# CHAPTER 20

# ATOMIC SPECTRA

## MULTIPLE CHOICE

**1. The electric potential energy of an electron in an orbit at a distance rn from positive charge is**

A $\frac{Ke}{r_n^2}$ B. $\frac{Ke^2}{r_n^2}$ C. $-\frac{Ke^2}{r_n^2}$ D. $\frac{Ke^2}{r_n}$

**2. Bohr proposed his model of hydrogen atom in**

A 1820 B 1813 C. 1913 D. 1914

**3. The value of Rydberg constant is 1.0974 ×**

A 107 m$^{1}$ B. 1010 m$^{1}$
C. 104 m$^{1}$ D. 10$^{34}$ m$^{1}$

**4. Net force on an electron in an orbit revolving around the nucleus:**

A. Positive B. Negative C. Zero D. None

**5. The scientist who studied the wavelength of all lines of hydrogen spectrum in visible region was:**

A Lymann B. Balmer
C Paschen D. Braekett

**6. When electron absorbs energy, it jumps to:**

A. Lower energy level B. Higher energy level
C Ground level D. Infinity

**7. The numerical value of ground state energy for the hydrogen atom is:**

A. -10.6 eV B 13.6 eV C -13.6 eV D. -5.6 eV

**8. Radiation with wavelength shorter than violet is called:**

A x-rays B. Infrared C. Ultraviolet D $\gamma$-rays

**9. The residing time of atoms in meta stable state in case of laser action is**

A $10^{-4}$ s B. $10^{-5}$ s C $10^{-8}$ s D. $10^{-3}$ s

**10. Life time of a Meta stable state in a substance is**

A. $10^{-3}$ s B $10^{-6}$ s C $10^{-8}$ s D $10^{-9}$ s

**11. In the spectrum of which of the following will you find B aimer series**

A. Oxygen B. Nitrogen
C. Hydrogen D All of these

**12. Bracket series is obtained when all transitions of electron terminate on.**

A $4^{th}$ orbit B. [illegible] orbit
C $3^{rd}$ orbit D $2^{nd}$ orbit

**13. In an electronic transition atom cannot emit:**

A. Visible light
B. Ultraviolet rays
C. $\gamma$-rays
D. Infrared rays

**14. X-rays exhibit the phenomenon of:**

A. Interference
B. Diffraction
C. Polarization
D. All

**15. X-rays are affected by:**

A. Electric field
B. Magnetic field
C. Electric and magnetic field
D. None of these

**16. The emission of X-rays leaves the atom of the target in**

A. Ground state
B. Excited state
C. Doubly ionized state
D. Singly ionized state

**17. X-Ray photon moves with a velocity of**

A. light
B. less than light
C. greater than light
D. sound

**18. LASER can only be produced if an atom is in its**

A. Normal state
B. Excited state
C. Ionized state
D. de-excited state

**19. When an electron in hydrogen atom jumps from a higher orbit into the first orbit, the set of lines emitted is called**

A. Balmer series
B. Lyman series
C. Bracket series
D. Paschen series

**20. The wavelength of Lyman series for hydrogen spectrum lies in:**

A. Infrared region
B. Visible region
C. Ultraviolet region
D. None

**21. When an electron is in its lowest energy state it is called:**

A. Ground state
B. Excited state
C. Ionized state
D. None

**22. The type of radiation which can burn the human skin is called:**

A. x-rays
B. Microwaves
C. Ultraviolet
D. Infrared

**23. X-rays cannot produce pair production because:**

A. They have no charge
B. Their rest mass is zero
C. They are electromagnetic waves
D. Their energy is less than 1.02 Mev

**24. X-rays are radiation of:**

A. High energy
B. High frequency
C. Low wavelength
D. All

**25. X-rays are similar in nature to**

A. Alpha rays
B. Beta rays
C. Cathode rays
D. Gamma rays

**26. According to de-Broglie the electrons in the Bohr orbits may appear as:**

A. Particle
B. Photon
C. Standing wave
D. Compressive wave

**27. Laser can be made by creating:**

A. Meta-stable state B. Population inversion

C. Stimulated emission D. All

**28. Laser is a beam which is:**

A. Monochromatic B. Intense C. Coherent D. All

**29. Which is an example of continuous spectra?**

A. Black Body radiation spectra B. molecular spectra

C. atomic spectra D. None of these

**Answers:**

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

# SHORT & LONG QUESTIONS

**Q1: Briefly describe about the spectroscopy?**

**Ans: Spectroscopy:**

The branch of physics that deals with the investigation of wavelengths and intensities of electromagnetic radiation emitted or absorbed by atoms is called spectroscopy

**Types of spectra:**

It includes the study of spectra produced by atoms. In general there are three types of spectra called.

**(i) Continuous spectra:**

Black body radiation spectrum, is an example of continuous spectra;

**(ii) Band spectra:**

Molecular spectra are the examples of band spectra

**(iii) Discrete or line spectra or atomic spectra:**

The atomic spectra of hydrogen,

**Q2: Write a note on atomic spectra?**

**Ans: Atomic spectra:**

**i.** When an atomic gas or vapour at much less than atmospheric pressure is suitably excited, usually by passing an electric current through it, the emitted radiation has a spectrum, which contains certain specific wavelengths only.

**ii.** An idealized arrangement for observing such atomic spectra is shown in Fig. Actual spectrometer uses diffraction grating for better results.

**iii. Line spectrum:**

The impression on the screen is in the form of lines if the slit in front of the source S is narrow rectangle. It is for this reason that the spectrum is referred to as line spectrum

**iv. Identification of different elements:**

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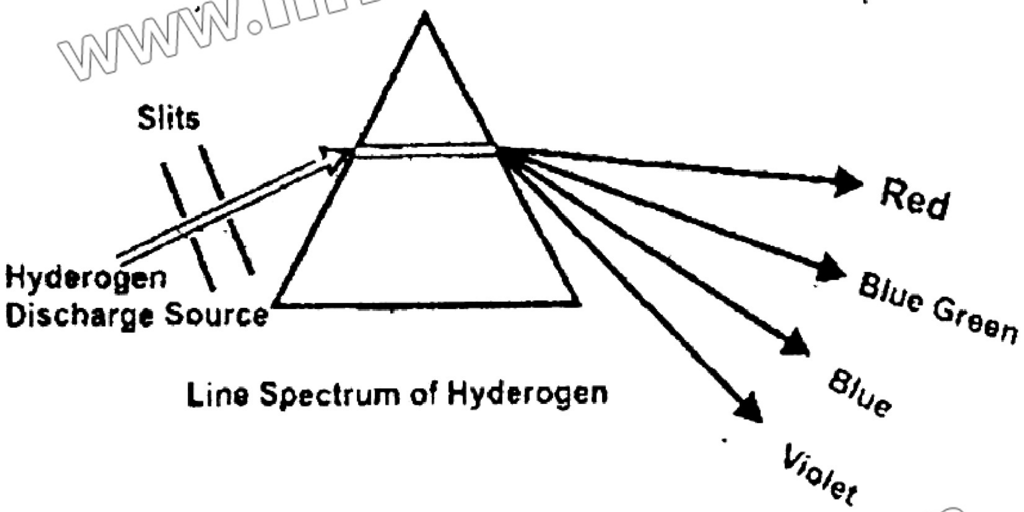
**iv. Identification of different elements:**

The fact that the spectrum of any element contains wavelengths that exhibit definite regularities was utilized in the second half of the 19th century in identifying different elements.

