Unit 26

# Atomic Physics

**Teaching Periods** 12 **Weightage %** 08

**The "electron cloud" model was proposed by Erwin Schrödinger in 1926, as part of his quantum mechanical theory. Schrödinger's model described the electrons in an atom as a cloud of probability, where the density of the cloud represents the likelihood of finding an electron within a given region. This replaced the earlier planetary model, which had electrons in fixed orbits.**

**In this unit student should 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 an element.
- Describe Bohr's postulates of Hydrogen atom
- Derive an expression for quantized radii
- 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 energy level diagram
- Illustrate the significance of the hydrogen spectrum in the development of Bohr's model of the atom.
- Derive $\frac{1}{\lambda} = RH\left[\frac{1}{P^2} - \frac{1}{n^2}\right]$.
- Solve problems using $\frac{1}{\lambda} = RH\left[\frac{1}{P^2} - \frac{1}{n^2}\right]$.
- Describe inner shell transitions
- Explain production and characteristics of X-rays based on inner shell transition
- Describe properties and uses of 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.
- Identify the useful properties of laser light and give some examples of their uses
- Identify the measures requirement for safe handling of lasers

## Atomic Spectra:

***Atomic spectra deal with the spectrum of frequencies of electromagnetic radiation emitted or absorbed by an electron during transitions between different levels of energy within an atom.***

Electrons present in an atom have discrete and specific energies. There are more energy states in an atom than there are electrons. The rainbows are the most common example of atomic spectra, even if it may seem as a continuous pattern; it has black lines that represent the absorption spectra of the sun. The spectrum is also used in astronomy to identify the composition of stars.

## 26.1.1: Optical Spectra:

***An optical spectrum is obtained, when light passes through a prism or a diffraction-grating. This spectrum can be obtained from the intensity and wavelength of the radiation.***

The spectrum may be observed visually in the limited wavelength region to which the eye is sensitive; it may be focused on a photographic plate. The spectra obtained from radiating bodies are called emission spectra and are classified into three types


Figure 26.1 Types of emission spectra

(i) **Continuous spectra:** These are emitted by solids, liquids and dense opaque gases at high temperatures. The spectrum of the sun, or of a black body, is a continuous spectrum. Gases at low pressures emit line spectra.

(ii) **Band spectra:** These are associated with similar changes in the molecules under high pressure.

(iii) **Line spectra:** These have their origin in the energy changes which take place in the atoms of a gas, while

An absorption spectrum is used to analyze the substance and this spectrum is obtained by passing white light from a continuous source through a gas or a dilute solution of the element being analyzed. The absorption spectrum consists of a series of dark lines superimposed on the continuous spectrum of the light source as shown in figure 26.2.

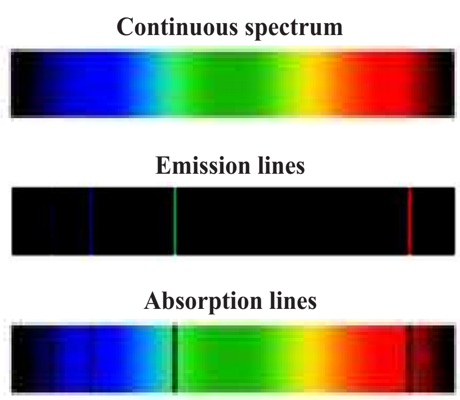



Figure 26.2 hydrogen absorption spectrum

## 26.1.2: Spectral lines:

***A line of particular frequency or wavelength emitted or absorbed by atoms is called spectral line.***

The four visible lines occur at the wavelengths 656 nm, 486 nm, 434 nm, and 410 nm. The complete set of lines is called the Balmer series. The wavelengths of these lines can be described by the following equation,

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right); n = 3,4,5, \ldots\ldots 26.1$$

1. $Balmer\ Series\ \frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$
2. $Paschen\ Series\ \frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$
3. $Lyman\ Series\ \frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$
4. $Brackett\ Series\ \frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$
5. $PFund\ Series\ \frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$

where $R_H$ is a constant called the Rydberg constant. The above equation and other lines in the spectrum of hydrogen atom (Lyman, Paschen, Brackett & Pfund Series) will be disused in the section

**DO YOU KNOW?**

Between 1860 and 1885, scientists collected data on atomic emissions using spectroscopy. In 1885, Johann Jacob Balmer discovered an equation that accurately predicted the wavelengths of hydrogen's four visible emission lines: Ha (red), Hb (green), Hg (blue), and Hd (violet),

### 26.2.1.3 The spectrum of hydrogen atom:

The shape of the spectrum proposed by Max Planck in 1900, that the energy of a given mode of vibration depended upon its frequency in accordance with the relationship.

$$E_n = nh\nu; n = 1,2,3, \ldots\ldots\ldots 26.2$$

This relation shows that the energy associated with each frequency for different transition has the discrete value.

