E$$

Putting values from equation 1 and 2, we get

$$E_n = -\frac{ke^2}{r_n} + \frac{ke^2}{2r_n}$$

$$E_n = \frac{-2ke^2 + ke^2}{2r_n}$$

$$E_n = -\frac{ke^2}{2r_n}$$

Putting $r_n = n^2\left(\frac{h^2}{4\pi^2 ke^2 m}\right)$

$$E_n = -\frac{ke^2}{2\left(\frac{n^2h^2}{4\pi^2 kme^2}\right)}$$

$$E_n = -\left(\frac{2\pi^2k^2me^4}{h^2}\right)\frac{1}{n^2} \quad \text{..................(3)}$$

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

where

$$E_o = \frac{2\pi^2k^2me^4}{h^2} = \text{constant}$$

> **Do You Know?**
> The orbital electrons have specific amount of energies where as free electrons may have any amount of energy.

> **FOR YOUR INFORMATION**
> The energy of the electron in an orbit always negative,

$$E_o = \frac{2\pi^2 k^2 m e^4}{h^2} = \frac{2(3.14)^2(9\times10^9)^2(9.11\times10^{-31})(1.6\times10^{-19})^4}{(6.63\times10^{-34})^2}$$

$$E_o = +2.17\times10^{-18}\,J$$

$$E_o = \frac{+2.17\times10^{-18}}{1.6\times10^{-19}}\,eV$$

$$E_o = +13.6\text{ eV}$$

As $$E_n = -\frac{E_o}{n^2} \qquad (4)$$

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

For different values of principal quantum number 'n', we get the allowed energy levels of hydrogen atom to be

$$E_n = -E_o,\ -\frac{E_o}{4},\ -\frac{E_o}{9},\ -\frac{E_o}{16},\ \ldots\ldots\ldots\ldots$$

These are called quantized energy status or allowed energy states.

The lowest stationary energy state, or ground state, corresponds to n = 1 and has energy $E_1 = -13.6$ eV. The next state, corresponding to n = 2, has an energy $E_2 = -\frac{E_1}{4} = -3.4$eV and so on.

> **Do You Know?**
> Photon must have energy exactly equal to the energy difference between the two shells for excitation with K.E greater that the required difference can excite the gas atom.

Q.5 Explain hydrogen emission spectrum on the basis of Bohr model of hydrogen atom and energy level diagram.

Hydrogen Emission Spectrum

Suppose that the electron in hydrogen atom is in the excited state with energy E_n and makes a transition to a lower energy state E_p

So $E_p < E_n$.

Then, $hf = E_n - E_p$

Putting $E_n = -E_o/n^2$ and $E_p = -E_o/p^2$

$$hf = -\frac{E_o}{n_2} - \left(\frac{-E_o}{p^2}\right)$$

putting $f = c/\lambda$

So $$\frac{hc}{\lambda} = E_0\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

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

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

where $$R_H = \frac{E_o}{hc} = \frac{13.6eV}{(6.63\times10^{-34})(3\times10^8)}$$

$$R_H = \frac{E_o}{hc} = \frac{(13.6)(1.6\times10^{-19})}{(6.63\times10^{-34})(3\times10^8)}$$

$$\mathbf{R_H = 1.0974\times10^7\,m^{-1}}$$

The different energy levels for hydrogen atoms are shown in figure.

Energy – Level Diagram

According to Bohr's theory the total energy and the radii of the electron orbits in hydrogen atom are respectively given by the following relations.

$$E_n = \frac{-E_0}{n^2} = \frac{-13.6eV}{n^2} \text{ and } r_n = r_1 n^2$$

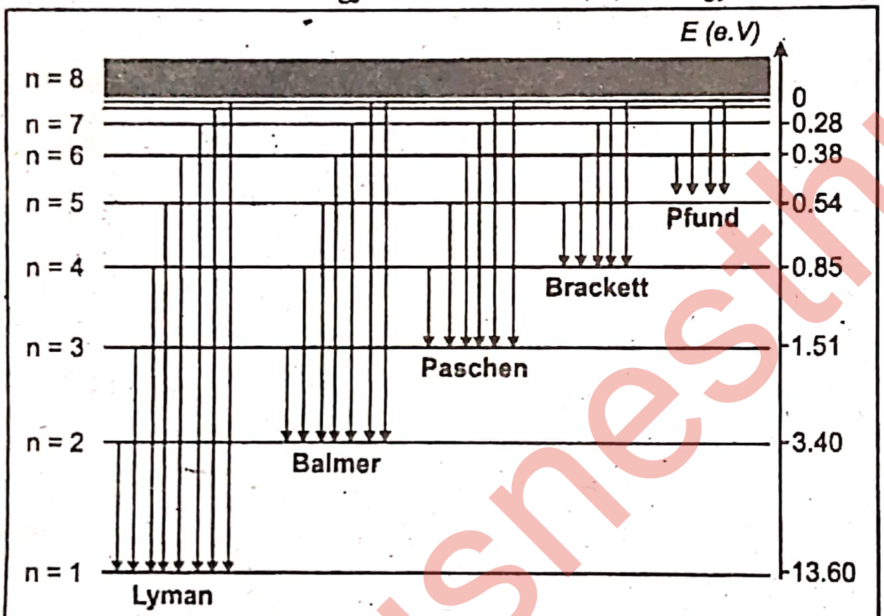
When n = 1, the electron is in the first orbit; the energy is minimum and has the value $E_1 = -E_o = -13.6eV$. When $n \to \infty$, then $r_n \to \infty$, $E\infty \to 0$.

The electron become free from the nucleus. The atom is then said to ionized. It is convenient to represent the energy of the quantized states of the atom on an energy level diagram as shown in Fig 19.4.

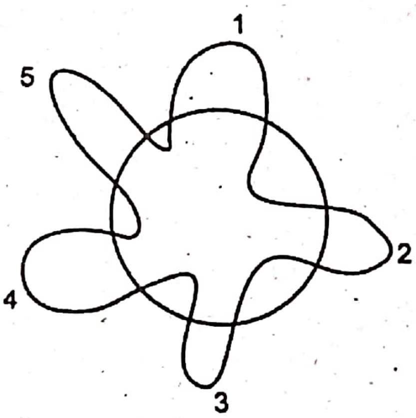
The energy levels of the atom En are represented by a series of horizontal lines. Transition between the levels are represented by vertical arrows.

- When the electron is free from the atom and is at rest, both its kinetic and potential energies are zero at $n = \infty$ level.

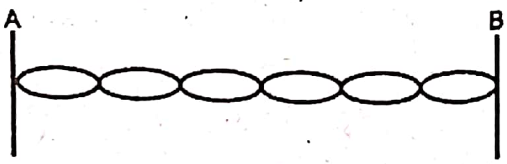
The energy level diagram can be used to illustrate the origin of various spectral series observed in the emission spectrum of hydrogen. The transition from various energy level to the lowest level (n = 1) gives rise to lyman series. Balmer series occurs for transition ending at second energy level (n = 2). The paschen, bracket and pfund series occurs for transitions from various energy levels to the r = 3, 4, 5 energy levels, respectively.



Energy level diagram Energy levels of the hydrogen atom with some of the transitions between them to give rise to the spectral lines.



Standing wave pattern for an electron wave in a stable orbit of hydrogen. There are five full wavelengths in this orbit.



Standing waves pattern for a vibrating stretched string.

De-Broglie Waves And The Hydrogen Atom

One of the postulates made by Bohr in his theory of the hydrogen atom was that angular momentum of the electron is quantized in units of

$$\frac{h}{2\pi} \text{ or } mvr = n\frac{h}{2\pi}$$

For more than a decade following Bohr's publication, no one was able to explain why the angular momentum of the electron was restricted to these discrete values. Finally, de Broglie recognized a connection between his theory of the wave character of material properties and the quantization condition given above. De-Broglie assumed that an electron orbit would be stable (allowed) only if it contained an integral number of electron wavelengths.Figure (19.5) demonstrate this point when five complete wavelengths are contained in one circumference of the orbit similar patterns can be drawn for orbits of four wavelengths, three wavelengths, two wavelengths, etc. This situation is analogous to that of standing waves on a string figure.

Now imagine that the vibrating string is removed from its support at A and B and bent into a circular shape such that A and B are brought together. The end result is a pattern similar to that shown in (fig 19.5). Standing waves pattern for a vibrating stretched string fixed at its ends. This pattern has three full wavelengths. In general, the condition for de-Broglie standing wave in an electron orbit is that the circumference must contain an integral multiple of electrons wavelengths. We can express this conditions as

$$2\pi r = n\lambda$$

$$(n = 1, 2, 3, \ldots)$$

De-Broglie's equation for the wavelength of an electron in terms of its momentum

$$\lambda = \frac{h}{mv}$$

Substituting λ in Eq. (19.21), we have,

$$2\pi r = n\frac{h}{mv}$$

$$mvr = n = \frac{h}{2\pi}$$

This precisely explains the quantization of angular momentum condition imposed by Bohr in his original theory of hydrogen atom.

Limitations of Bohr's Theory

- Bohr's theory successfully explains the spectra of simpler atoms or ions which contain only one electron e.g., hydrogen, singly ionized helium, doubly ionized lithium etc.
- But this theory fails to explain

i. spectra of many electrons atom.
ii. Also when a spectral line of hydrogen is examined more closely with high precision instruments it reveals a fine structure i.e., the spectral lines is found to consist of a number of closely spaced lines.
iii. The existence of non-radiating stationary orbits.
iv. The energy of electrons in sub-shells of an atom.
v. Bohr's theory could not explain the fine structure of the spectral lines of hydrogen atom.
vi. Later researchers studied the effect of electric and magnetic fields on spectral lines.
vii. Bohr's theory could not explain spectral line found to split into a number of lines under the influence of magnetic field (Zeeman Effect) and electric field (Stark effect).

Q.6 Define excitation energy, excitation potential; ionization energy and ionization potential.

Excitation and Ionization Potential

Ground State

When the electron is in its lowest energy state (i.e. n = 1), it is said to be in its ground state.

> **Check Points**
> What postulate of Bohr's model is justified by de-Broglie?

Excited State

When the electron is in the higher orbits it is said to be in excited state.

The allowed energies are given by a relation of the form.

$$E_n = \frac{-E_0}{n^2}, \; n = 1, 2, 3, \ldots\ldots$$

The state n = 1 is called ground state, while states with n = 2, 3, 4, ...are called exited states.

When energy is supplied to the atom, then an electron in the atom reaches one of its exited states. The atom in an exited state cannot stay for a long time. The electron in an exited atom soon returns to lower energy levels by emitting photons.

Excitation Energy

The energy required to move electron from its ground state to an exited state is known as excitation energy. For example the first and second excitation energies of hydrogen atom are calculated to be.

$$\frac{-E_0}{2^2} - (-E_0) = \frac{3}{4}E_0 = \frac{3}{4}(13.6\,eV) = 10.2eV$$

$$\frac{-E_0}{3^2} - (-E_0) = \frac{8}{9}E_0 = \frac{8}{9}(13.6\,eV) = 12.1eV$$

Excitation Potential

The potential difference V in volts applied to an electron in its ground state to get an amount of energy equal to the excitation energy of the electron in the atom is called excitation potential of the atom. For example, the first and second excitation potential of H-atom are respectively 10.2V and 12.1V.

Ionization Energy

Ionized State

When the electron is isolated from the atom then atom is said to be ionized. In ionized state

$E_\infty = 0.$

Ionization energy

The minimum energy required to remove an electron from its ground state is called ionization energy of the atom.

If an atom absorbs sufficient amount of energy, an electron may be raised to a level $n = \infty$. The electron then becomes free from the attractive force of the nucleus, i.e., the electron is removed from the atom. An atom which has lost one or more electrons is said to be ionized.

- But the energy of the electron in the initial (ground) state is E_0, and its energy in the final (ionized) state is zero. Thus the ionization energy of the atom is $(0 - (-E_0)) = E_0$.
- This means that the ionization energy of the atom is numerically equal to the ground state energy of the atom. For example, the ionization energy of H-atom is 13.6eV.