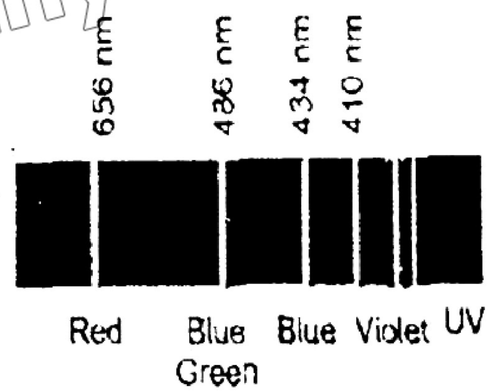



Line Spectrum of Hyderogen

These regularities were classified into certain groups called the spectral series.

**v. Balmer series:**

The first such series was identified by J.J Balmer in 1885 in the spectrum of hydrogen. This series, called the Balmer series, is shown in Fig., and is in the visible region of the electromagnetic spectrum.




**vi. Rydberg constant:**

The results obtained by Balmer were expressed in 1896 by J R Rydberg in the following mathematical form

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

Where $R_H$ is the Rydberg's constant. Its value is $1.0974\times10^7\ m^{-1}$.

**Q3: Describe briefly atomic spectrum of hydrogen?**

**Ans: Atomic spectrum / Line spectrum of hydrogen:**

Line spectrum of hydrogen atom consists of different types of radiations. These radiations are divided into five categories called spectral series.

**i. Lyman series:**

The spectral lines of hydrogen in the ultraviolet and infrared regions fall into several other series. In the ultraviolet region, the Lyman series contains the wavelengths given by the formula

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

where $n = 2,3,4 \ldots\ldots$

**ii. Balmer series:**

The Balmer series contain wavelengths in the visible portion of the hydrogen spectrum

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

where $n = 3, 4, 5 \ldots$

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

**iii. Paschen series:**

In the infrared region, three spectral series have been found whose lines have the wavelengths specified by the formulae:

Paschen series

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

where $n = 4, 5, 6 \ldots\ldots$

**iv. Brackett series:**

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

where $n = 5, 6, 7$

**v. Pfund series:**

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

where $n = 6, 7, 8, \ldots\ldots$

**Q4: Illustrate the postulate of Bohr's model of the hydrogen atom?**

**Ans: Bohr's model of the hydrogen atom:**

In order to explain the empirical results obtained by Rydberg, Neils Bohr, in 1913, formulated a model of hydrogen atom utilizing classical physics and Planck's quantum theory. This semi classical theory is based on the following three postulates:

**Postulate 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.

**Postulate II:**

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

$$mvr = \frac{nh}{2\pi} \quad (1)$$

where $n = 1, 2, 3, \ldots$ and n is called the principal quantum number, m and v are the mass and velocity of the orbiting electron respectively and h is Planck's constant

**Postulate III:**

Whenever an electron makes a transition, that is, jumps from high energy state $E_n$ to a lower energy state $E_p$, a photon of energy h f is emitted so that

$$hf = E_n - E_p \quad \ldots\ldots\ldots \quad (2)$$

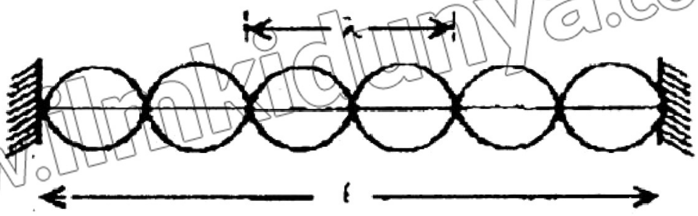
where $f = c/\lambda$ is the frequency of the radiation emitted.

**Q5: Derive de-Broglie's interpretation of Bohr's orbits?**

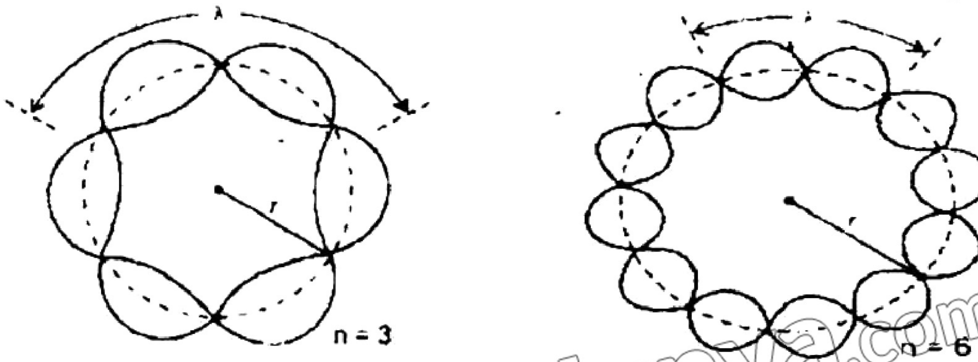
**Ans: de-Broglie's interpretation of Bohr's orbits:**

At the time of formulation of Bohr's theory, there was no justification for the first two postulates, while Postulate III had some roots in Planck's thesis. Later on with the development of de Broglie's hypothesis, some justification could be seen in Postulate II as explained below:

**Derivation of postulate II of the Bohr's model:**




Consider a string of length l as shown in Fig. If this is put into stationary vibrations, we must have $\ell = n\lambda$ where n is an integer. Suppose that the string is bent into circle of radius r, as demonstrated for n = 3 and n = 6 in Figs., so that




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

or $$\lambda = \frac{2\pi r}{n} \quad (1)$$

**From de Broglie's hypothesis**

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

thus $$\frac{h}{mv} = \frac{nh}{2\pi}$$

or $$mvr = \frac{nh}{2\pi}$$

Which is Postulate II of the Bohr's model.

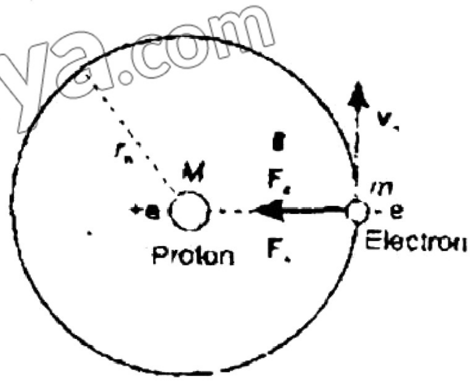
**Q6: Derive a relation for the first Bohr orbit radius and speed of electron in the nth orbit of the hydrogen atom? OR Derive a relation for quantized radii?**

**Ans: Quantized radii:**

Consider a hydrogen atom in which electron moving with velocity $v_n$ is in stationary circular orbit of radius $r_n$. From Eq.

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

$$v_n = \frac{nh}{2\pi m r_n} \quad \ldots\ldots (1)$$




As electron to stay in the circular orbit, shown in Fig., the centripetal force

$F_c = \frac{mv_n^2}{r_n}$ is provided by the Coulomb's force

$F_e = \frac{ke^2}{r_n^2}$, where 'e' is the magnitude of charge on electron as well as on the hydrogen nucleus consisting of a single proton. Thus,

$$\frac{mv_n^2}{r_n} = \frac{ke^2}{r_n^2} \quad \ldots\ldots (2)$$

where constant k is equal to $\frac{1}{4\pi\varepsilon_0}$.

After substituting for $v_n$ from Eq. 1, we have

$$r_n = \frac{n^2h^2}{4\pi^2kme^2} = n^2r_1 \text{..........} \quad (3)$$

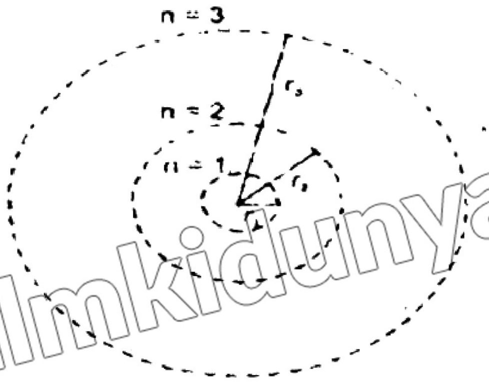
where $$r_1 = \frac{h^2}{4\pi^2kme^2} = 0.053 \text{ nm}$$

This agrees with the experimentally measured values and is called the first Bohr orbit radius of the hydrogen atom.