**DO YOU KNOW?**

Early solar spectrum studies revealed unknown lines, leading to the discovery of helium, named after the Greek word for Sun, Helios. Since then, analyzing starlight has only detected elements found on Earth, suggesting a universal consistency of elements.

### 26.1.3: Identification of Elements by Uniqueness of Spectra:

***Each element has its own unique line spectrum which is referred as the "fingerprint" of a particular element.***

The spectra for each element are unique because each element contains different numbers of electrons and different energy levels. The absorption spectrum of an element has many practical applications. For example, various absorption lines observed in the solar spectrum have been used to identify elements in the solar atmosphere.

**Self-Assessment Questions:**

1. Why are some spectral lines brighter than others?
2. Why different elements have the different spectra?
3. Differentiate between emission and absorption spectra.

## 26.2 Bohr's Model and its Postulates:

In 1913, Niels Bohr introduced atomic model in order to give quantitative determination of frequency emitted during de-excitation of an electron in Hydrogen -atom.

The discovery of the electron in the late 19th century marked the beginning of a new era in scientific research, helping physicists understand the structure and nature of atoms

***Niels Bohr had a remarkable idea that explained the atom of hydrogen-consist of a proton and an electron revolving around the nucleus*** as shown in figure 26.3.

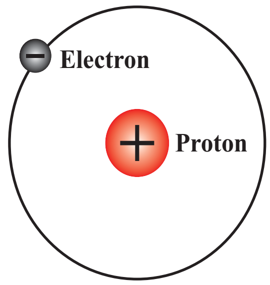


Figure 26.3 hydrogen atom

The following are the postulates of Bohr

**Postulates I:**

The electron in a hydrogen atom orbits the nucleus,

$$\mathbf{F}_C = \frac{mx\,v^2}{r} = \mathbf{F} = k \times \frac{q_1\,x\,q_2}{r^2}$$

**Postulates II:**

The magnitude of the angular momentum $L$ of the electron in its orbit is equal to the integral multiple of $\frac{h}{2\pi}$ i.e.,

$L = n\frac{h}{2\pi}$ , n= 1,2,3,4,…….

where $h$ is called Plank's constant and n is positive integer (quantum number).

**Postulates III:**

Only certain orbits are stable in which electrons are revolving and these orbits are called stationary states. The atom emits radiation (photon) when the electron makes a transition from a higher energy state ($E_n$) to the lower energy state ($E_p$).

$$hv = E_n - E_p \text{ ……………26.3}$$

where $v$ is the frequency of emitted photon.

**DO YOU KNOW?**

Limitations of Bohr's Model are:

1. Failed to explain Zeeman Effect.
2. Failed to explain Stark Effect.
3. Could not explain spectra obtained from larger atoms.

These phenomena were later explained by Schrodinger Atomic Model

### 26.2.2 Bohr's radius:

The electron revolving around the nucleus is in uniform circular motion and thus experiences a centripetal force. Here centripetal force is provided by electrostatic force between electron and proton.

$$F_c = \frac{mv^2}{r} (i)$$

where V is the speed of electron. The magnitude of electrostatic force $\left(F_e = \frac{kq_1q_2}{r^2}\right)$between the electron $(q_1 = -e)$ and the proton $(q_1 = e)$ separated by the orbital radius $r$ is given as.

$$F_e = \frac{ke^2}{r^2} \qquad (ii)$$

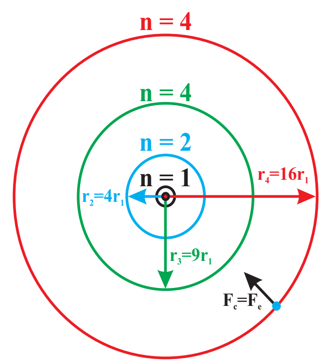


Figure 25.4 quantized radii for hydrogen atom

where $k = 9.0 \times 10^9 Nm^2/C^2$ is called Coulomb's constant.
The electron can only move in a particular orbit if the above two forces are balanced each other.
Comparing equation (i) and (ii)

$$\frac{ke^2}{r^2} = \frac{mV^2}{r} \qquad (iii)$$

From Bohr's postulate (2),
$L = mVr = n\frac{h}{2\pi}$
Substituting the value of $V = \frac{nh}{2\pi mr}$