Ionization Potential

The potential difference applied to an electron to provide it the requisite amount of ionization energy is called ionization potential.

MCQ's From Past Board Papers

1. If electrons jumps from second orbit to first orbit in hydrogen atom it emits photon of:
   (A) 3.40eV (B) 10.20 eV (C) 13.6eV (D) 3.8 eV
2. The value of Rydberg's constant is
   (A) $1.09\times10^{7}\,m^{-1}$ (B) $1.09\times10^{8}\,m^{-1}$ (C) $1.09\times10^{9}\,m^{-1}$ (D) $1.09\times10^{19}\,m^{-1}$
3. Which of the following series lies in the ultraviolet region?
   (A) Lyman series (B) Balmer series (C) P fund series (D) Braeckat series
4. The value of radius of 1st Bohr's orbit is
   (A) 0.53 nm (B) 0.053 nm (C) 0.0053 nm (D) 0.00053 nm
5. Radius of 3rd Bohr orbit in hydrogen atom is greater than radius of 1st orbit by ______. (Federal 2012)
   (A) 2 (B) 3 (C) 4 (D) 9
6. If the ionization energy of hydrogen atom is 13.6 eV, its ionization potential will be ______. (Federal 2013)
   (A) 13.6 V (B) 136.0 V (C) 3.4 V (D) None of these
7. Which of the following series of H–Spectrum lies in ultraviolet region:
   (A) Lyman series (B) Balmer series (C) Paschen series (D) Bracket series
8. Energy of the 4th orbit in hydrogen atom is:
   (A) –25.51 eV (B) –3.50 eV (C) –13.6 eV (D) –0.85 eV
9. In which region of electromagnetic spectrum of Hydrogen, the balmer series lies? (Federal 2011)
   (A) Infrared (B) Visible (C) Ultraviolet (D) Far ultraviolet
10. Speed of the electron in the first Bohr's orbit is:
    (A) 2.19×10^{6} m/s (B) 2.19×10^{-6} m/s (C) 2.19×10^{5} cm/s (D) 2.19×10^{-5} m/s
11. Which series lies in the ultraviolet region?
    (A) Balmer series (B) Bracket series (C) Pfund series (D) Lyman series
12. The unit of R_H (Rydberg's constant) is:
    (A) ms^{-1} (B) m (C) m^2 (D) m^{-1}
13. The shortest wave length in Bracket Series have wave length:
    (A) $\frac{16}{R_H}$ (B) $\frac{R_H}{16}$ (C) $16R_H$ (D) $4R_H$
14. The speed of an electron in nth orbit is given as:
    (A) $4\pi^2ke^2/nh$ (B) $2\pi ke^2/nh$ (C) $4\pi ke/n^2h^2$ (D) $2\pi^2ke^2/nh$
15. Which series is visible from the following:
    (A) Paschen series (B) Pfunds series (C) Lyman series (D) Balmer series

16. The relation between Rydberg constant 'R_H' and ground state energy 'E_0' is given by:
(A) $R_H = \frac{E_0}{hc}$ (B) $R_H = \frac{hc}{E_0}$ (C) $E_0 = \frac{R_H}{hc}$ (D) $R_H = E_0 hc$

17. The radius of 3rd Bohr orbit in hydrogen atom is greater than the radius of 1st orbit by a factor of
(A) 2 (B) 3 (C) 4 (D) 9

18. Atomic spectra are the examples of ________ spectra.
(A) Continuous (B) Line (C) Band (D) Mix

19. K_α – X rays are produced due to transition of electrons from:
(A) K to L shell (B) L to K shell (C) M to K shell (D) M to L shell

20. The following gas was identified in the sun using spectroscopy:
(A) Hydrogen (B) Helium (C) Carbon (D) Nitrogen

21. The dimensions of Planck's Constant is same as that of:-
(A) Energy (B) Power (C) Acceleration (D) Angular Momentum

22. In electronic transition, atom can not emit:-
(A) γ – rays (B) Ultraviolet rays (C) Visible light (D) Infrared

23. The relation for paschen series is given as
(A) $\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ (B) $\frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$ (C) $\frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$ (D) $\frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$

24. Hydrogen atom spectrum does not lie in
(A) Ultraviolet region (B) Visible region (C) Infra-red region (D) X-ray region

25. The equation of Rydberg constant is given by:
(A) $R_H = \frac{H_0}{m_0}$ (B) $R_H = \frac{E_0}{hc}$ (C) $R_H = \frac{E_0}{\lambda}$ (D) $R_H = \frac{1}{he}$

26. The radius of 10th orbit in hydrogen atom is:
(A) 0.053 nm (B) 0.53 nm (C) 5.3 nm (D) 53 nm

27. In a electronic transition atom cannot emit:
(A) Infrared radiations (B) Ultraviolet radiations (C) Visible radiations (D) γ-radiations

28. First spectral series of Hydrogen atoms was discoverd by
(A) Lyman (B) Rydberg (C) Balmer (D) Paschen

29. Second pastulate of Bohar's atomic model is
(A) $mvr = \frac{nh}{2\pi}$ (B) $mvr = 2\pi nh$ (C) $mv = \frac{nhr}{2\pi}$ (D) $mvr = \frac{2\pi}{nh}$

30. The radiations emitted from hydrogen filled discharge tube can be analyzed Into:-
(A)Band Spectrum (B)Line Spectrum (C)Continuous Spectrum (D)Absorption Spectrum

31. For Panchen series the value of n starts from
(A)2 (B)4 (C)6 (D) 8

32. The energy of electron in ground state of hydrogen atom is -13.6ev,then its energy in forth orbit is
(A)−3.4eV (B)−0.85eV (C)−54.4eV (D) −13.6eV

Answers Key

1. B	2. A	3. A	4. B	5. D	6. A	7. A	8. D	9. B	10. A	11. D	12. D
13. A	14. B	15. D	16. A	17. D	18. B	19. B	20. A	21. D	22. A	23. B	24. D
25. B	26. C	27. D	28. C	29. B	30. B	31. B	32. D				

Q.7 Describe Briefly the Inner Shell Transitions and Characteristic X-rays.

Inner shell Transition and Characteristic X-Rays

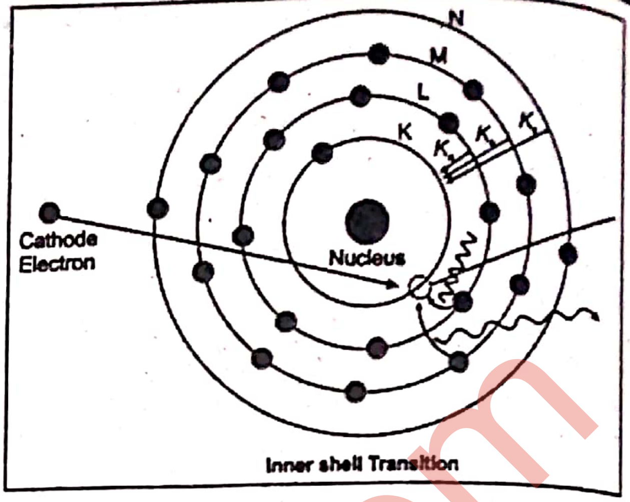
Inner-Shell Transitions and Characteristic X-Rays

When the transition of electron takes place in hydrogen or some other lighter atom, it results in the emission of spectral lines in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy difference in transition levels.

When the transition of electron takes place in heavy elements then x-rays photons are emitted.

Characteristic x-rays

In heavy atom, the electrons are assumed to be arranged in concentric shells labeled as K, L, M, N, O, etc. The K shell being closest to the nucleus, the L shell next, and so on. The inner shell electrons are tightly bound and large amount of energy is required for their displacement from their normal energy levels. When a heavy target material is bombarded with a beam of electrons, that has been accelerated by several keV. Some of these electrons will collide with inner-shell electrons of the target and knock them out of their respective atoms.

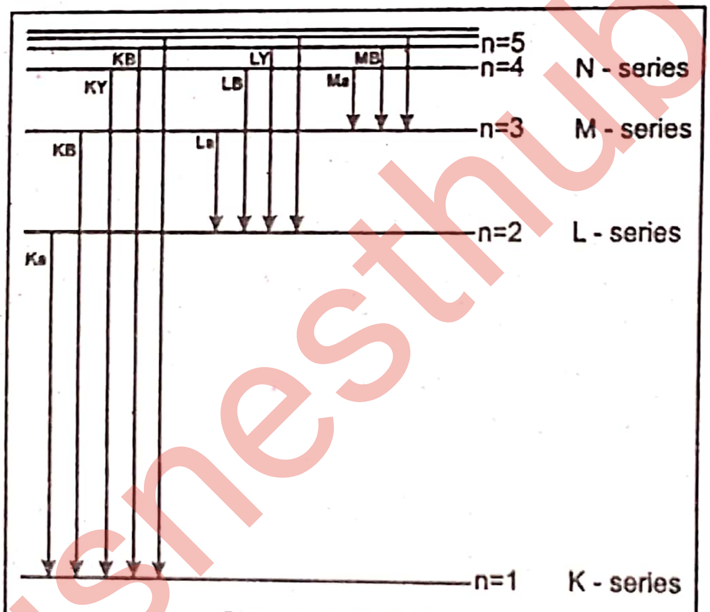


Inner shell Transition

Let a K-shell electron is knocked out from an atom creating a vacancy in K-shell.

Then an electron from either, L, M, or N-shell will quickly jump down to fill the vacancy in the K-shell emitting the excess energy as x-rays photon.

These x-rays consists of series of **specific wavelengths or frequencies and hence are called characteristic x-rays.** An x-ray photon due to transition from L-shell to the vacancy in the K-shell is called K_α characteristic x-rays. The transition from M- and N-shell to the K-shell gives rise to K_β and K_γ characteristic x-rays respectively. The study of characteristic x-rays spectra has played a very important role in the study of atomic structure and the periodic table of elements.



Characteristic X - Rays

Q.8 What are continuous x-rays? How is it produced?

Continuous x-rays

"X-rays emitted in all directions with a continuous range of frequencies are called continuous X-rays".

- Consider an electron traveling towards a target nucleus in the x-rays tube. The incident electron has coulomb interaction with the nucleus is very strong. The force of attraction accelerates the electron. According to the classical theory of electromagnetism, an accelerated charge emits radiation called Bremsstrahlung, a Germen word meaning braking radiation.
- Also Spectrum is obtained due to deceleration of impacting electrons. When a fast moving electron bombard the target, they are suddenly slowed down .These impacting electrons emit radiation as they are decelerated by the target.