**Note:**

Thus according to Bohr's theory, the radii of different stationary orbits of the electrons in the hydrogen atom are given by

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




The first Bohr orbit in the hydrogen atom has a radius $r_1 = 5.3 \times 10^{-11}$ m. The second and third Bohr orbits have radii $r_2 = 4r_1$ and $r_3 = 9r_1$ respectively

**Speed of electron in nth orbit:**

Substituting the value of $r_n$ from Eq. 3 in Eq. 1, the speed of electron in the nth orbit is

$$v_n = \frac{2\pi ke^2}{nh} \quad \text{..........} \quad (4)$$

**Q7: Calculate the total energy of the electron in the Bohr orbit?**

**OR**

**Derive a relation for quantized energies?**

**Ans: Quantized energies:**

Let us now calculate the total energy $E_n$ of the electron in the Bohr orbit; $E_n$ is the sum of the kinetic energy K.E. and the potential energy U i.e.,

$$E_n = K.E. + U = \frac{1}{2}mv_n^2 + \left(\frac{-ke^2}{r_n}\right) \quad (1)$$

Since $$\frac{mv_n^2}{r_n} = \frac{ke^2}{r_n^2} \quad (2)$$

By rearranging Eq. 2, we get

$$\frac{1}{2}mv_n^2 = \frac{ke^2}{2r_n} \text{.........} \quad (3)$$

then put in Eq. 1 $$E_n = \frac{ke^2}{2r_n} - \frac{ke^2}{r_n} = -\frac{ke^2}{r_n} \text{.........} \quad (4)$$

Since $$r_n = \frac{n^2h^2}{4\pi^2kme^2} \text{.........} \quad (5)$$

By substituting the value of $r_n$ from Eq.. we have

$$E_n = -\frac{1}{n^2}\left(\frac{2\pi^2 me^4}{h^2}\right) = -\frac{E_0}{n^2} \quad \ldots\ldots (6)$$

where $E_0 = \frac{2\pi^2 k^2 me^4}{h^2}$ = constant = 13.6 eV

which is the energy required to completely remove an electron from the first Bohr orbit. This is called ionization energy. The ionization energy may be provided to the electron by collision with an external electron.

**Ionization potential:**

The minimum potential through which this external electron should be accelerated so that it can supply the requisite ionization energy is known as ionization potential. Thus for n = 1, 2, 3 we get the allowed energy levels of a hydrogen atom to be

$$E_n = -E_0,\ -\frac{E_0}{4},\ -\frac{E_0}{9},\ -\frac{E_0}{16},\ \ldots\ldots$$

The experimentally measured value of the binding energy of the electron in the hydrogen atom is in perfect agreement with the value predicted by Bohr theory

**Excitation potential:**

The potential through which an electron should be accelerated so that, on collision it can lift the electron in the atom from its ground state to some higher state, is known as excitation potential.

**Q8: Describe the difference between amount of energies of orbital electrons and free electrons?**

**Ans:** The orbital electrons have specific amount of energies where as free electrons may have any amount of energy.

**Q9: Derive an expression for the wavelength of hydrogen emission spectrum?**

**Ans: Hydrogen emission spectrum:**

Suppose that the electron in the hydrogen atom is in the excited state n with energy $E_n$ and makes a transition to a lower state p with energy $E_p$, where $E_p < E_n$, then

$$hf = E_n - E_p \quad \ldots\ldots (1)$$

where $E_n = -\frac{E_0}{n^2}$ (2) and $E_p = -\frac{E_0}{p^2}$ (3)

hence by putting values of $E_n$ and $E_p$ in Eq. 1

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

Substituting for $f = c/\lambda$ and rearranging

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

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

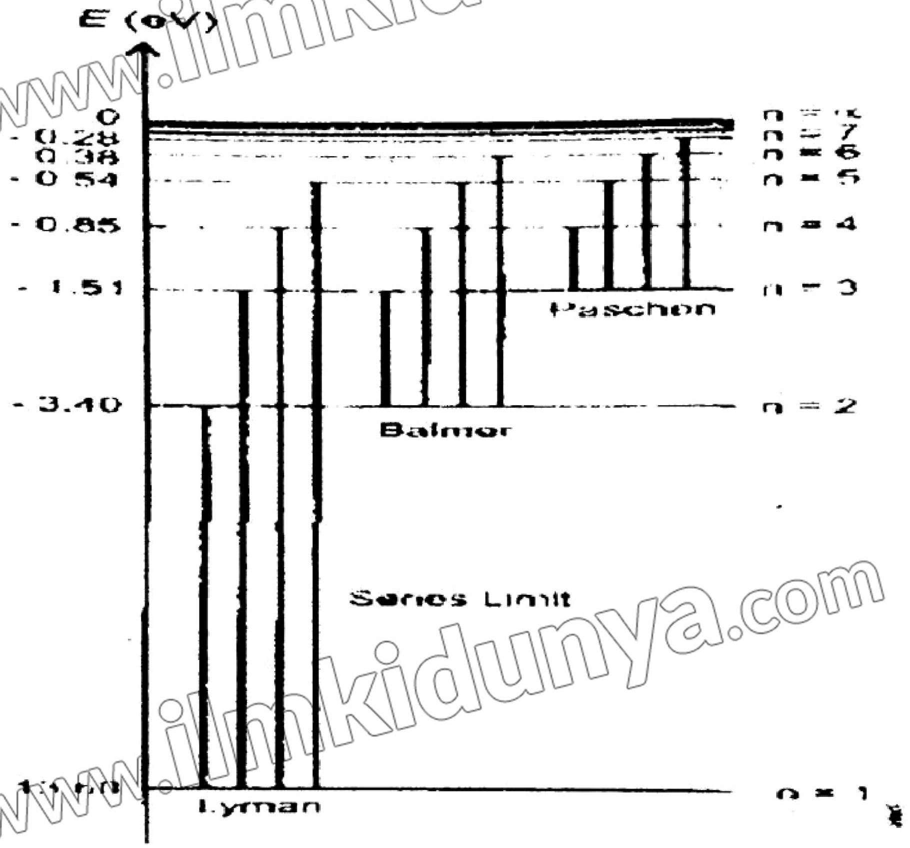
where $R_H$ is the Rydberg constant given by the equation

$$R_H = \frac{E_0}{hc} = 1.0974 \times 10^7 m^{-1} \quad \ldots\ldots (5)$$

which agrees well with the latest measured value for hydrogen atom.

**Q10: Draw energy level diagram for the hydrogen atom?**

**Ans: Energy level diagram for the hydrogen atom:**




**Q11: How much energy is required for the excitation of an atom by photon?**

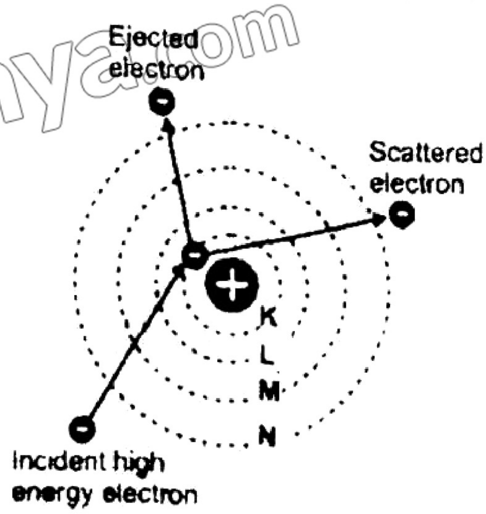
**Ans:** Photon must have energy exactly equal to the energy difference between the two shells for excitation of an atom but an electron with K.E greater that the required difference can excite the gas atoms.