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

Where,
$k = \frac{1}{4\pi\varepsilon_0}$
$h = 6.63 \times 10^{-34} js$
$m = 9.1 \times 10^{-31} kg$
$\varepsilon_0 = 8.85 \times 10^{-12} C^2/Nm^2$
$r = \frac{n^2\varepsilon_0 h^2}{\pi m e^2} \qquad (IV)$
$r = r_0 n^2 \qquad (v)$
where $r_0 = 5.29 \times 10^{-11} m = 0.53 A^0$ is called Bohr's first orbit.
As the values of $r$ is depending only on the principle quantum number $n$. Therefore, the radii have the quantized values as shown in figure 26.4.

$$r_n = r_1 n^2 \qquad \ldots\ldots\ldots 26.4$$

### 26.2.3: Orbital Energy of hydrogen atom:

The allowed energy levels and quantitative values of the emission wavelengths of the hydrogen atom can be calculated from the postulate (3) suggests the qualitative existence of a characteristic discrete emission spectrum and corresponding absorption spectrum for hydrogen. The electron has kinetic energy ($K = \frac{1}{2}mV^2$) and electric potential energy ($U = -\frac{kq_1q_2}{r}$). The total energy will be

$$E = K + U$$

$$E = \frac{1}{2}mV^2 - \frac{ke^2}{r} \ldots\ldots\ldots 26.5$$

Putting the value of $mV^2 = \frac{ke^2}{r}$ from equation (III)

$$E = \frac{ke^2}{2r} - \frac{ke^2}{r}$$

$$E = -\frac{ke^2}{2r}$$

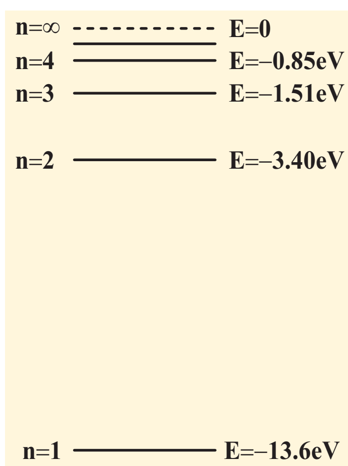



Figure 26.5
various excitation levels

Substitute the value of r from equation( IV)

$$E = -\frac{me^4}{8\varepsilon_0{}^2 h^2}\left(\frac{1}{n^2}\right) \qquad (26.6)$$

The numerical value of this energy will be

$$E_n = \frac{-13.6}{n^2}\, eV \qquad (26.7)$$

The energy level diagram (see figure 26.5) shows the various -excitation levels.

## 26.2.4 Excitation & Ionization Energy:

### Excitation:

***The process of transferring energy to an atom or molecule, raising it to a higher energy state, often resulting in the emission of photons as it returns to its ground state.***

### Ionization Energy:

***The minimum energy required to remove an electron from an atom or molecule, resulting in the formation of an ion*** from figure 26.5 the energy levels corresponding to various of n as given inequation $E_n = \frac{-13.6}{n^2} eV$ are mentioned. The lowest level for *n=1* is the ground state of hydrogen atom and higher levels correspond to excited states. The energy for the greatest value of $n = \infty$ become zero and for any energy *E = 0* in which the electron and proton do not bound together is called ionization energy. Therefore, the energy E = 13.6 eV is required to ionize the hydrogen atom.

## 26.2.5 The spectrum of Hydrogen atom:

The electron in a hydrogen atom can jump between quantized energy levels by emitting or absorbing Photon for some different values of wavelengths. Any such wavelength is often called a line spectrum which can be absorption or emission lines. The lines for hydrogen are said to be grouped into series, according to the level at which upward jumps start and downward jumps end. The formula for these series corresponding to the different wavelengths can be obtained from equation

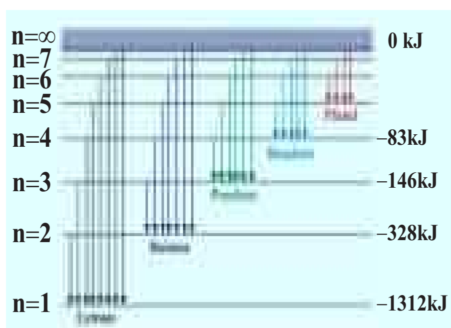



**Figure 26.6 Atomic spectrum of hydrogen**

$$E = -\frac{me^4}{8\varepsilon_0{}^2 h^2}\left(\frac{1}{n^2}\right)$$

The frequency of the photon emitted when the electron makes a transition from an orbit to an inner orbit as stated in postulate **-III**.