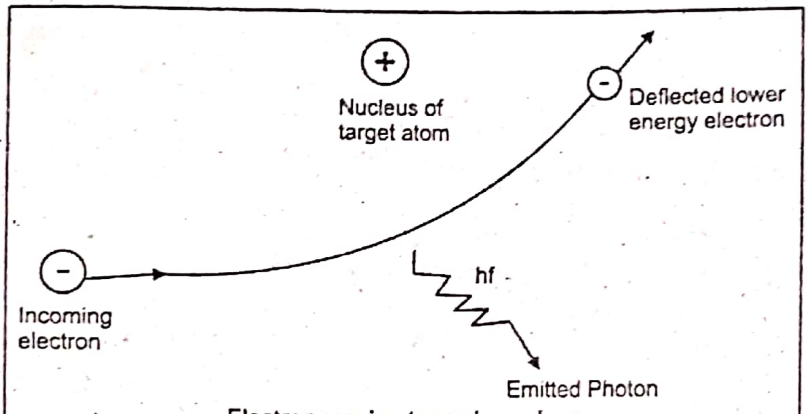
Since the rate of deceleration is so large that electrons lose all the K.E in the 1st collision, the whole K.E appears as the X-ray photons of energy hf_{max}. i.e.,

$$Ve = hf_{max}$$

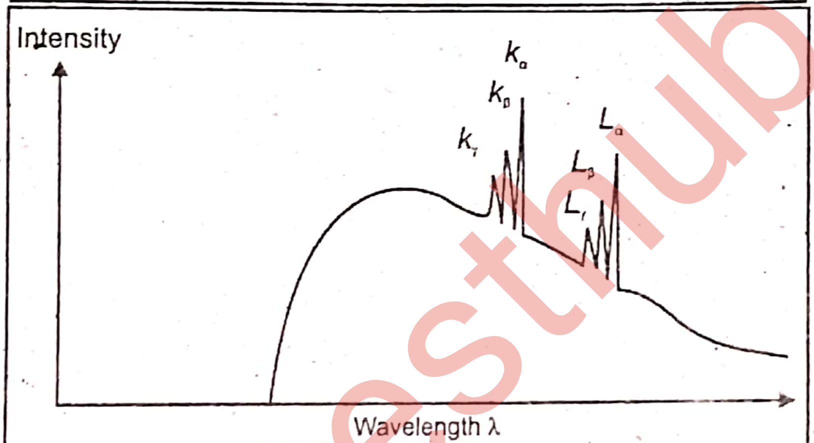
$$Ve = \frac{hc}{\lambda_{min}}$$

$$\lambda_{min} = \frac{hc}{eV}$$

The wavelength λ_{min} corresponds to frequency f_{max} as shown in figure. Other electrons do not lose all their energy in their first collision. They may suffer a number of collisions before coming to rest. This will give rise the photons of smaller energy or x-rays of longer wave length. Thus the continuous spectrum is obtained due to the deceleration of impacting electrons.



Electron moving towards nucleus



Continuous x - rays curve.

Q.9 Describe the production of x-rays. *GRW 2015, LHR 2016 G II, 2017 G I, Bwp 2014*

Production of X-Rays

X-rays were discovered by Germen physicist **Dr. Rontgen in 1895.** X-rays have very smaller wavelength or high frequency. *The production of x-rays is the reverse process of photoelectric effect.*

When fast moving electrons strike on a metal surface, photon of very high energy (i.e. high frequency) are emitted known as x-rays.

Working: The cathode and anode are enclosed inside an evacuated glass chamber and a high DC voltage of the order of 50,000 V is maintained between them. The electrons emitted from the cathode are accelerated by the high potential difference. The energetic electrons strike the target T and X-rays are produced.

It may be mentioned that a small part of the kinetic energy of the incident electrons is converted into X-rays, the rest is converted into heat. The target T becomes very hot and must, therefore, have a high melting point. The heat generated in target T is dissipated through the copper rod. Sometime the anode is cooled by water flowing behind the anode.

When such highly energetic electrons are suddenly stopped by target T,a n intense beam of X-rays produced.

- The X-rays have larger penetrating capacity and are called **hard X-rays,**
- while those with small penetrating power are called **soft X-rays.**

If V is the potential applied, then the K.E of electrons with which they collides the target is

$$K.E = Ve \qquad (1)$$

K_α x-rays

Suppose that a fast moving election of energy Ve strike target of tungsten or any other heavy atom. Let an electron from K- shell of the atom is removed, it produces a vacancy of electron or hole in K shell.

The electron from L shell jumps to occupy the hole, there by the emitting a photon of energy $hf_{k\alpha}$ called K_α x-rays and is given by

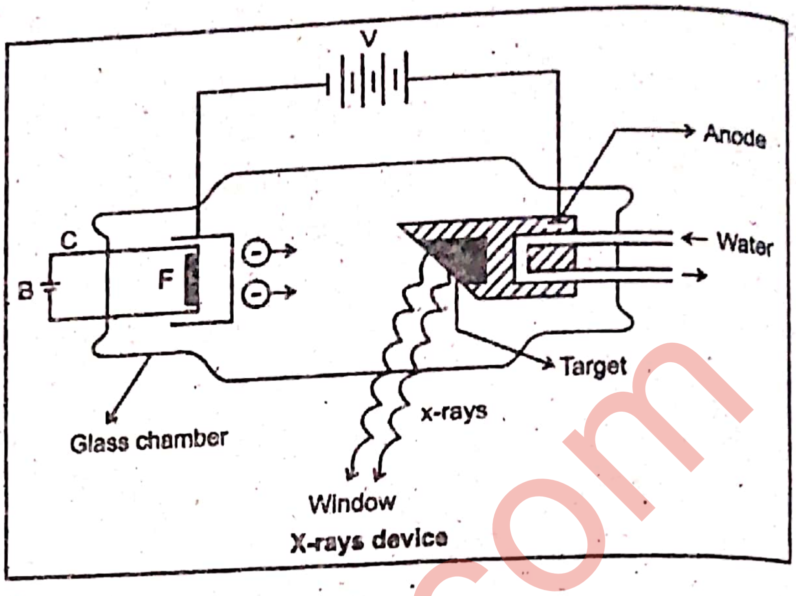
$$hf_{k\alpha} = E_L - E_K$$

K_β x-ray

It is also possible that electron jumps from M-shell into K- shell. The photons emitted K_β x-ray with energy $hf_{k\beta}$. so

$$hf_{k\beta} = E_M - E_K$$

The photons emitted in such transition i.e., inner shell transition are called characteristics X-ray ,because energies depend upon the type of target material.



X-rays device

Q.10 Describe the properties and uses of x-rays?

Rwp 2017

Properties of X-rays

X-rays have the following properties.

1. X-rays can be diffracted by crystals.
2. X-rays cause fluorescence in many substances e-g zinc sulphide, sodium iodide and barium platinocyanide.
3. X-rays blackened the photographic plates.
4. X-rays penetrate solid substances which are opaque to ordinary visible light.
5. When X-rays are pass through a solid, liquid or gas they ionize the atoms.
6. X-rays are invisible.
7. X-rays cannot be smelled.
8. X-rays cannot be heard.
9. X-rays are electromagnetic waves of shorter wavelength and high frequency.
10. X-rays photons are neutral.
11. X-rays photons are not deflected by electric and magnetic fields.
12. X-rays photon travel with speed of light in free space. $C = 3 \times 10^8$ m/s
13. X-rays can produce photoelectric effect.
14. X-rays can produce Compton effect.
15. X-rays have high penetrating power.
16. X-rays photon have energy and momentum.
17. X-rays cast shadows of the obstacles placed in their path.
18. X-rays are not refracted as they pass from one medium into another.
19. Rest mass of X-rays photon is zero.

Q.11 Give applications of x-rays.

Applications of X-rays

The important practical applications of X-rays can be categorized as (i) Scientific (ii) Industrial and (iii) medical.

Scientific Applications

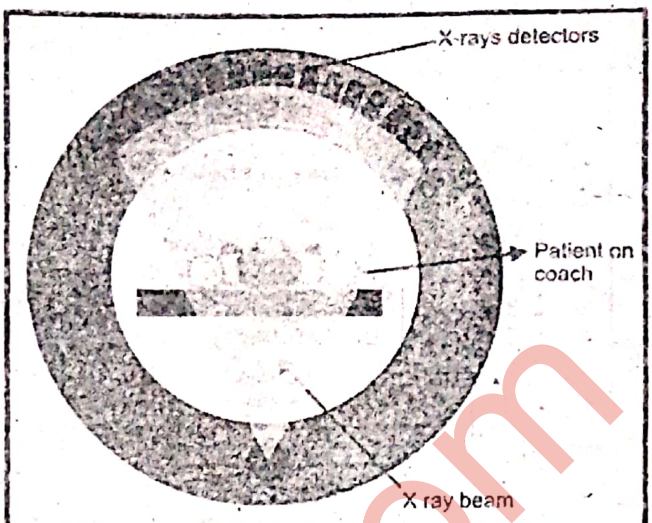
The diffraction of x-rays at crystals gave birth to x-ray crystallography.

The Laue diffraction pattern can be used to determine the internal structure of the crystals.

The spacing and dispositions of the atom of a crystal can be precisely determined.

Industrial Applications

- Since X-rays penetrate the materials on which they are incident, they are used in industry to detect defects in metallic structures in big machines, railway tracks and bridges.
- X-rays are used to analyze the compositions of alloys such as bronze, steel and artificial pearls.
- The structure of rubber and plastics can be analyzed and controlled by X-rays studies.



CT scanner with the X-rays source and detectors

Medical Applications

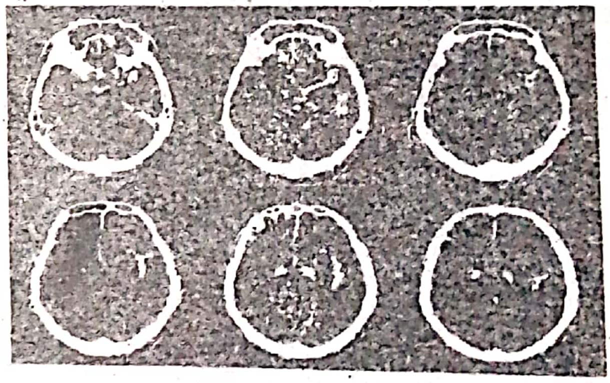
- Almost immediately after their discovery by Roentgen, X-rays were used in hospitals in Vienna for surgical operations.
- Since bone is more opaque to x-rays than flesh, if x-rays are allowed to pass through a human body, the bones cast their shadow on the photographic plate.
- The X-ray photographs reveal fractures of bones or the presence of foreign bodies.
- X-rays can also be used for curing malignant tissues of the body.
- X-ray therapy has also been used for the treatment of cancer.

CT Scanner

A 'normal' X-ray gives only limited information because it is rather like a shadow picture-fine detail within the image may be invisible especially if one organ lies in front of the region of the body being studies. To give a high quality images CT Scans are used to identify internal structures of various part of the human body. CT Scans Machine is 3D machine with computer model.

In the CT scanner there is one X-ray source but a large number of detectors.

- The source and the detectors are mounted in a large ring-shaped machine and the patient is placed inside this on a couch as shown in figure. Each detector records an image and the source and detectors are then rotated around the patient to give views from a variety of direction. The image is called a tomogram. The couch and patient are then moved along the axis of the machine and another set of images is taken.
- This large number of images (many hundreds) are then combined by a computer to give a composite detailed 3D image of the organs under investigation. The development of the CT scanner has been of enormous help in the study of the tumours in cancer patients where images of high quality are essential.


CT scan images

MCQ's From Past Board Papers

1. Production of x-rays can be regarded as the inverse of
   (A) Pair production (B) Compton effect (C) Photo electric effect (D) Annihilation of matter
2. Photons emitted in inner shell transition are:
   (A) Continuous X-rays (B) Discontinuous X-rays (C) Characteristic X-rays (D) Energetic X-rays
3. When X-rays are passed through successive aluminum sheets, their hardness ____. (Fed 2013)
   (A) Decreases (B) Increases (C) Remains the same (D) None of these
4. Which is not true for x-rays:
   (A) X–rays are not deflected by electro field (B) X–rays are polarized
   (C) X–rays consist of electromagnetic waves (D) X–rays can be diffracted by grating
5. X–rays can be:
   (A) reflected (B) diffracted (C) polarized (D) all of these

X-rays are electromagnetic radiations having wavelength in the range

(A) 10^{-12}m (B) 10^{-10}m (C) 10^{-18}m (D) 10^{-6}m

7. The reverse phenomenon of photoelectric effect is called as:

(A) Radioactivity, (B) Compton effect (C) Zeeman effect (D) Pair production

8. The reverse process of photo-electric effect is:

(A) Compton effect (B) X–rays production (C) Pair production (D) pair annihilation

9. The rest mass of X-rays photon is

(A) 9.1×10^{-31} kg (B) 1.67×10^{-27} kg (C) zero (D) smaller than a light ray photon

10. For Holography we use:

(A)X-rays (B)Laser (C)γ-rays (D) β-rays

11. X-rays diffraction reveals that these are

(A)Particular type (B)Wave type (C)Both wave and particular (D)None of above

Answers Key

1. C	2. C	3. A	4. D	5. D	6. B	7. B	8. B	9. C	10. B	11. B

Q.12 What is laser? Describe its principle and operation.