**Q12: Write a note inner shell transitions and characteristic x-rays?**

**Ans: Inner shell transitions:**

**i.** The transitions of electrons in the hydrogen or other light elements result in the emission of spectral lines in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy differences in the transition levels.

**ii.** The inner shell electrons are tightly bound and large amount of energy is required for their displacement from their normal energy levels. After excitation, when an atom returns to its normal state, photons of larger energy are emitted.




**Inner shell transitions and characteristic x-rays:**

The transition of inner shell electrons in heavy atoms gives rise to the emission of high energy photons or X-rays. These X-rays consist of series of specific wavelengths or frequencies and hence are called characteristic X-rays.

**Q13: Describe the construction and working of X-rays production unit?**

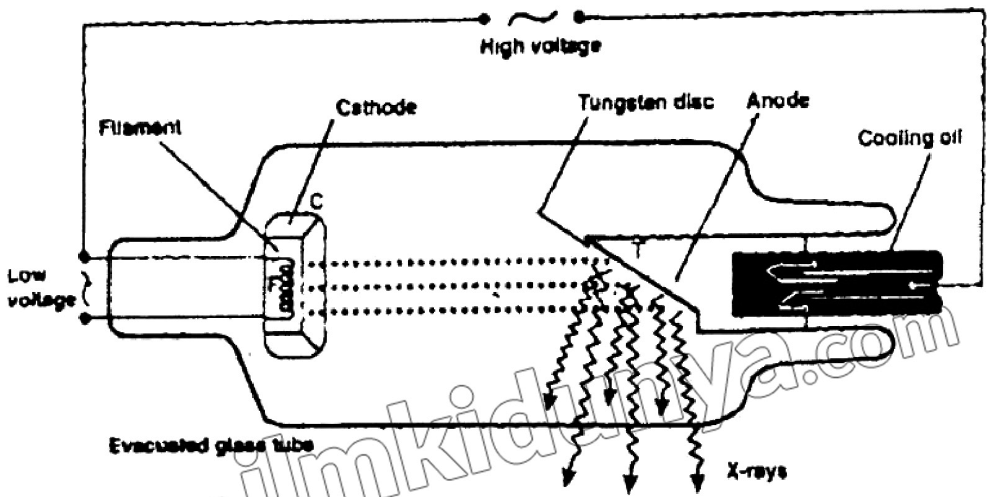
**Ans: X-rays production unit:**

**i. X-ray tube:**

It consists of a high vacuum tube called X-ray tube.

**ii. Function of filament:**

When the cathode is heated by the filament F, it emits electrons which are accelerated towards the anode T




**ii. Kinetic energy of electron:**

If V is the potential difference between C and T the kinetic energy K.E with which the electron strike the target is given by

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

**Production of $K_\alpha$X-ray:**

Suppose that one of the electrons in the K shell is removed, thereby producing a vacancy or hole in that shell. The electron from the L shell jumps to occupy the hole in the K shell, thereby emitting a photon of energy $hf_{k\alpha}$ called the $K_\alpha$X-ray given by

$$hf_{k\alpha} = E_L - E_K \qquad (2)$$

**Production of $K_\beta$X-ray:**

It is also possible that the electron from the M shell might also jump to occupy the hole in the K shell. The photons emitted are $K_\beta$ X-ray with energies

$$hf_{k\beta} = E_M - E_K \quad \ldots\ldots\ldots \quad (3)$$

These photons give rise to $K_\beta$ X-ray and so on.

**Characteristic X-rays:**

The photons emitted in such transitions i.e., inner shell transitions are called characteristic X-rays, because their energies depend upon the type of target material.

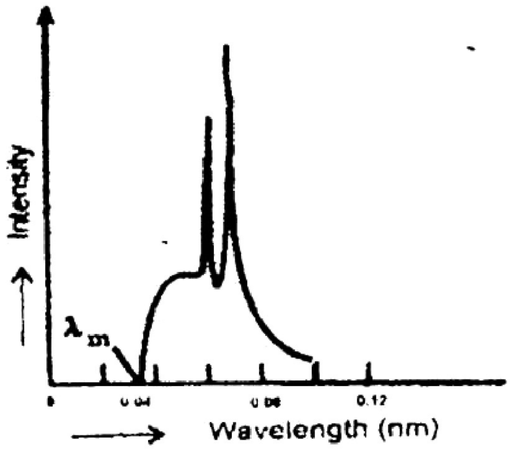
**Creation of holes:**

The holes created in the L and M shells are occupied by transitions of electrons from higher states creating more X-rays. The characteristic X-rays appear as discrete lines on a continuous spectrum.

**Q14: Briefly describe the continuous X-ray spectrum? OR Write a note on bremsstrahlung or braking radiation?**

**Ans: The continuous X-ray spectrum:**

The continuous spectrum is due to an effect known as **bremsstrahlung** or **braking radiation**




**i.** When the fast moving electrons bombard the target, they are suddenly slowed down on impact with the target. We know that an accelerating charge emits electromagnetic radiation. Hence, these impacting electrons emit radiation as they are strongly decelerated by the target.

**ii.** Since the rate of deceleration is so large, the emitted radiation corresponds to short wavelength and so the bremsstrahlung is in the X-ray region. In the case when the electrons lose all their kinetic energy in the first collision, the entire kinetic energy appears as a X-ray photon of energy $hf_{max}$ i.e.,

$$K.E. = hf_{max}$$

**iii.** The wavelength $\lambda_{min}$ in Fig. corresponds to frequency $f_{max}$. Other electrons do not lose all their energy in the first collision. They may suffer a number of collisions before coming to rest. This will give rise to photons of smaller energy or X-rays of longer wavelength. Thus the continuous spectrum is obtained due to deceleration of impacting electrons.

**Q15: Illustrate the properties of and uses of X-rays?**

**Ans: Properties and uses of X-rays:**

X-rays have many practical applications in medicine and industry.

**i.** X-rays can penetrate several centimeters into a solid matter, so they can be used to visualize the interiors of the materials opaque to ordinary light, such as fractured bones or defects in structural steel.

**ii. Procedure to detect fracture by X-rays:**

The object to be visualized is placed between an X-ray source and a large sheet of photographic film; the darkening of the film is proportional to the radiation exposure. A crack or air bubble allows greater amount of X-rays to pass. This appears as a dark area on the photographic film. Shadow of bones appears lighter than the surrounding flesh. It is due to the fact that bones contain greater proportions of elements with high atomic number and so they absorb greater amount of incident X-rays than flesh. In flesh, light elements like carbon, hydrogen and oxygen predominate. These elements allow greater amount of incident X-rays to pass through them.

**Q16: Write a note on CAT-scanner?**

**Ans: CAT-scanner:**

In the recent past, several vastly improved X-ray techniques have been developed. One widely used system is computerized axial tomography; the corresponding instrument is called CAT-Scanner.

### Working of CAT-scanner:

The X-ray source produces a thin fan-shaped beam that is detected on the opposite side of the subject by an array of several hundred detectors in a line. Each detector measures absorption of X-ray along a thin line through the subject. The entire apparatus is rotated around the subject in the plane of the beam during a few seconds. The changing reactions of the detector are recorded digitally. a computer processes this information and reconstructs a picture of different densities over an entire cross section of the subject. Density differences of the order of one percent can be detected with CAT-scans.

### Use of CAT-scanner:

Tumors and other anomalies much too small to be seen with older techniques can be detected.

**Q17: Briefly describe the biological effects of X-rays?**

**Ans: Biological effects of X-rays:**

**i.** X-rays cause damage to living tissue. As X-ray photons are absorbed in tissues, they break molecular bonds and create highly reactive free radicals (such as H and OH), which in turn can disturb the molecular structure of the proteins and especially the genetic material.

**ii.** Young and rapidly growing cells are particularly susceptible; hence X-rays are useful for selective destruction of cancer cells. On the other hand a cell may be damaged by radiation but survive, continue dividing and produce generation of defective cells. Thus X-rays can cause cancer.