$\nu = \frac{(E_n - E_p)}{h}$ using equation (6)

$\nu = \frac{me^4}{8\varepsilon_0{}^2h^3}\left(\frac{1}{P^2} - \frac{1}{n^2}\right)$

To express above equation in terms of wavelength, it is convenient to use

$c = \nu\lambda$

$$\frac{1}{\lambda} = \frac{me^4}{8c\varepsilon_0{}^2h^3}\left(\frac{1}{P^2} - \frac{1}{n^2}\right)$$

where $R_H = \frac{me^4}{8c\varepsilon_0{}^2h^3} = 1.097 \times 10^7 m^{-1}$, is called Rydberg constant.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{P^2} - \frac{1}{n^2}\right) \qquad (26.8)$$

The possible series associated the different wavelengths can be explained from equation (8). The emission and absorption lines for all possible jumps up from the $n = 1$ level and down to the $n = 1$ level are said to be in the Lyman series. Similarly, other series are illustrated in the figure 26.6.

**Worked Example 26.1**

The electron in a hydrogen atom makes a transition from the n =3 energy level to the ground level (n = 1). Find the wavelength and frequency of the emitted photon.

**Solution:**

**Step 1: Write down the known quantities and quantities to be found.**

n =3

p = 1

$R_H = \frac{me^4}{8c\varepsilon_0{}^2h^3} = 1.097 \times 10^7 m^{-1}$

**Step 2: Write down the formula and rearrange if necessary.**

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

$$c = \nu\lambda$$

**Step 3: Put the values in formula and calculate.**

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{3^2}\right) = \frac{8}{9}R_H$$

$$\frac{1}{\lambda} = 0.975 \times 10^7 m^{-1}$$

$$\lambda = 102.56\ nm$$

$$\nu = \frac{c}{\lambda} = \frac{3.0 \times 10^8 m/s}{102.56 \times 10^{-9} m}$$

$$\nu = 2.925 \times 10^{15} Hz$$

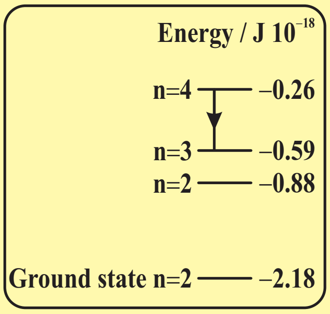
## Worked Example 26.2

The lowest energy levels of a mercury atom are shown below. The diagram is not to scale. Calculate the frequency of an emitted photon due to a transition, shown by an arrow, from level n = 4 to level n = 3. Which transition would cause the emission of a photon of a longer wavelength than that emi1ted in the transition from level n = 4 to level n = 3?

**Solution:**

**Step 1: Write down the known quantities and quantities to be found.**

$$E_4 = -0.26 \times 10^{-18} j$$
$$E_3 = -0.59 \times 10^{-18} j$$
$$h = 6.63 \times 10^{-34} js$$




**Step 2: Write down the formula and rearrange if necessary.**

$$h\nu = E_4 - E_3$$
$$c = \nu\lambda$$

**Step 3: Put the values in formula and calculate.**

$$\nu = \frac{-0.26 \times 10^{-18} + 0.59 \times 10^{-18} j}{6.63 \times 10^{-34} js}$$
$$\nu = 4.9773 \times 10^{14} Hz$$
$$\lambda = \frac{c}{\nu} = \frac{3.0 \times 10^{8} m/s}{4.9773 \times 10^{14} Hz}$$
$$\lambda = 6.027 \times 10^{-7} m$$
$$h\nu = E_n - E_p = \Delta E$$
$$\lambda = \frac{hc}{\Delta E}$$

From this relation, it clear that the wavelength will increase for lowest value of $\Delta E$. The longer wavelength can be calculated from the transition n = 3 to n = 2.

$$\lambda = \frac{hc}{\Delta E} = \frac{6.63 \times 10^{-34} js \times 3.0 \times 10^{8} m/s}{(0.88 - 0.59) \times 10^{-18} j}$$
$$\lambda = 6.858 \times 10^{-7} m$$

### Self-Assessment Questions:

1. A mercury atom de-excites from its 4.9 eV energy level to the ground state. Calculate the wavelength of the photon released.
2. What is the ratio of the shortest wavelength of the Balmer series to the shortest wavelength of the Lyman series?

## 26.3 X-Rays:

These are powerful electromagnetic rays of higher energy and can pass through most objects, including the body. Most of them have a wavelength ranging from 0.01 to 10 nanometres, corresponding to frequencies $3 \times 10^{19}$ Hz to $3\times10^{16}$ Hz. X-rays are used to generate images of tissues and structures inside the body.