Lasers

The term laser is an abbreviation of **light amplification by stimulated emission of Radiation. Laser** is a remarkable device that produces an intense and highly parallel beam of coherent light.

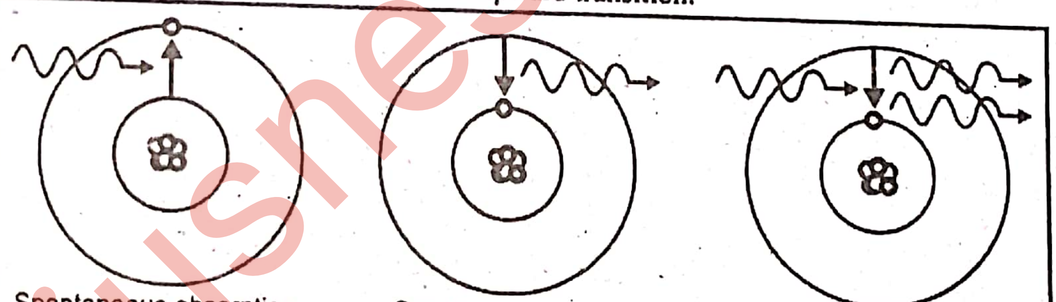
The first laser was fabricated by T.H.Maiman in 1960. To understand the working of a laser, terms such as spontaneous emission, stimulated emission and population inversion must be understood.

Spontaneous and Stimulated Emission

We have seen that one possible method of exciting an atom is to send photons whose energy is equal to excitation energy of the atom.

- The excitation energy ΔE is the difference between the two possible energy states of an atom.
- The excited atom wait for a brief period of about 10^{-8} s and then spontaneously drops back to its lowest energy state, emitting photon of energy exactly equal to ΔE in arbitrary direction .

The only role of the passing photon is to give up its entire energy in exciting the electron to a higher energy state. This is a form of resonance in which a photon induces an upward transition.



Spontaneous absorption Spontaneous emission Stimulated absorption

Electron falls back to its lower energy state E, and emitting a photon, thus duplicating the stimulated photon.

Can the photon play the opposite role, i.e. can it induce or stimulate the downward transition? The answer is, Yes. Imagine a photon of energy ΔE incident on an atom which is already excited, its excitation energy being equal to the energy ΔE of the photon.

The photon can stimulate the excited electron to fall back to the lowest energy state, instead of the excited electron waiting for 10^{-8}s for its spontaneous transition. This transition can then take place much sooner than 10^{-8}s. In this process a photon of energy ΔE is emitted and we already have the incident photon of the same energy because, now it is not absorbed.

The emitted photons travel in exactly the same direction as the stimulated photon and are exactly in phase. This phenomenon is called stimulated emission as shown in (Fig 19.10).

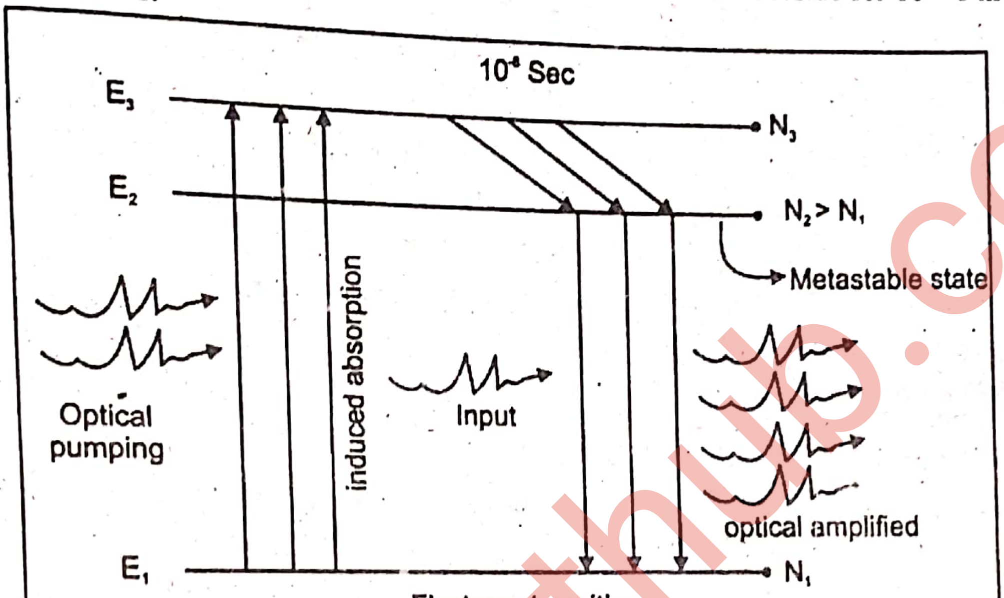
Stimulated Emission

The excited atom decays by stimulated or induced emission. In this case, the photon of energy $hf = E_2 - E_1$ induces the atom to decay by emitting a photon of same energy, going in the same directions

Population Inversion and Laser Action

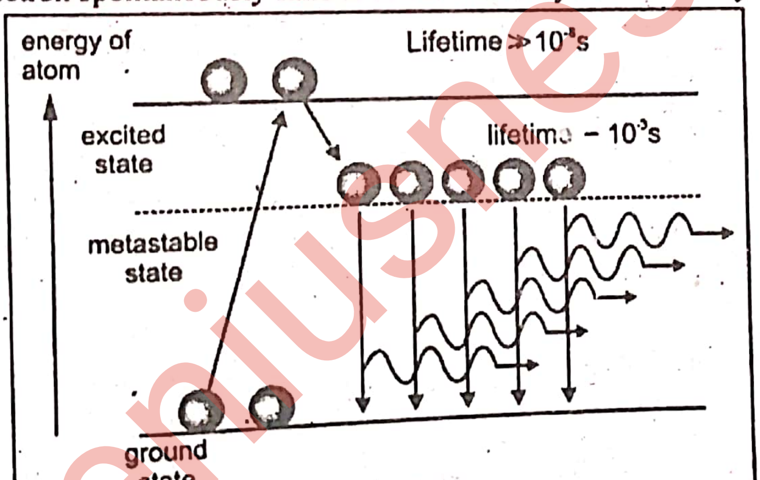
Let us consider a simple case of a material whose atoms can reside in three different states as shown in fig 19.11.

- State E_1 is ground state,
- Metastable state= E_2
- Excited state= E_3,
- The atoms can reside only for 10^{-8} s in excited state E_3 and the atoms can reside for 10^{-3} s in metastable state E_2, much longer than 10^{-8} s.

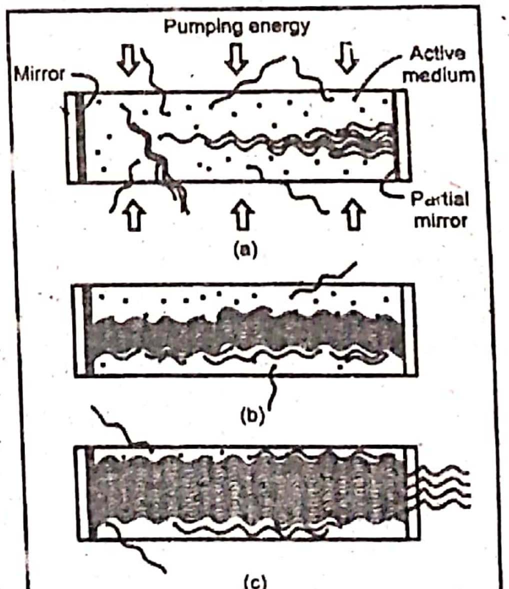


Electrons transition

- A metastable state is an excited state in which an excited electron in unusually stable and from which the electron spontaneously falls to lower state only after relatively longer time.



Metastable states



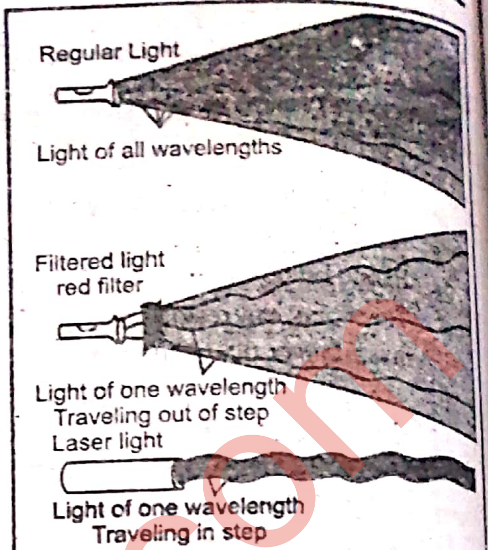
Photons move back and forth inside reflecting mirrors.

The transition from or to this state are difficult as compared to other excited states.

Hence, instead of direct excitation to this state, the electrons are excited to higher level for spontaneous fall to metastable state.

- Also let us assume that the incident photons energy $hf = E_3 - E_1$ raise the atom from ground state E_1 to the excited state E_3, but the excited atoms do not decay back to E_1. Thus the only alternative for the atoms in the excited state E_3 is to decay spontaneously to state E_2.

- **In this situation, the state E_2 contains more atom than E_1. This situation is called population inversion.**
- Once the population inversion has been reached, the lasing action of a laser is simple to achieve.
- The photons of energy $hf = E_2 - E_1$, produces stimulated emission in the atoms of metastable state E_2. As a result of an induced emission, an intense, coherent beam in the direction of the incident photon is produced.



Comparison of light sources with laser.

The emitted photons must be confined in the assembly long enough to stimulate further emission from other excited atoms. This is achieved by using mirrors at the two ends of the assembly. One end is made totally reflecting, and the other end is partially transparent to allow the laser beam to escape (Fig 19.12). As the photons move back and forth between the reflecting mirrors they continue to stimulate other excited atoms to emit photons. As the process continues the number of photons multiply, and the resulting radiation is, therefore, much more intense and coherent than light from ordinary sources.

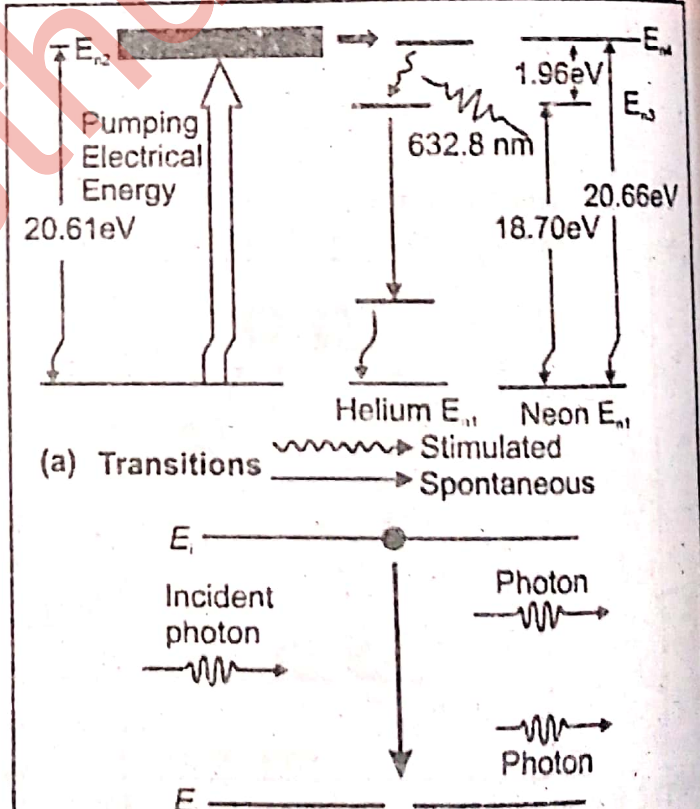
Helium – Neon Laser

It is the most common type of lasers used in physics laboratories. Its discharge tube is filled with 85% helium and 15% neon gas.

- The neon is the lasing or active medium in this tube.

  By chance, helium and neon have nearly identical metastable states, respectively located 20.61 eV and 20.66 eV level.

  The high voltage electric discharge excites the electrons in some of the helium atoms to the 20.61 eV state. In this laser, population inversion in neon is achieved by direct collisions with same energy electrons of helium atoms.