**iii.** Excessive radiation exposure can cause changes in their productive system that will affect the organism's offspring.

**Q18: With the help of uncertainty principle show that electron can exist in the atom but outside the nucleus? OR Explain the Heisenberg uncertainty within the atom?**

**Ans: Uncertainty within the atom:**

One of the characteristics of dual nature of matter is a fundamental limitation in the accuracy of the simultaneous measurement of the position and momentum of a particle.

Heisenberg showed that this is given by the equation

$$\Delta p \, . \, \Delta x \geq \frac{h}{2\pi}$$

### Presence of electrons within the atom:

However, these limitations are significant in the realm of atom. One interesting question is whether electrons are present in atomic nuclei. As the typical nuclei are less than $10^{-14}$ m in diameter. for an electron to be confined within such a nucleus. the uncertainty in its position is of the order of $10^{-14}$ m. The corresponding uncertainty in the electron's momentum, is

$$\Delta p \geq \frac{h}{\Delta x} \qquad \Delta p \geq \frac{6.63 \times 10^{-34}}{10^{-14}} = 6.63 \times 10^{-20} \text{ kg ms}^{-1}$$

As $\Delta p = m \Delta v$

Hence $\Delta v = \frac{6.63 \times 10^{-20}}{9.11 \times 10^{-31}} \geq 7.3 \times 10^{10} \text{ ms}^{-1}$

Hence, for the electron to be confined to a nucleus, its speed would have to be greater than $10^{10}$ ms$^{-1}$ i.e., greater than the speed of light. Because this is impossible, we must conclude that an electron can never be found inside of a nucleus.

**Can an electron reside inside the atom:**

To find this, we again calculate the speed of an electron and if it turns to be less than the speed of light, we have reasonable expectation of finding the electron within the atom but outside the nucleus.

The radius of the hydrogen atom is about $5 \times 10^{-11}$ m. Applying the uncertainty principle to the momentum of electron in the atom we have

$$\Delta p \geq \frac{h}{\Delta x}$$

As $\Delta p = m\Delta v$

Therefore, $\Delta v = \frac{h}{m\Delta x}$

For an atom $\Delta x$ is given $5 \times 10^{-11}$ m

Thus $\Delta v = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 5 \times 10^{-11}} = 1.46 \times 10^{7}\ ms^{-1}$

**Note:**

This speed of the electron is less than the speed of light, therefore, it can exist in the atom but outside the nucleus.

**Q19: What stands for the word "laser"? Describe the purpose of laser?**

**Ans: Laser:**

Laser is the acronym for Light Amplification by Stimulated Emission of Radiation.

**Purpose or use of laser:**

Lasers are used for producing an intense, monochromatic, and unidirectional coherent beam of visible light. Working of a laser depends upon stimulated emission and population inversion.

**Q20: Explain spontaneous and stimulated emission as a working of laser?**

**Ans: Steps for spontaneous and stimulated emission:**

**i. Stimulated or induced absorption:**

The incident photon absorbed by an atom in the ground state $E_1$ thereby leaving the atom in the excited state $E_2$ is called stimulated or induced absorption.

**ii. Spontaneous or induced emission:**

Spontaneous or induced emission is that in which the atom emits a photon of energy $hf = E_2 - E_1$ in any arbitrary direction.

**iii. Stimulated or induced emission:**

Stimulated or induced emission is that in which the incident photon of energy $hf = E_2 - E_1$ induces the atom to decay by emitting a photon that travels in the direction of the incident photon. For each incident photon, we will have two photons going in the same direction giving rise to an amplified as well as a unidirectional coherent beam. Such a beam is called laser.

(a) Induced Absorption

(b) Spontaneous Emission

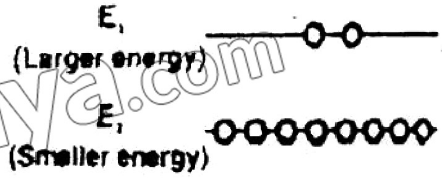
(c) Induced Emission

**Q21: Explain population inversion and laser action?**

**Ans: Population inversion and laser action:**

**Normal population:**

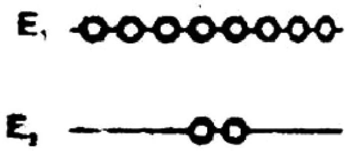
A normal population of atomic energy state, with more atomic in the lower energy state $E_1$ than in the excited state $E_2$.




(a) Normal population

**Population inversion:**

A population inversion, in which the higher energy state has a greater population than the lower energy state.

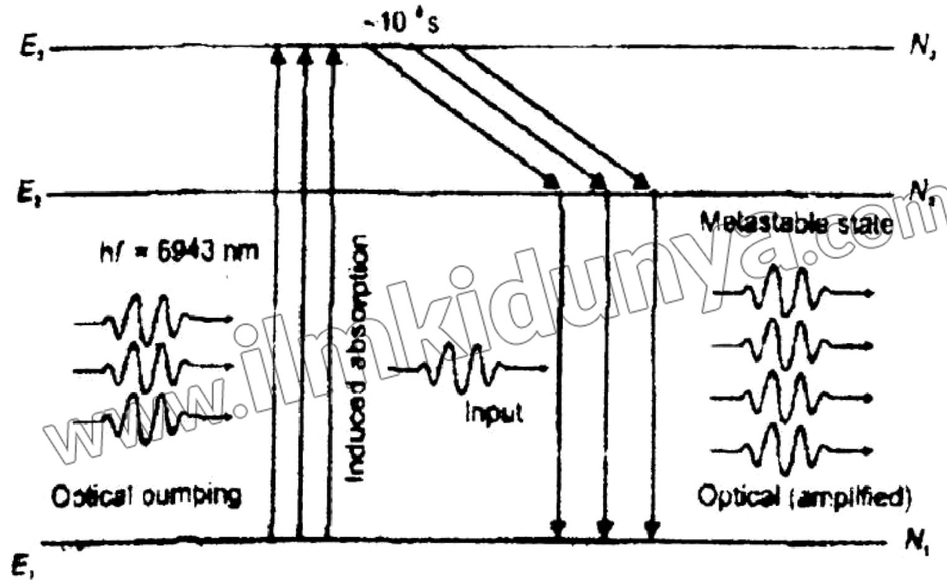


(b) Population inversion

**Explanation:**

**i. Ground state ($E_1$) and excited state ($E_3$):**

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




State $E_1$, which is ground state; the excited state $E_3$ in which the atoms can reside only for $10^{-8}$ s and the metastable state $E_2$ in which the atoms can reside for $\sim 10^{-8}$ s, much longer than 10 s.

**ii. Metastable state ($E_2$):**

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

**iii. Population inversion:**

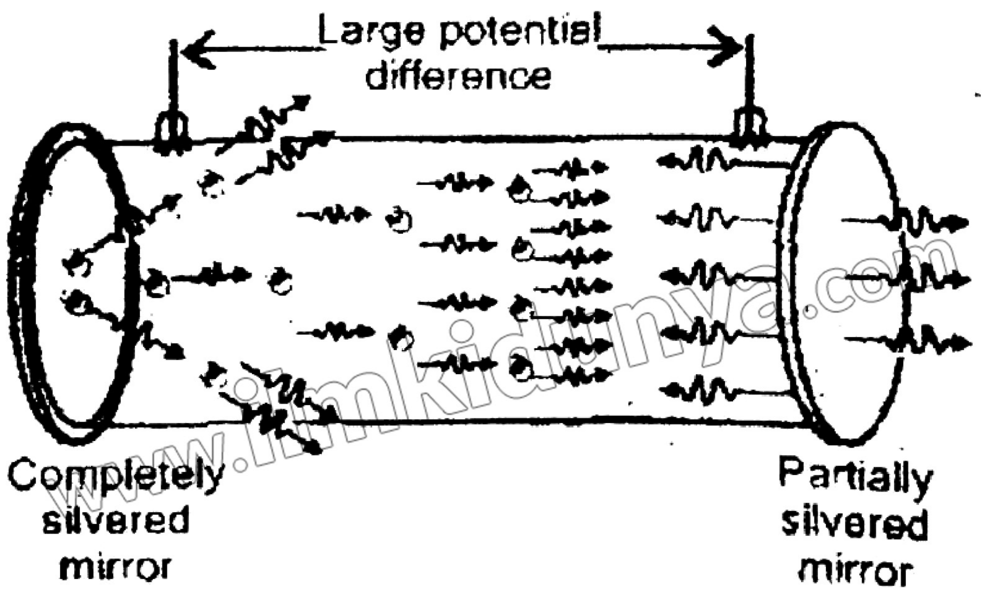
Also let us assume that the incident photons of energy $hf = E_3 - E_1$ raise the atom from the ground state $E_1$ to the excited state $E_3$, but the excited atoms do not decay back to $E_1$. Thus the only alternative for the atoms in the excited state $E_3$ is to decay spontaneously to state $E_2$, the atoms reach state $E_2$ much faster than they leave state $E_2$. This eventually leads to the situation that the state $E_2$ contains more atoms than state $E_1$. This situation is known as population inversion.

**Laser action:**

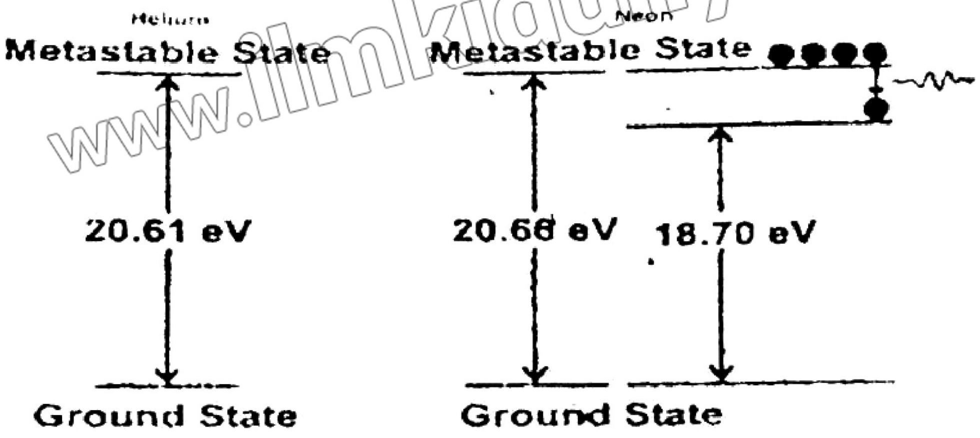
**i.** Once the population inversion has been reached, the lasing action of a laser is simple to achieve. The atoms in the metastable state $E_2$ are bombarded by photons of energy $hf = E_2 - E_1$ resulting in an induced emission, giving an intense, coherent beam in the direction of the incident photon. Such a beam is called laser.

**ii. Use of mirrors:**

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. 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.



**Ans: Helium –neon laser:**




**i.** It is a 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.

**ii.** 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. 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.

**iii.** 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.

**Use of helium-neon laser:**

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.

**Q23: Briefly describe the uses of laser in medicine and industry?**

**Ans: Uses of laser in medicine and industry:**

**1.** Laser beams are used as surgical tool for "welding" detached retinas.

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

**3.** Finely focused beam of laser has been used to destroy cancerous and pre-cancerous cell.

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

**5.** The intense heat produced in small area by a laser beam is also used for welding and machining metals and for drilling tiny holes in hard materials.

6. The precise straightness of a laser beam is also useful to surveyors for lining up equipment especially in inaccessible locations.
7. It is potential energy source for inducing fusion reactions.
8. It can be used for telecommunication along optical fibers.
9. **Holography:**
Laser beam can be used to generate three-dimensional images of objects in a process called holography.

# SUMMARY

1. When an atomic gas or vapours at less than atmospheric pressure is suitably, excited, usually by passing electric current through it, the emitted radiation has a spectrum which contains certain specific wavelengths only.
2. Postulates of Bohr's model of hydrogen 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 h 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 h f is emitted so that hf = $E_n - E_p$.
3. The transition of electrons in the hydrogen or other light elements result in the emission of spectral lines in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy differences in the transition levels.
4. The X-rays emitted in inner shell transitions are called characteristic X-rays, because their energy depends upon the type of target material.
5. The X-rays that are emitted in all directions and with a continuous range of frequencies are known as continuous X-rays.
6. Laser is the acronym for Light Amplification by Stimulated Emission of Radiation.
7. The incident photon absorbed by an atom in the ground state $E_1$ thereby leaving the atom in the excited state $E_2$ is called stimulated or induced absorption.
8. Spontaneous or induced emission is that in which the atom emits a photon of energy hf = $E_2 - E_1$ in any arbitrary direction.
9. Stimulated or induced emission is that in which the incident photon of energy hf = $E_2 - E_1$ induces the atom to decay by emitting a photon that travels in the direction of the incident photon. For each incident photon, we will have two photons going in the same direction giving rise to an amplified as well as a unidirectional coherent beam.

# SOLUTION OF EXERCISE

**20.1. Bohr's theory of Hydrogen atom is based upon several assumptions. Do any of these assumptions contradict classical physics?**

**Ans:** According to first postulate of Bohr's theory, an electron in an orbit around the nucleus does not radiate energy this postulate contradict classical theory

According to the classical theory an accelerated electron radiates energy. As the motion of electron is circular so the velocity is not uniform, the motion must be accelerated. When an electron is accelerated it radiates energy in the form of electromagnetic waves.

The electron moves into shorter and short orbit so that it should ultimate fall into the nucleus but it never happens and the atom remains stable.

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

**Ans: Line spectrum:**

When an atomic gas or vapour at much less than atmospheric pressure is suitably excited. usually by passing an electric current through it, the emitted radiation has a spectrum, which contains certain specific wavelengths only

The impression on the screen is in the form of lines. It is for this reason that the spectrum is referred to as line spectrum.

**Identification of different elements:**

These regularities were classified into certain groups called the spectral series

It belongs to an isolated atom. In it each discrete line represents a transition between two of its energy levels. As the differences between energy levels of the atom do not resemble with those of the atom of any other element, hence can be used for identification of elements.

**20.3. Can the electron in the ground state of hydrogen absorb a photon of energy 13.6 eV and greater than 13.6 eV?**

**Ans:** Yes the electron can, in the ground state of hydrogen absorb a photon of energy 13.6 eV and greater than 13.6 eV. Because 13.6 eV is the minimum energy required for ionization and any extra amount will be converted into the K.E. of the escaping electron.

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

**Ans:** Hydrogen atom contains one electron. It will emit one spectral line, if it jumps direct from higher energy state to the ground state.

The electron does not necessarily return to the ground state in the single jump but may return by several jumps. That is why hydrogen spectrum contains many lines

**20.5. Is energy conserved when an atom emits a photon of light?**

**Ans:** Yes energy is conserved when an atom emits a photon of light, as it emits the same amount of energy which it had absorbed during excitation which is equal to the energy emitted during its de-excitation.

**20.6. Explain why a glowing gas gives only certain wavelengths of light and why that gas is capable of absorbing the same wavelengths? Give reason why it is transparent to the other wavelengths?**

**Ans:** A glowing gas gives only certain wavelengths of light because it can absorb or emit only those wavelengths whose corresponding energies match the differences between any two of its energy levels. A glowing gas is transparent for the wavelength other than its characteristic wavelength because it will absorb only those radiations which it can also emit.