(b) Stimulated emission

- Thus excited helium atoms collide with neon atoms, each transferring its own 20.61 eV of energy to an electron in the neon atom along with 0.05 eV of K.E from the moving atom. As a result, the electrons in neon atoms are raised to the 20.66 eV state.
- In this way, a population inversion is sustained in the neon gas relative to an energy level of 18.70 eV. Spontaneous emission from neon atoms initiate laser action and stimulated emission causes electrons in the neon to drop from 20.66 eV to the 18.70 eV level and red laser light of wavelength 632.8 nm corresponding to 1.96 eV energy is generated (Fig 19.13).

Q.13 What are the Uses of Laser in medicine and industry?

Uses of LASER

1) **Surgical Tool**

Laser beams are used as a surgical tool for welding detached retinas.

2) **Destroy Tissue**

The narrow intense beam of laser can be used to destroy the tissue in a particular area. Tiny organelles with the living cell have been destroyed by using laser to study how the absence of that organelle affects the behavior of cell.

Hologram

3) **To diagnose Diseases**

The helium-neon beam of laser is used to diagnose the disease of eye.

4) **Cancer Cure**

Fine focused beam has been used to destroy cancerous and pre-cancerous cell.

5) **Seal off the Capillaries**

The heat of the laser seals off capillaries and lymph vessels to prevent the spread of disease.

6) **Welding and Drilling**

The intense heat produced in small area by laser may used for welding and drilling the tiny holes in hard materials.

7) **Lining up the Equipment**

The precise straightness of laser beam is also useful to surveyor for lining up equipment.

8) **Fusion Reactions**

It is potential energy source for inducing fusion reaction.

9) **Telecommunication**

It can be use for telecommunication in fiber optical.

10) **Holography (Whole picture)**

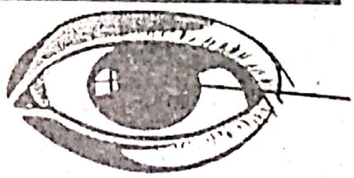
Laser beam can used to generate the three dimensional image of objects in a process called holography.

11) **To Read Bar Codes**

He-Ne laser is the laser whose narrow red beam is used in super markets to read bar codes.

> **Holography**
> It is a scheme for recording the intensity and phase of the waves from objects. This type of image formation called holography from Greek word meaning entire picture and the image is called hologram.

Do You Know?



The helium-neon laser beam is being used to diagnose diseases of the eye. The use of laser technology in the field of ophthalmology is widespread.

MCQ's From Past Board Papers

1. Atom can reside in metastable state for:
   (A) 10^{-1} sec (B) 10^{-2} sec (C) 10^{-3} sec (D) 10^{-4} sec
2. In Helium-Neon laser, discharge tube is filled with Neon gas:
   (A) 10% (B) 15% (C) 85% (D) 90%
3. For holography we use a beam of:
   (A) γ–rays (B) X–rays (C) β–rays (D) LASER
4. Laser is beam of light which is:
   (A) monochromatic (B) coherent (C) unidirectional (D) All these
5. What is the colour of light emitted from He-Ne Laser?
   (A) Blue (B) Green (C) Red (D) Yellow
6. Electron can reside in excited state for about:
   (A) 10^{-3} sec (B) 10^{-5} sec (C) 10^{-8} sec (D) 10^{-11} sec
7. If number of atoms in metastable state (E_2) is "N_2" and in ground state (E_1) is "N_1" the population inversion means ___ (Fed 2014)
   (A) $N_2 = N_1$ (B) $N_2 < N_1$ (C) $N_2 > N_1$ (D) $\frac{N_1}{N_2} = \frac{E_2}{E_1}$

8. Which is not characteristic of LASER?
(A) Monochromatic (B) Coherent (C) Intense (D) Multi directional

9. Normally electron can reside in excited state for about
(A) 10^{-3} s (B) 10^{-8} s (C) 10^{-6} s (D) 10^{8} s

Answers Key

1. C	2. B	3. D	4. D	5. C	6. A	7. C	8. D	9. B

FORMULAE

1	Balmer series	$\frac{1}{\lambda}=R_H\left(\frac{1}{2^2}-\frac{1}{n^2}\right)$ where n=3,4,5,…………		
2	Lymen series	$\frac{1}{\lambda}=R_H\left(\frac{1}{1^2}-\frac{1}{n^2}\right)$ where n = 2, 3, 4,……		
3	Paschen series	$\frac{1}{\lambda}=R_H\left(\frac{1}{3^2}-\frac{1}{n^2}\right)$ where n = 4, 5, 6,……		
4	Brackett series	$\frac{1}{\lambda}=R_H\left(\frac{1}{4^2}-\frac{1}{n^2}\right)$ where n = 5, 6, 7,……		
5	Pfund series	$\frac{1}{\lambda}=R_H\left(\frac{1}{5^2}-\frac{1}{n^2}\right)$ where n = 6, 7, 8,……		
6	General formula for any spectral series	$\frac{1}{\lambda}=R_H\left(\frac{1}{p^2}-\frac{1}{n^2}\right)$ n > p Where n = p + 1, p + 2, p + 3, ….		
7	Angular momentum of electron in H-atom	$mvr=\frac{nh}{2\pi}$		
8	Energy of emitted photon	$hf = E_n - E_p$		
9	Velocity of electron in H-atom	$v_n=\frac{nh}{2\pi m r_n}$	$v_n=\frac{2\pi k e^2}{nh}$	
10	Radius of nth orbit in H-atom	$r_n=\frac{n^2h^2}{4\pi^2ke^2m}$	$r_n=n^2\times 0.053nm$	$r_n=r_1 n^2$
11	K.E. of electron in nth orbit of H-atom	$K.E.=\frac{1}{2}mv_n^2$	$K.E.=\frac{ke^2}{2r_n}$	

12	P.E. of electron in nth orbit of H-atom	$U = -q\Delta V$		$U = -\frac{ke^2}{r_n}$
13	T.E. of electron in nth orbit of H-atom	$E_n = -(\frac{2\pi^2 k^2 me^4}{h^2})\frac{1}{n^2}$	$E_n = -\frac{E_o}{n^2}$	$E_n = -\frac{13.6}{n^2}eV$
14	Emission spectrum of Hydrogen atom	$\frac{1}{\lambda} = \frac{E_o}{hc}(\frac{1}{p^2} - \frac{1}{n^2})$	$\frac{1}{\lambda} = R_H(\frac{1}{p^2} - \frac{1}{n^2})$	
15	K_α- characteristic X- rays	$hf_{k\alpha} = E_L - E_K$		
16	K_β- characteristic X- rays	$hf_{k\beta} = E_M - E_K$		
17	Maximum energy of breaking radiation	$K.E = hf_{max} = \frac{hc}{\lambda_{min}}$	$K.E = hf_{max} = \frac{hc}{\lambda_{min}}$	$K.E = hf_{max} = \frac{hc}{\lambda_{min}}$
18	Minimum wavelength of breaking radiation	$\lambda_{min} = \frac{hc}{K.E}$	$\lambda_{min} = \frac{hc}{Ve}$	

UNITS

1	Rydberg's constant	m^{-1}	
2	Planck's constant	J-s	
3	Energy of electron in an orbit	J	eV
4	Speed of light	m/s	
5	Angular momentum	J-s	

CONSTANTS

1	Rydberg constant	$1.097 \times 10^{-7} m^{-1}$	
2	Planck's constant	6.63×10^{-34} J-s	
3	Speed of light	3×10^{8} m/s	

Key Points

- When an atom gas or vapours at less than atmospheric pressure is suitably exited, usually bypassing electric current through it, the emitted radiation has a spectrum which contains certain specific wavelengths only.
- Postulates of Bohr's model of H-atom are:
  - i. An electron bound to the nucleus in an atom, can move around the nucleus in certain circular orbits without radiating. These orbits are called the discrete stationary states of the atom.
  - ii. Only those stationary states are allowed for which orbital angular momentum is, equal to an integral multiple of $\frac{h}{2\pi}$ i.e, $mvr = \frac{nh}{2\pi}$
  - iii. Whenever an electron makes a transition, i.e, jumps from high energy state E_n to a lower energy state E_p, a photon of energy hf is emitted so that $hf = E_n - E_p$
- The transition of electrons in the hydrogen or other light elements results in the emission of spectral line in the infrared, visible ultraviolet region of electromagnetic spectrum due to small energy difference in the transition levels.
- The X-rays emitted in inner shell transition are called characteristics X-rays, because their energy depends upon the type of target materials.
- The X-rays that ate emitted in all directions and with a continuous range of frequencies are known as continuous X-rays.
- Laser is the acronym for light amplification by stimulated Emission of Radiation.
- The incident photon absorbed by an atom in the ground state E_1, there by leaving the atom in the exited state E_2 called stimulated or induces absorption.
- Spontaneous or induced emission is that in which the atom emits a photon of energy $hf = E_2 - E_1$ induce the atom to decay by emitting a photon that travels in the direction of the incident photon. For each incident photon, we have two photons going in the same direction giving rise to an amplified as well as unidirectional coherent beam.

Solved Examples

Example 19.1:

The electron in the hydrogen atom makes a transition from n = 2 energy state to the ground state n = 1. Find the wavelength of the emitted photon.

Solution:

We can use the equation

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3R_H}{4}$$

$$\lambda = \frac{4}{3R_H}$$

$$\lambda = \frac{4}{3(1.097\times10^7)}$$

$$\lambda = .215\times10-7m = 121.5nm$$

Example 19.2:

The Balmer series for hydrogen atom corresponds to electronic transitions that terminate in the state of quantum number n = 2. Find the longest wavelength of photon emitted.

Solution:

The longest – wavelength in the Balmer series result from the transition.
From n = 3 to n = 2

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

$$\lambda_{max} = \frac{36}{5R_H}$$

$$\lambda_{max} = \frac{36}{5(1.097\times10^7)} = 656.3\,nm$$

Example 19.3:

Find the shortest wavelength photon in the Balmer series.

Solution:

The shortest – wavelength photon in the Balmer series is emitted when the electron makes

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

$$\lambda_{min} = \frac{4}{R_H} = \frac{4}{1.097\times10^7} = 364.36\,\text{nm}$$

Example 19.4:

When a hydrogen atom is bombarded, the atom may be raise into a higher energy state. As the excited electron fall back to the lower energy levels light is emitted. What are the three longest wavelength spectral lines emitted by the hydrogen atom as it returns to the n = 1 state from higher energy states?

Solution:

$$n=2 \rightarrow n=1:\ \Delta E_{2,1} = -3.4-(-13.6) = 10.2\text{eV}$$

$$n=3 \rightarrow n=1:\ \Delta E_{3,1} = -1.5-(-13.6) = 12.1\text{eV}$$

$$n=4 \rightarrow n=1:\ \Delta E_{4,1} = -0.85-(-13.6) = 12.8\text{eV}$$

$$n=2 \rightarrow n=1:\ \Delta E_{2,1} = -3.4-(-13.6) = 10.2\text{eV}$$

$$n=3 \rightarrow n=1:\ \Delta E_{3,1} = -1.5-(-13.6) = 12.1\text{eV}$$

$$n=4 \rightarrow n=1:\ \Delta E_{4,1} = -0.85-(-13.6) = 12.8\text{eV}$$

To find the corresponding wavelength we can use $\Delta E = hf = \frac{hc}{\lambda}$.

For n = 2 to n = 1 transition

$$\lambda = \frac{hc}{\Delta E_{2,1}}$$

$$\lambda = \frac{6.63\times10^{-34}\,\text{j.s}\left(3\times10^8\,ms^{-1}\right)}{(10.2\text{eV})\left(1.60\times10^{-19}\,\text{JeV}^{-1}\right)} = 121\text{nm}$$

For n = 3 to n = 1 transition

$$\lambda = \frac{hc}{\Delta E_{3,1}}$$

$$\lambda = \frac{(6.63\times10^{-34}\,\text{js})(3\times10^{8}\,\text{ms}^{-1})}{(12.1\text{ev})(1.60\times10^{-19}\,\text{JeV}^{-1})} = 102\,\text{nm}$$

For n = 4 to n = 1 transition

$$\lambda' = \frac{hc}{\Delta E_{4,1}}$$

$$\lambda = \frac{(6.63\times10^{-34}\,\text{js})(3\times10^{8}\,\text{ms}^{-1})}{(12.8\text{ev})(1.60\times10^{-19}\,\text{JeV}^{-1})} = 96.9\text{nm}$$

These are the first three lines of the Lyman series.