**20.7. What do we mean when we say that the atom is excited?**

**Ans:** When the electron is lifted up to one of its excited states then the atom is said to excite.

It means that one of the electrons of the atom has absorbed required energy and has been raised to some of the higher energy orbit.

**20.8. Can x-rays be reflected, refracted, diffracted and polarized just like other waves? Explain.**

**Ans:** x-rays can be reflected, refracted, diffracted and polarized just like other waves. We know that x-rays are extremely high energy electromagnetic waves (which travel in free space with the velocity of lite). Hence, like all other waves x-rays have all the wave properties.

**20.9. What the advantages of lasers over ordinary light?**

**Ans:** Lasers are used for producing an intense, monochromatic, and unidirectional coherent beam of visible light.

It is more intense, monochromatic, unidirectional and coherent, whereas, ordinary light does not have such properties. Therefore a laser beam is much more power full than an ordinary light beam. Energy of laser can be focused at a point to get energy for welding and surgical purpose while ordinary light cannot do so.

**20.10. Explain why laser action could not occur without population inversion between atomic levels?**

**Ans:** Once the population inversion has been reached, the lasing action of a laser is simple to achieve. The atoms in the metastable state $E_2$ are bombarded by photons of energy $hf = E_2 - E_1$ resulting in an induced emission, giving an intense, coherent beam in the direction of the incident photon. Such a beam is called laser.

So population inversion between atomic levels is necessary for laser production or action because without it, all the input photons would have been consumed in raising the electrons from their ground states to the metastable states and there would have been no photons to cause induced emission which is the base of laser action.

# SOLUTION OF EXAMPLES

**Example 20.1:** **Find the speed of electron in the first Bohr orbit.**

**Solution:**

$n = 1$

$h = 6.63 \times 10^{-34}\ J\,s$

$e = 1.6 \times 10^{-19}\ C$

$k = 9 \times 10^{9}\ Nm^2 C^{-2}$

$v_1 = ?$

According to Bohr Theory

$$v_n = \frac{2\pi k e^2}{nh}$$

$$v_1 = \frac{2 \times 3.14 \times 9 \times 10^{9} \times (1.6 \times 10^{-19})^2}{1 \times 6.63 \times 10^{-34}} = \frac{2 \times 3.14 \times 9 \times 10^{9} \times 2.56 \times 10^{-38}}{6.63 \times 10^{-34}}$$

$v_1 = 2.19 \times 10^{6}\ ms^{-1}$

# SOLUTION OF PROBLEMS

**20.1 A hydrogen atom is in its ground state (n = 1). Using Bohr's theory, calculate (a) the radius of the orbit, (b) the linear momentum of the electron, (c) the angular momentum of the electron (d) the kinetic energy, (e) the potential energy, and (f) the total energy.**

**Solution:** Mass of electron = $m = 9.1 \times 10^{-31}$ kg

Charge on proton = $e = 1.6 \times 10^{-19}$ C

Orbit number = $n = 1$

Plank's Constant = $h = 6.63 \times 10^{-34}$ J s

$K = 9 \times 10^{9}\ Nm^2 C^{-2}$

**(a)** The radius of 1st orbit = $r_1 = ?$

**(b)** Linear momentum of electron = $P = ?$

**(c)** Angular momentum of electron = $L = ?$

**(d)** Kinetic energy of electron = $K.E. = ?$

**(e)** Potential Energy of electron = $P.E. = ?$

**(f)** Total Energy of electron = $E = ?$

**(a)** **The radius of 1st orbit = $r_1$ = ?**

Radius of nth orbit is

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

$$r_1 = \frac{(1)^2 \times (6.63 \times 10^{-34})^2}{4 \times (3.14)^2 \times 9 \times 10^{9} \times 9.11 \times 10^{-31} \times (1.6 \times 10^{-19})^2} = 0.0529 \times 10^{-9}\ m$$

$r_1 = 0.529 \times 10^{-10}\ m$

**(b)** **Linear momentum of electron = P = ?**

Linear momentum in 1st orbit is

$$P_1 = \frac{nh}{2\pi r_1}$$

# SOLUTION OF EXAMPLES

**Example 20.1:** **Find the speed of electron in the first Bohr orbit.**

**Solution:**

$n = 1$

$h = 6.63 \times 10^{-34}$ J s

$e = 1.6 \times 10^{-19}$ C

$k = 9 \times 10^{9}$ Nm$^{2}$ C$^{-2}$

$v_1 = ?$

According to Bohr Theory

$$v_n = \frac{2\pi k e^2}{n h}$$

$$v_1 = \frac{2 \times 3.14 \times 9 \times 10^{9} \times (1.6 \times 10^{-19})^2}{1 \times 6.63 \times 10^{-34}} = \frac{2 \times 3.14 \times 9 \times 10^{9} \times 2.56 \times 10^{-38}}{6.63 \times 10^{-34}}$$

$v_1 = 2.19 \times 10^{6}$ ms$^{-1}$

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**20.1 A hydrogen atom is in its ground state (n = 1). Using Bohr's theory, calculate (a) the radius of the orbit, (b) the linear momentum of the electron, (c) the angular momentum of the electron (d) the kinetic energy, (e) the potential energy, and (f) the total energy.**

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Charge on proton = $e = 1.6 \times 10^{-19}$ C

Orbit number = $n = 1$

Plank's Constant = $h = 6.63 \times 10^{-34}$ J s

$K = 9 \times 10^{9}$ Nm$^{2}$ C$^{-2}$

**(a)** The radius of 1$^{st}$ orbit = $r_1 = ?$

**(b)** Linear momentum of electron = $P = ?$

**(c)** Angular momentum of electron = $L = ?$

**(d)** Kinetic energy of electron = $K.E. = ?$

**(e)** Potential Energy of electron = $P.E. = ?$

**(f)** Total Energy of electron = $E = ?$

**(a) The radius of 1$^{st}$ orbit = $r_1$ = ?**

Radius of nth orbit is

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

$$r_1 = \frac{(1)^2 \times 6.63 \times 10^{-34}}{4 \times (3.14)^2 \times 9 \times 10^{9} \times 9.11 \times 10^{-31} \times (1.6 \times 10^{-19})^2} = 0.0529 \times 10^{-9} \text{ m}$$

$r_1 = 0.529 \times 10^{-10}$ m

**(b) Linear momentum of electron = P = ?**

Linear momentum in 1$^{st}$ orbit is,

$$P_1 = \frac{nh}{2\pi r_1}$$

$$P_1 = \frac{1\times6.63\times10^{-34}}{2\times3.14\times0.53\times10^{-9}} = 1.99\times10^{-24}\ kg\ ms^{-1}$$

**(c) Angular momentum of electron = L = ?**

Angular momentum in 1st orbit is,

$$L_1 = P_1\times r_1$$

$$L_1 = 1.99\times10^{-24}\times0.53\times10^{-10} = 1.05\times10^{-34}\ kg\ m^2s^{-1}$$

**(d) Kinetic energy of electron = K.E. = ?**

K.E. in 1st orbit is,

$$K.E = \frac{Ke_2}{2r_1}$$

$$K.E = \frac{9\times10^9\times(1.6\times10^{-19})^2}{2\times0.053\times10^{-9}} = 217.35\times10^{-20}\ J$$

$$K.E = \frac{217.35\times10^{-20}}{1.6\times10^{-19}} = 13.6\ eV$$

**(e) Potential Energy of electron = P.E. = ?**

P.E. in 1st orbit is,

$$P.E = \frac{-Ke^2}{r_1}$$

$$P.E = \frac{-9\times10^9\times(1.6\times10^{-19})^2}{0.053\times10^{-9}} = -4.35\times10^{-18}\ J$$

$$P.E = \frac{-4.35\times10^{-18}}{1.6\times10^{-19}} = -27.2\ eV$$

**(f) Total Energy of electron = E = ?**

Total energy is,

$$T.E. = K.E + P.E$$

$$T.E = 13.6\ eV + (-27.2\ eV) = -13.6\ eV$$

**20.2 What are the energies in eV of quanta of wavelength? λ= 400, 500 and 700nm.**

**Solution:** $\lambda_1 = 400\ nm = 400\times10^{-9}\ m$

$\lambda_2 = 500\ nm = 500\times10^{-9}\ m$

$\lambda_3 = 700\ nm = 700\times10^{-9}\ m$

$c = 3.0\times10^8\ m\ s^{-1}$

$h = 6.63\times10^{-34}\ J\ s$

$E_1 = ?$

$E_2 = ?$

$E_3 = ?$

The formulae can be written as.