Example 19.5:
Calculate the minimum wavelength produced when electrons are accelerated through a potential difference of 1000, 00 V, for an X-ray tube.

Solution:

Using (Eq 19.23)

$$\lambda_{\text{min}} = \frac{hc}{eV}$$

$$\lambda_{\text{min}} = \frac{(6.63\times10^{-34}\ \text{J.s})(3\times10^{8}\ \text{m/sec})}{(1.60\times10^{-19}\text{c})(10^{5}\ \text{V})}$$

$$\lambda_{\text{min}} = 1.24\times10-11\text{m}$$

Text Book Exercises

Q.1 Select the correct answer of the following questions.

(i) If 13.6eV energy is required to ionize the hydrogen atom, then the required energy to remove an electron from n = 2 is:

(a) 10.2eV (b) 0 eV (c) 3.4 eV (d) 6.8 eV

(ii) For an atom of hydrogen atom the radius of the first orbit is given by:

(a) $\frac{h}{me^2}$ (b) $\frac{me}{4h^2}$ (c) $\frac{h^2}{4\pi^2 kme^2}$ (d) $h^2 me^2$

(iii) The Balmer series is obtained when all the transition of electron terminate on:

(a) 1st orbit (b) 2nd orbit (c) 3rd orbit (d) 4th orbit

(iv) In accordance with Bohr's theory the K.E. of the electron is equal to:

(a) $\frac{ke^2}{2r}$ (b) $\frac{ke^2}{r}$ (c) $\frac{ke^2}{r^2}$ (d) $\frac{ke^2}{2r^2}$

(v) According to Bohr's theory the radius of quantized orbit is given by:

(a) $\frac{4\pi^2 m}{n^2 h^2 ke^2}$ (b) $\frac{n^2 h^2}{4\pi^2 m ke^2}$ (c) $\frac{4\pi^2 m Ze^2 k}{n^2 h^2}$ (d) $\frac{n^2 h^2 ke^2}{4\pi^2 m}$

(vi) In the Bohr's, model of the hydrogen atom, the lowest orbit corresponds to:

(a) Infinite energy (b) Maximum energy (c) Minimum energy (d) Zero energy

(vii) When an electron in an atom goes from a lower to higher orbit its:

(a) K.E increases, P.E decreases (b) K.E increases, P.E increases
(c) K.E decreases, P.E increases (d) K.E decreases, P.E decreases

(viii) Frequency of X-rays depends upon:

(a) Number of electrons striking target (b) Accelerating potential
(b) Nature of the target (d) Both b and c

(ix) Target material used in X-rays tube must have following properties:

(a) high atomic number and high melting point (b) high atomic number and low melting point. (c) low atomic number and low melting point (d) high atomic number only

(x) Laser is device which can produce:

(a) Intense beam of light (b) Coherent beam of light
(c) Monochromatic beam of light (d) All of the above

No.	Option	ANSWER	EXPLANATION
(i)	c	3.4 eV	As I.E = $E_\infty - E_n$ I.E = $E_\infty - E_2$ As $E_2 = \frac{E_o}{2^2}$ $= \frac{-13.6}{4}$ $= -3.4$ eV So I.E = $0 - (-3.4 \text{ eV})$ = 3.4 eV
(ii)	c	$\frac{h^2}{4\pi^2 kme^2}$	As $r_n = \frac{n^2h^2}{4\pi^2 kme^2}$ for n = 1 $r_1 = \frac{h^2}{4\pi^2 kme^2}$
(iii)	b	2^{nd} orbit	$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ n = 3, 4, 5, ...
(iv)	a	$\frac{ke^2}{2r}$	K.E = $\frac{ke^2}{2r_n}$ Where k is coulomb's constant and r_n is the radius of orbit.
(v)	b	$\frac{n^2h^2}{4\pi^2 m Ze^2}$	$r_n = \frac{n^2h^2}{4\pi^2 kme^2}$
(vi)	c	Minimum energy	As $E_n = -\frac{E_o}{n^2}$ For lowest orbit put n = 1 $E_1 = \frac{-13.6}{1^2} = -13.6$ eV It has minimum value but not few.

(vii)	c	K.E decreases, P.E increases	$K.E = \frac{ke^2}{2r_n}$ and $P.E = \frac{-ke^2}{r_n}$ So with increase in r_n The P.E will increase and K.E will decrease
(viii)	d	Both b and c	Frequency of continuous X-rays will depends on these. So $Ve = K.E = hf_{max}$ where as frequency of characteristic X-ray depends upon nature of target metal.
(ix)	a	high atomic number and high melting point	Target must be of heavy metal, because energy differences in there material is large so x-rays can be produced. Whereas on hitting the electrons with target, the temperature increases. So metal must have high temperature stability.
(x)	d	All of the above	They are the basic properties of laser which differentiate it from ordinary light.

Comprehensive Questions

Q.2 Write short answers of the following questions.

1. Describe the spectrum of hydrogen atom in detail.

Ans: See Theory Question No. 1

2. What are Bohr's postulates about hydrogen atom? Hence derive expression for the (a) radii of electron orbit (b) energy of the electron.

Ans: See Theory Question No. 2

3. What do you understand by the terms normal state, Excited state, Excitation energy, ionization energy.

Ans: See Theory Question No. 6

4. What are X-rays? Give an account of the properties, and uses of X-rays.

Ans: See Theory Question No. 7

5. What is a laser? Explain the principle and operation of a laser. Describe some practical uses of lasers.

Ans: See Theory Question No. 12

Conceptual Questions

1. Why does the spectrum of hydrogen consists of many lines even though a hydrogen atom has only a single electron?

Ans: The spectrum of hydrogen atom consists of many lives although a hydrogen atom consist of a single electron. A hydrogen atom has only a single electron, it contains many energy levels. When an electron jumps from higher energy level to a lower energy level, it will emit a photon of energy equal to energy difference of two energy levels.

When the electron de-excites from excited to ground state in several jumps rather than a single jump. So several spectral lines are obtained rather than a single spectral line.

2. Suppose that the electron in hydrogen atom obeyed classical mechanics rather quantum mechanics. Why would such a hypothetical atom emit a continuous spectrum rather than the observed line spectrum?

Ans: According to classical electromagnetic wave theory, every accelerating charge must radiate the electromagnetic radiations. So due this continuous emission of energy, the spectrum obtained from hydrogen atom must be continuous and also it must fall into the nucleus, which will not happen in real.

3. Can the electron in the ground state of hydrogen absorb a photon of energy (a) less than 13.6eV (b) greater than 13.6eV? Explain.

Ans: Electron can absorb a photon of 13.6 eV or greater than 13.6 eV in ground energy state.
If a photon of energy 13.6 eV falls on the electron of H-atom it will remove the electron from atom. If photon of energy greater than 13.6 eV is incident of electron of H-atom then 13.6 eV energy is used for removing the electron and extra energy is taken up by electron as K.E.

4. Why do solids give rise to continuous spectrum while hot gases give rise to line spectrum?

Ans: In solids, atoms and molecules are very closed to each other. The energy of the electron in an energy level is influenced by electrons of neighbouring atoms. So energies in the energy levels is changed. Hence due to transition, all wavelengths are emitted and continuous spectrum is obtained.
In gases, due to electric discharge, the atoms become excited. As the atoms in gases state have well defined energy levels, in these levels the energies are decrete. When de-excition of atom take place, the decrete energies are released whose value are equal to the energy difference of two energy levels. That is why the line spectrum is obtained.

5. Explain the difference between laser light and light from an incandescent lamp.

Ans:

- Laser light is mono-chromatic which means it consist of single wavelength where as light coming from in candesent source is polychromatic.
- Laser light is highly coherent which means that all laser light waves are in phase with each other where as light coming from incandescent source is not coherent.
- Laser light is of high intensity which mean that number of photon in a unit volume for laser is much greater than the number of photon of incandescent light in the same volume.
- Laser light is highly directional which mean it emitted with a narrow beam in a specific direction where as light coming from a incandescent source is emitted in many directions in moving away from the source.

6. Why Bohr extends quantum theory to the structure of the atom?

Ans: As the classical electromagnetic wave theory fail to explain the structure of atom. According to this theory due to accelerating charge the electron must fall into nucleus and the spectrum of atom be continuous which is not practically happen. So Bohr explain the structure of atom by mean quantum mechanics. According to him the only certain orbits are allowed for which orbital angular momentum is quantized (i.e $mvr = \frac{nh}{2\pi}$), also during the transitions between two energy states, the absorbed / emitted energies are quantized (i.e. $hf = E_n - E_p$)

7. Why $_2He^4$ has larger ionization energy than H?

Ans: The amount of energy required to remove the electron from is ground state is called ionization energy.
In case of helium ^4_2He, it has two electrons and two protons rather thus one electron and one proton as in hydrogen ^1_1H.
So, coulomb's one in case ^4_2He is doubled to hydrogen ^1_1H. He more energy (called ionization energy) is required to remove the electron from ground state.

I.E of helium $= E_\infty - E_1 = 0 - (-54.4) = 54.4$ eV

I.E of hydrogen $= E_\infty - E_1 = 0 - (-13.6) = 13.6$ eV

8. X-rays can emit electrons from metal surface and X-rays can be diffracted Comment?

Ans: X-ray region lies between U.V and γ-ray regions in electromagnetic spectrum.

⇒ As x-rays are high energy radiations than U.V and visible radiation, so x-rays can also produce the phenomenons as U.V radiations like photoelectric effect. In which the metal is exposed by suitable frequency of light and the electrons are liberated. i.e.,

$$hf = \phi + (K.E)_{max}$$

⇒ As x-rays also exhibits the wave behaviours. Their wavelength ($\sim 10^{-10}$m) is of the order of lattice spacing in a crystal. So the reflecting planes of crystals serve like mirrors and x-ray are diffracted from them the Bragg's law for x-rays diffraction is

$$d \sin\theta = n\lambda$$

where d is interplaner spacing and n is the order of diffraction.

9. Why X-rays have different properties from light even though both originate from orbital transition of electron in excited atoms?

Ans: Although x-rays are of similar nature as that of other electromagnetic waves, but due to their high energy they have some different properties than light:

- They can produce compton's scattering but light cann't do so.
- They cann't diffract from ordinary diffraction grating but suffers diffraction from grating.
- As they are more energetic. So their penetrating power is more than light.
- X-ray spectrum consists of both characters and continuous spectrum.

10. What is meant by the statement that a laser beam is coherent, monochromatic and parallel?

Ans: Phase coherence, monochromatic and unidirectional are the basic properties of laser which differentiate it from ordinary light.

- Monochromatic means that laser light consist single wavelength.
- Phase coherence mean the constant phase relationship of photons with each other. It is achieved by mean of stimulated emission.
- Parallel mean uni-directional, the laser light is parallel means uni-directional and well collimated and will not disperse at all.

11. What are laser knives?

Ans: Generally the term "Laser" refers to "Knives" because both are thin at spine and very thin behind the edge. This thin gemetery make them vary efficient cutters. As they are very thin so have very small resistance when cutting through items allowing them to cut with less effort.

They tend to be very light weight and more flexible then thicker knives.

They are commonly used in bloodless surgery to cut the blood vessel without bleeding. It is used to remove tumor. It is used to cut glass, paper and plastic.

12. Why we cannot see atom?

Ans: An atom is much smaller than wavelength of visible light, so we can not see them by using optical, microscope.

Only those objects become visible whose size is greater than size of wavelength of light used (i.e., visible). As size of the atom is of the order of $\sim 10^{-10}$ m where as wavelength of visible light is of the order of $\sim 10^{-7}$ m.