$$E_1 = \frac{hc}{\lambda_1}$$

$$E_1 = \frac{6.63\times10^{-34}\times3\times10^8}{400\times10^{-9}} = 4.97\times10^{-19}\ J$$

$$E_1 = \frac{4.97\times10^{-19}}{1.6\times10^{-19}} = 3.10\ eV$$

Now $$E_2 = \frac{hc}{\lambda_2}$$

$$E_2 = \frac{6.63\times10^{-34}\times3\times10^8}{500\times10^{-9}} = 3.978\times10^{-19}J$$

$$E_2 = \frac{3.978\times10^{-19}}{1.6\times10^{-19}} = 2.49\ eV$$

Also $$E_3 = \frac{hc}{\lambda_3}$$

$$E_3 = \frac{6.63\times10^{-34}\times3\times10^{8}}{700\times10^{-9}} = 2.84\times10^{-19}\,J$$

$$E_3 = \frac{2.84\times10^{-19}}{1.6\times10^{-19}} = 1.77\,eV$$

**20.3 A electron jumps from a level $E_1 = -3.5\times10^{-19}$ J to $E_f = -1.20\times10^{-18}$ J. What is the wavelength of the emitted light?**

**Solution:** $E_i = -3.5\times10^{-19}\,J$

$E_f = -1.2\times10^{-18}\,J$

$$\Delta E = E_i - E_f$$

$$\Delta E = -3.5\times10^{-19} - (-1.2\times10^{-18}) = -3.5\times10^{-19} + 12\times10^{-19}$$

$\Delta E = 8.5\times10^{-19}\,J$

$\lambda = ?$

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

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{8.5\times10^{-19}} = 234\times10^{-9}\,m = 234\,nm$$

**20.4 Find the wavelength of the spectral line corresponding to the transition in hydrogen from n = 6 state to n = 3 state?**

**Solution:** $P = 3$

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

$n = 6$

$\lambda = ?$

The general formula to find wavelength in hydrogen spectrum:

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

$$\frac{1}{\lambda} = 1.097\times10^{7}\left(\frac{1}{9} - \frac{1}{36}\right) = 1.097\times10^{7}\left(\frac{3}{36}\right) = 1.094\times10^{-9}\,m$$

$\lambda = 1094\,nm$

**20.5 Compute the shortest wavelength radiation in the Balmer series? What value of n must be used?**

**Solution:** For Balmer series

$P = 2$

$n = \infty$ (infinity only for shortest wavelength)

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

$\lambda_{min} = ?$

The general formula to find wavelength in hydrogen spectrum:

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

$$\frac{1}{\lambda} = 1.097\times10^{7}\left(\frac{1}{(2)^2} - \frac{1}{(\infty)^2}\right) = 1.097\times10^{7}\times\frac{1}{4} \qquad (\because \frac{1}{\infty} = 0)$$

$$\lambda = \frac{4}{1.097\times10^{7}} = 364.5\times10^{-9} = 364.5\,nm$$

**The value of n:** $n = \infty$

**20.6 Calculate the longest wavelength of radiation for the Paschen series.**

**Solution:** For longest wavelength in Paschen series

P = 3
n = 4
$R_H$ = $1.0974 \times 10^7\ m^{-1}$
$\lambda_{max}$ = ?
The general formula to find wavelength in hydrogen spectrum

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

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{9} - \frac{1}{16}\right) = 1.097 \times 10^7 \left(\frac{7}{9 \times 16}\right) = \frac{16 \times 9}{7 \times 1.097 \times 10^7}$$

$\lambda = 18.75 \times 10^{-7} = 1875 \times 10^{-9}\ m = 1875\ nm$

**20.7 Electron in an x-ray tube is 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?**

**Solution:** V = 3000 volts
$\lambda_{min}$ = ?

The energy of a photon is given by

$$E = \frac{hc}{\lambda} \quad (1)$$

The electric potential energy is given by

$$U = eV \quad (2)$$

By equating above two energies we get

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

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

$$\lambda_{min} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 3000} = \frac{19.89 \times 10^{-26} \times 10^{16}}{4.8} = 4.14 \times 10^{-10}\ m$$

**20.8 The wavelength of K x-ray from copper is $1.377 \times 10^{-10}$ m. What is the energy difference between the two levels from which this transition results?**

**Solution:** λ = $1.373 \times 10^{-10}$ m
ΔE = ?

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

$$E_2 - E_1 = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.377 \times 10^{-10}} = 1.44 \times 10^{-15}\ J$$

$$\Delta E = \frac{1.44 \times 10^{-15}}{1.6 \times 10^{-19}} = 9027\ eV = 9.03 \times 1000 = 9.03\ KeV$$

**20.9 A tungsten is struck by electrons that have been accelerated from rest through 40 kV potential differences. Find the shortest wavelength of the Bremsstrahlung radiation emitted?**

**Solution:** V = 40 kV
V = 40 × 1000 Volts
e = $1.6 \times 10^{-19}$ C
$\lambda_{min}$ = ?

The energy of a photon is given by

$$E = \frac{hc}{\lambda} \quad (1)$$

The electric potential energy is given by

$$U = eV \quad (2)$$

By equating above two energies we get.

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

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

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times4000} = 3.10\times10^{-11} = 0.31\times10^{-10}\,m$$

**20.10 The orbital electron of a hydrogen atom moves with a speed of $5.456 \times 10^5\ ms^{-1}$.**

**(a) Find the value of the quantum number n associated with this electron.**

**(b) Calculate the radius of this orbit, and**

**(c) The energy of the electron in this orbit?**

**Solution:** $V_n = 5.456 \times 10^5\ ms^{-1}$

Charge of electron $= e = 1.6 \times 10^{-19}$ C

$n = ?$

$r_4 = ?$

$E_4 = ?$

**(a) Find the value of the quantum number n associated with this electron.**

Velocity of electron in nth orbit is,

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

$$\Rightarrow \quad n = \frac{2\pi Ke^2}{V_n h}$$

$$n = \frac{2\times3.142\times9\times10^9(1.6\times10^{-19})^2}{5.456\times10^5\times6.63\times10^{-34}} = \frac{144.69\times10^{-29}}{36.173\times10^{29}} = 4$$

**(b) Calculate the radius of this orbit,**

Radius of nth orbit is,

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

$$r_4 = \frac{(4)^2\times(6.63\times10^{-34})^2}{4\times(3.142)^2\times9\times10^9\times(1.6\times10^{-19})^2\times9.11\times10^{-31}} = \frac{703.296\times10^{-68}}{8268.309\times10^{-60}}$$

$$r_4 = 0.846\times10^{-9} = 0.846\ nm$$

**(c) The energy of the electron in this orbit.**

Since $$E_n = -\frac{1}{n^2}\left(\frac{2\pi^2me^4}{h^2}\right) = -\frac{E_0}{n^2}$$

$$E_0 = \frac{2\pi^2k^2me^4}{h^2} = \text{constant} = 13.6\ eV$$

Energy of electron in nth orbit is,

$$E_n = \frac{-E_0}{n^2}$$

$$E_4 = \frac{-13.6}{(4)^2} = -0.85\ eV$$