As wavelength of visible light is greater than size of atom. So it can not be visible for us.

13. What meant by braking radiation?

Ans: X-rays produced as result of deceleration of electrons by target material are called Breaking radiations or Bremsstrahlung. In x-ray tube, the electrons are accelerated by on several kilovotts toward heavy target. Striking these electrons lose their kinetic energy which will convert in form of high energy x-ray photons. If there electron lose their whole kinetic energy in first collision then

$$K.E = Ve = hf_{max} = \frac{hc}{\lambda\ min}$$

Otherwise they lose their energy in several collisions and x-rays of continuous energies are obtained. Such x-rays are continuous x-rays.

14. What is optical pumping?

Ans: In pumping process the energy is given to the electrons in ground energy state to move them to the excited state, which can be made by several pumping techniques like electronic pumping, thermionic pumping or optical pumping.

In optical pumping the photons are used to raise (or pump) the electrons from low energy level to higher energy level. It is commonly used is laser construction to pump the active laser medium so as to achieve population inversion.

Numerical Problems

1. Find the shortest wavelength photon emitted in the layman series of hydrogen.

Given:

Energy level $n = \infty$

Energy level $P = 1$

Rydberg constant $R_H = 1.0974 \times 10^7$ m

To Find:

Wavelength $\lambda = ?$

Solution:

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

Putting values: $\frac{1}{\lambda} = 1.0974 \times 10^7\ m^{-1}\left(\frac{1}{(1)^2} - \frac{1}{(\infty)^2}\right)$

Or $\frac{1}{\lambda} = 1.0974 \times 10^7\ m^{-1}$ $\lambda = \frac{1}{1.0974 \times 10^7}$ m

$$\frac{1}{\lambda} = 0.911244 \times 10^{-7} m$$

$$\boxed{\lambda = 9.11 \times 10^{-8}\ m = 91.1 \times 10^{-9}\ m = 91nm}$$

2. What is the wavelength of the second line of paschen series?

Given:

Energy level $n = 5$

Energy level $P = 3$

Rydberg constant $R_H = 1.0974 \times 10^7$m

To Find:

Wavelength $\lambda = ?$

Solution:

The general formula for wavelength and lines in hydrogen atoms is:

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

Putting values:

$$\frac{1}{\lambda} = 1.0974 \times 10^7\ m^{-1}\left(\frac{1}{(3)^2} - \frac{1}{(5)^2}\right)$$

$$\frac{1}{\lambda} = 0.718 \times 10^7\ m^{-1} \Rightarrow \frac{1}{\lambda} = \frac{1}{0.07804 \times 10^7}\ m$$

$$\frac{1}{\lambda} = 12.813494 \times 10^{-7}\ m$$

$$\boxed{\lambda = 1.281 \times 10^{-6} = 1281.4 \times 10^{-9}\ m = 1281.4nm}$$

3. Calculates the longest wavelength of radiation for the paschen series.

Given:

Energy level $n = 4$

Energy level $P = 3$

Rydberg's constant $R_H = 1.0974 \times 10^7$m

To Find:

Wavelength $\lambda = ?$

Solution:

The general formula for wavelength and lines in hydrogen atoms is

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

Putting values:

$$\frac{1}{\lambda} = 1.0974 \times 10^7 m^{-1}\left(\frac{1}{(3)^2} - \frac{1}{(4)^2}\right)$$

Or $$\frac{1}{\lambda} = 0.5334 \times 10^7 m^{-1}$$

$$\lambda = \frac{1}{0.05334 \times 10^7} m$$

$$\lambda = 18.747655 \times 10^{-7} m$$

$$\lambda = 1.8747655 \times 10^{-6} m$$

$$\lambda = 1874.76 \times 10^{-9} m$$

$$\boxed{\lambda = 1874.8 nm}$$

4. The series limit wavelength of the Balmer series is emitted as the electron in the hydrogen atom falls from $n = \infty$ to the $n = 2$ state. What is the wavelength of this line? Where $\Delta E = 3.40 eV$?

Given:

Energy difference $\Delta E = 3.040 eV$

Energy level $n = \infty$

Energy level $P = 2$

Rydberg constant $R_H = 1.0974 \times 10^7 m$

To Find:

Wavelength $\lambda = ?$

Solution:

The general formula for wavelength and lines in hydrogen atom is:

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

Putting values:

$$\frac{1}{\lambda} = 1.0974 \times 10^7 m^{-1}\left(\frac{1}{(2)^2} - \frac{1}{(\infty)^2}\right)$$

Or $$\frac{1}{\lambda} = 0.27435 \times 10^7 m^{-1}$$

Or $$\lambda = \frac{1}{0.27435 \times 10^7}$$

$$\lambda = 3.644979 \times 10^{-7}$$

$$\boxed{\lambda = 364.49 \times 10^{-9} m = 364.49 nm}$$

5. A photon is emitted from a hydrogen atom, which undergoes a transition from that $n = 3$ state to the $n = 2$ state. Calculate (a) the energy (b) the wavelength, and (c) frequency of the emitted photon.

Given:

Energy level $n = 3$

Energy level $P = 2$

Rydberg constant $R_H = 1.0974 \times 10^7 m$

Planck's constant $h = 6.626 \times 10^{-34}$ Js

Speed of light $C = 3 \times 10^{8}\ ms^{-1}$

To Find:

Wavelength $\lambda = ?$

Energy $E = ?$

Frequency $f = ?$

Solution:

The general formula for wavelength and lines in hydrogen atom is

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

Putting values:

$$\frac{1}{\lambda} = 1.0974 \times 10^{7} m^{-1}\left(\frac{1}{(2)^2} - \frac{1}{(3)^2}\right)$$

Or

$$\frac{1}{\lambda} 0.152417 \times 10^{7}\ m^{-1}$$

$$\lambda = \frac{1m}{0.152417 \times 10^{7}}$$

$$\lambda = 6.560974 \times 10^{-7} m$$

Therefore

$$\boxed{\lambda = 656.09 \times 10^{-9} m = 656nm}$$

By Planck's hypothesis $E = \frac{hC}{\lambda}$

Putting values:

$$E = \frac{6.626 \times 10^{-34}\ Js \times 3 \times 10^{8}\ ms^{-1}}{6.5609 \times 10^{-7} m}$$

Therefore,

$$E = 300298 \times 10^{-19}\ J$$

Hence

$$\boxed{E = \frac{3.0298 \times 10^{-19}\ J}{1.602 \times 10^{-19} C} = 1.8912eV}$$

Again by Planck's quantum theory

$$E = hf$$

$$f = \frac{E}{h}$$

Putting values:

$$f = \frac{3.0298 \times 10^{-19} J}{6.626 \times 10^{-34}\ Js}$$

$$\boxed{f = 4.57 \times 10^{14}\ Hz}$$

Find the longest wavelength of light capable of ionizing a hydrogen atom. How much energy in needed to a hydrogen atom?

Given:

Energy level $n = \infty$

Energy level $P = 1$

Rydberg constant $R_H = 1.0974 \times 10^{7} m$

Plank's constant $h = 6.26 \times 10^{-34}$ Js

Speed of light $C = 3 \times 10^{8}\ ms^{-1}$

To Find:

Wavelength $\lambda = ?$ Energy $E = ?$

Solution:

The general formula for wavelength and lines in hydrogen atom is

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

Putting values: $\frac{1}{\lambda} = 1.0974 \times 10^7 m^{-1}\left(\frac{1}{(1)^2} - \frac{1}{(\infty)^2}\right)$

Or $\frac{1}{\lambda} = 1.0974 \times 10^7 m^{-1}$

$$\lambda = \frac{1}{1.0974 \times 10^7} m$$

$$\lambda = 0.911244 \times 10^{-7} m$$

$$\boxed{\lambda = 9.11 \times 10^{-8} m = 91.1 \times 10^{-9} m = 91nm}$$

By Plank's hypothesis $E = \frac{hC}{\lambda}$

Putting values: $E = \frac{6.626 \times 10^{-34} Js \times 3 \times 10^8 ms^{-1}}{9.11 \times 10^{-8} m}$

Therefore, $E = 2.1819 \times 10^{-18} J$

Hence, $E = \boxed{\frac{2.1819 \times 10^{-18} J}{1.602 \times 10^{-19} C} = 13.619eV}$

7. Calculate the radius of the innermost orbital level of the hydrogen atom.

Given:

Energy level n = 1

Plank's constant $h = 6.626 \times 10^{-34}$ Js

Number $\pi = 3.14$

Electron mass $m = 9.109 \times 10^{-31}$ kg

Coulomb's constant $k = 8.988 \times 10^9 Nm^2/C^2$

Charge on electron $e = 1.602 \times 10^{-19}$ C

To Find:

Radius $r_1 = ?$

Solution:

From Bohr's model for hydrogen atom

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

Putting values $r_1 = \frac{(1)^2(6.63 \times 10^{-34} Js)^2}{4(3.14)^2(9.11 \times 10^{-31}kg)(8.99 \times 10^9 Nm^2 C^2)(1.67 \times 10^{-19})^2}$

$$\boxed{r_1 = 0.53 \times 10^{-19} m}$$

8. (a) Determine the energy associated with innermost orbit of the hydrogen atom (n-1). (b) Determine the energy associated with the second orbit of the hydrogen atom. (c) What energy does an incoming photon possess to raise an electron from first to the second allowed orbit of the hydrogen atom?

Given:

Energy level n = 1

Plank's constant $h = 6.626 \times 10^{-34}$ Js

Electron mass $m = 9.109 \times 10^{-31}$kg

Coulomb's constant $k = 8.988 \times 10^9 Nm^2/C^2$

Charge on electron $e = 1.602 \times 10^{-19}$ C

o Find:

irst orbit energy E_1 =?

$$E_n = \frac{2\pi^2 mk^2e^4}{h}$$

$$E_1 = -\frac{1}{(1)^2} \times \frac{2(3.14)^2 (9.11 \times 10^{-31})(8.99 \times 10^9)(1.67 \times 10^{-19})^4}{(6.63 \times 10^{-34} Js)^2}$$

$$\boxed{E_1 = -2.17 \times 10^{-18} J = -13.6 eV}$$

Similarly,

$$E_2 = -\frac{1}{(2)^2} \times \frac{2(3.14)^2 (9.11 \times 10^{-31})(8.99 \times 10^9)(1.67 \times 10^{-19})^4}{(6.63 \times 10^{-34} Js)^2}$$

$$\boxed{E_2 = 0.54 \times 10^{-18} J = -3.4 eV}$$

The energy difference is

$$\Delta E = E_2 - E_1$$

Putting values

$$\Delta E = -3.4 eV - (-13.6 eV)$$

$$\boxed{\Delta E = 10.2 eV}$$

9. An electron drops from the second energy level to the first energy level within an excited hydrogen atom (a) determine the energy of the photon emitted (b) calculate the frequency of the photon emitted (c) calculate the wavelength of the photon emitted.

Given:

Energy level $n = 2$
Energy level $P = 1$
Planck's constant $h = 6.62 \times 10^{-34}$ Js
Speed of light $C = 3 \times 10^8 ms^{-1}$
$E_o = 2.17 \times 10^{-18}$ J = 13.6eV

Solution:

If E_p = initial energy before transition
E_n = Final energy after transition

Then

$$E = E_n - E_p$$

From energy of electron in quantized orbit $E_n = \frac{E_0}{n^2}$ And $E_p = -\frac{E_0}{P^2}$

$$E = \left(-\frac{E_0}{n^2}\right)$$

Putting values $E = \frac{13.6 eV}{(1)^2}$

$$E = 3.4 eV + 13.6 eV$$

$$\boxed{E = 10.2 eV}$$

The energy in joules will be

$$E = 10.2 eV \times 1.602 \times 10^{-19} C = 16.3404 \times 10^{-19} J$$

By Plank's quantum theory

$$E = hf,$$

putting values $f = \frac{16.3404 \times 10^{-19} J}{6.626 \times 10^{-34} Js}$

$$\boxed{f = 2.466 \times 10^{15} Hz}$$

By Plank hypothesis

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

Putting values:

$$= \frac{6.626 \times 10^{-34} Js \times 3 \times 10^8 ms^{-1}}{16.3404 \times 10^{-19} J}$$

$$\boxed{\lambda = 1.216 \times 10^{-7} m}$$

10. An electron is in the first Bohr orbit of hydrogen. Find (a) the speed of the electron. (b) the time required for the electron to circle the nucleus.

Given:

Energy level n = 1

Planck's constant $h = 6.626 \times 10^{-34}$ Js

Number π=3.14

Mass of electron $m = 9.109 \times 10^{-31}$kg

Radius of first Bohr orbit $r_1 = 0.53 \times 10^{-10}$m

To Find:

Speed v = ? Time period = ?

Solution:

From Bohr's second postulate

$$mvr_n = n\frac{h}{2\pi}$$

or

$$mvr_1 = n\frac{h}{2\pi}$$

$$v = n\frac{h}{2\pi m r_1}$$

Putting values: $v = 1 \times \frac{6.626 \times 10^{-34}\ Js}{2 \times 3.14 \times 9.109 \times 10^{-31} \times 0.53 \times 10^{-10}}$

$$\boxed{v = 2.19 \times 10^{6}\ ms^{-1}}$$

Also the speed 'v' is

$$speed = \frac{distance}{time}$$

$$speed = \frac{circumference\ of\ sircle}{time\ period}$$

or

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

$$T = \frac{2\pi r_1}{v}$$

Putting values

$$T = \frac{2 \times 3.14 \times 0.53 \times 10^{-10} m}{2.19 \times 10^{6}\ ms^{-1}}$$

$$\boxed{T = 1.52 \times 10^{-16} s}$$

11. Electrons in an x-ray tube are accelerated through a potential difference of 3000 V. If these electrons were slowed down in a target, what will be the minimum wavelength of x-rays produced.

Given:

Potential difference $\Delta V = 3000V$

Plancks constant $h = 6.626 \times 10^{-34}$Js

Charge on electron $q = 1.602 \times 10^{-19}$C

Speed of light = $c = 3 \times 10^{8}\ ms^{-1}$

To Find:

Minimum wavelength λ = ?

Solution:

By Planck hypothesis $E = \frac{hC}{\lambda} \longrightarrow$ (i)

The electric potential energy is $E = q\,\Delta V \longrightarrow$ (ii) from equation (i) and equation (ii)

$$q\Delta V = \frac{hC}{\lambda}$$

$$\lambda = \frac{hC}{q\Delta v}$$

putting values

$$\lambda = \frac{6.626 \times 10^{-34}\, Js \times 3 \times 10^{8}\, ms^{-1}}{1.602 \times 10^{-19}\, C \times 3000v}$$

$$\boxed{\lambda = 4.14 \times 10^{-10} m = 4.14 A^{o}}$$

12. Compute the potential difference through which an electron must be accelerate in order that the short-wave limit of the continuous x-ray spectrum shall be exactly 0.1nm.

Given:

Wavelength $\lambda = 0.1 \times 10^{-9}$ m
Planck's constant $h = 6.626 \times 10^{-34}$ Js
Charge on electron $q = 1.602 \times 10^{-19}$ C
Speed of light $C = 3 \times 10^{8}$ ms^{-1}

To Find:

Potential difference ΔV = ?

Solution:

By Plancks hypothesis $E = \frac{hC}{\lambda} \longrightarrow$ (i)

The electric potential energy $E = q\Delta V \longrightarrow$ (ii)
from equation (i) and equation (iii)

$$q\Delta V = \frac{hC}{\lambda}$$

putting values

$$\Delta V = \frac{6.626 \times 10^{-34}\, Js \times 3 \times 10^{8}\, ms^{-1}}{1.602 \times 10^{-19}\, C \times 0.1 \times 10^{-19} m}$$

$$\Delta V = 12412.5V$$

$$\Delta V = 12400V$$

Additional Conceptual Short Questions With Answers

1. The total energy of the hydrogen orbits are negative. Why?

Ans. The negative sign show that the electron is bound to the nucleus by electrostatic force of attraction and that energy must be supplied to detach an electron from the nucleus.

2. Name the different types of emission spectrum:

Ans. These are three kinds of spectra which are:

(1) **Continuous spectra,** e.g. radiation spectrum of black body.
(2) **Band spectra,** e.g. molecular spectra.
(3) **Line or discrete spectra,** e.g. atomic spectra of hydrogen.

3. Calculate the speed of electron in the first orbit of hydrogen atom.

Ans. As expression for speed is

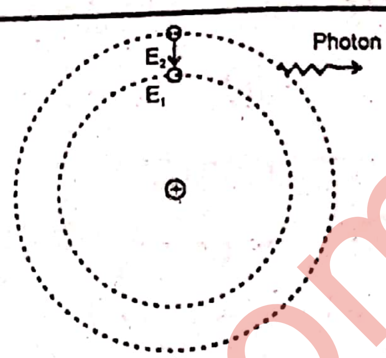
$$V_n = \frac{2\pi Ke^2}{nh}$$

As electron lies in the first orbit i.e. $n = 1$

$$\text{Thus } V_1 = \frac{2\times 3.14\times 9\times 10^9\times(1.6\times 10^{-19})^2}{6.63\times 10^{-34}} = 2.18\times 10^6\ ms^{-1}$$

4. What is meant by a line spectrum? Explain, how line spectrum can be used for the identification of elements?

Ans. When the atoms of an element are excited by absorbing the energy from incident photons, the excited atoms must return to their normal state by the emission of energy, absorbed during excitation. This energy released forms a spectrum which consists of sharply defined spectral lines. Such a spectrum is called line spectrum.



Each element gives its own characteristics lines of definite wavelength. Thus an element can be easily identified by observing its spectrum.

5. How can the spectrum of hydrogen contain so many lines when hydrogen contains one electron?

Ans. When the energy is supplied to the atom of hydrogen atom, it will be excited, then its single electron will jump from its ground level to some higher energy level. Now when it de-excites, it will emit one spectral line, if it jumps direct from higher energy state to ground state. The electron does not necessarily return to the ground state in a single jump, but may return by several jumps. Thus hydrogen spectrum contains many lines.

6. What is the basic difference between X-rays and Gamma rays?

Ans. X-rays are produced by stopping high energy electrons on heavy atoms whereas γ-rays are produced due to radioactive decay of nuclei. Thus the source of origin for both is different.

7. Name the reverse process of X-ray production?

Ans. The reverse process of X-rays production is "Photo electric effect".

Self-Assessment Paper 1

Q.No.1 Encircle the correct option.

1. If number of atoms in metastable state (E_2) is "N_2" and in ground state (E_1) is "N_1" the population inversion means ________

(A) $N_2 = N_1$ (B) $N_2 < N_1$ (C) $N_2 > N_1$ (D) $\frac{N_1}{N_2} = \frac{E_2}{E_1}$

2. If electrons jumps from second orbit to first in hydrogen atom it emits photon of

(A) 3.40 eV (B) 10.20 eV (C) 13.6 eV (D) none of these

3. Which series lies in the ultraviolet region?

(A) blamer series (B) bracket series (C) Pfund series (D) Lyman series

4. The shortest wave length in Bracket Series have wave length

(A) $\frac{16}{R_H}$ (B) $\frac{R_H}{16}$ (C) $16R_H$ (D) $4R_H$

5. The radius of the 3rd Bohr orbit in hydrogen atom is greater than the radius of 1st orbit by a factor of

(A) 2 (B) 3 (C) 4 (D) 9

6. Band spectrum is produced by

(A) H (B) H_2 (C) He (D) Na

7. In excited state the total energy is E, what is K.E with proper sign

(A) 2E (B) – E/2 (C) 2/E (D) – E

8. In an X – rays tube, electrons each of charge e are accelerated through V potential difference allowed to hit a metal target. The minimum wavelength of the X – rays emitted is ______

(A) $\frac{hc}{eV}$ (B) $\frac{he}{Vc}$ (C) $\frac{eV}{h}$ (D) impossible to predict

9. The electric P.E of an electron in an orbit at a distance r_n from the positive charge ______

(A) Ke^2/r_n (B) Ke^2/r_n^2 (C) $-Ke^2/r_n$
(D) $-Ke^2/r_n^2$

10. What is the velocity of a particle of mass m & de-Broglie wavelength λ?

(A) $\frac{h}{m\lambda}$ (B) $\frac{2h}{m\lambda}$ (C) $\frac{mh}{\lambda}$ (D) $\left(\frac{2hc}{m\lambda}\right)^{\frac{1}{2}}$

Q.No.2 Write Short Answers any SIX of the following questions.

1. Bohr theory of hydrogen atom consists of several assumptions, do any of the assumption contradicts the classical theory?
2. What is the difference between spontaneous and stimulated emission?
3. Write down four uses of laser light.
4. What do you mean when you say that atom become excited?
5. Can the electron in the ground state of hydrogen absorb a photon of energy 13.6eV and greater than 13.6eV?
6. Explain why laser action could not occur without population inversion between atomic levels?
7. What is meant by line spectrum? Explain. How the line spectrum is used for identification of elements
8. Define spectroscopy.

Q.No.3 Extensive Question.

Q. (a) What are LASERS. Discuss and laser principle and population inversion for laser production.
(b) Compute the potential difference through which an electron must be accelerate in order that the short wave limit of the continuous x-ray spectrum shall be exactly 0.1nm.

Self-Assessment Paper 2

Q.No.1 Encircle the correct option.

1. **In Helium-Neon laser, discharge tube is filled with Neon gas**
   (A) 10% (B) 15% (C) 85% (D) 90%

2. **The speed of an electron in nth orbit is given as**
   (A) $\frac{4\pi^2 ke^2}{nh}$ (B) $\frac{2\pi ke^2}{nh}$ (C) $\frac{4\pi ke}{n^2h^2}$ (D) $\frac{2\pi^2 ke^2}{nh}$

3. **The energy of electron in the 4th orbit of hydrogen atom is**
   (A) – 2.51 eV (B) – 3.50 eV (C) – 13.6 eV (D) – 0.85 eV

4. **In a meta stable state an atom can reside for about**
   (A) $10^{-8}s$ (B) $10^{-10}s$ (C) $10^{-9}s$ (D) $10^{-3}s$

5. **The energy of electro in second excited state will be hydrogen atom is**
   (A) −1.51eV (B) −0.48eV (C) −13.60eV (D) − 0.85eV

6. **X-rays diffraction reveals that these are**
   (A) Particular type (B) Wave type (C) Both wave and particular (D) None of above

7. **The unit of Rydberg's constant R_H is**
   (A) ms^{-1} (B) m (C) m^2 (D) m^{-1}

8. **Second postulate of Bohr's atomic model is**
   (A) $mvr = \frac{nh}{2\pi}$ (B) $mvr = 2\pi nh$ (C) $mv = \frac{nhr}{2\pi}$ (D) $mvr = \frac{2\pi}{nh}$

9. **Unit of Plank's constant is same as that of:**
   (A) Acceleration (B) Angular momentum (C) Linear momentum (D) Entropy

Q.No.2 Write Short Answers any SIX of the following questions.

1. Write the postulates of Bohr's atom model?
2. Explain why a glowing gas emits certain wavelengths of light and why that gas is capable of absorbing the same wavelengths? Give the reason, why it is transparent for the other wavelengths?
3. Name the pumping gas and lasing gas in He-Ne laser, also give their percentage in it.
4. Define (a) Population inversion (b) Metastable state
5. Write down the some uses of LASER.
6. Can x-rays be reflected, refracted, diffracted and polarized just like any other waves? Explain.
7. What are the advantages of laser over the ordinary light?

Q.No.3 Extensive Questions.

Q. (a) State postulates of Bohr's Model of hydrogen atom. Derive expression for quantized energies of electrons in any orbit of hydrogen atom.

(b) Calculates the longest wavelength of radiation for the Paschen series.