**DO YOU KNOW?**

The discovery of X-rays, was made by the German physicist Wilhelm Conrad Roentgen in 1895. He named them X-rays to highlight the fact that their nature was unknown.

### 26.3.1 Inner Shell Transitions:

The passage of electron from one energy level to another is called electron transition. Bohr Theory showed that the principal quantum number is used to determine the energy and an orbital radius of electron. The inner shells, designated K, L, M, etc., correspond to 1,2,3, respectively, the K shell having the greatest binding energy and being closest to the nucleus. The other quantum numbers have a relatively small effect on energy and cause the shells (other than the K shell) to be split into subshells. When the transition of electrons from the outer shell to the inner shell occurred then the electromagnetic radiation corresponding to the characteristic energy generated as shown in figure: 26.7.

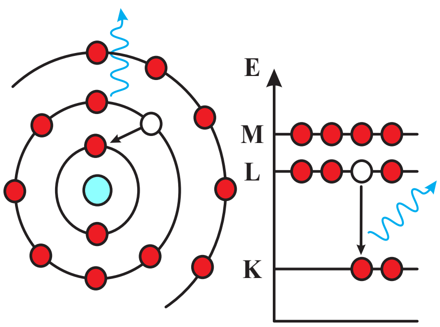



Figure: 26.7. Inner Shell Trasition

### 26.3.2 Production and characteristics of X-rays:

In 1895, Roentgen found that some photographic plates, kept carefully wrapped in his laboratory, had become fogged. Instead of merely throwing them aside he set out to find the cause of the fogging. He traced it to a gas-discharge tube, which he was using with a low pressure and high voltage. This tube appeared to emit a radiation that could penetrate paper, wood, glass, rubber, and even aluminum a centimeter and a half thick. Roentgen could not find out whether the radiation was a stream of particles or a train of waves. Newton had the same difficulty with light and he decided to call it X-rays.

X-rays as electromagnetic waves, but of much shorter wavelength: about 0.1nm to 10nm. They are produced when fast electrons, or cathode rays, strike a target, such as the walls or anode of a low-pressure discharge tube. In a modern X-ray tube there is no gas, or as little as high-vacuum technique can achieve: the pressure is about $10^{-5}$ mm Hg. The electrons are provided by thermionic emission from a white-hot tungsten filament.

**DO YOU KNOW?**

Roentgen's first X-ray was of his ***wife's left hand***, on which was her wedding ring. However, when she saw the image, she was not impressed. She said, "I have seen my death!

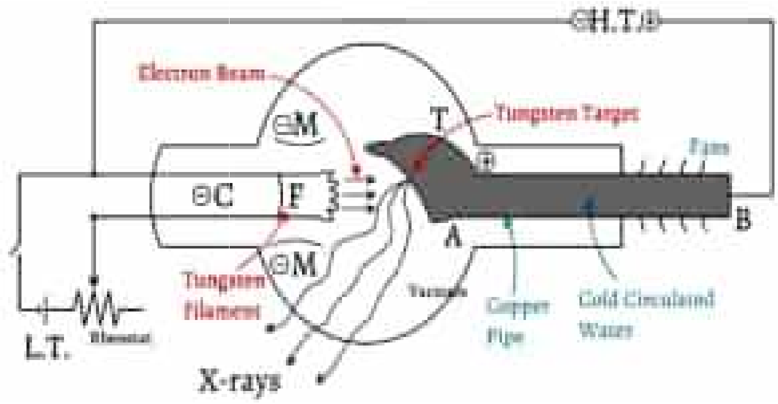



Figure: 26.8. Production of X-Rays

In Fig. 26.8 F is the filament and T is the target, or anode. Because there is so little gas, the electrons on their way to the anode do not lose any noticeable amount of their energy in ionizing atoms. From the a.c. supply, transformers provide about 10 volts (L.T) for heating the filament, and about 100 kV (H.T) for accelerating the electrons. On the half cycles when the target is positive, the electrons bombard it, and generate X-rays. On the half-cycles when the target is negative, nothing happens at all—there is too little gas in the tube for it to break down. Thus the tube acts, in effect, as its own rectifier providing pulses of direct current between target and filament. The heat generated at the target by the electronic bombardment is so enormous that the target must be cooled artificially.

**DO YOU KNOW?**

**L.T (Low Tension):** This refers to low voltage.
**H.T (High Tension):** This refers to high voltage.
Spine needs the longest exposure to X-ray, it exposed for 0.20 second to get proper image.

In an X-ray tube, very energetic electrons bombard on the atoms in a metal target, the atom will be left in an excited state with a hole in the electron shell. This process is illustrated in Fig. 26.7 for inner shell transition. When this hole is filled by an electron from an outer shell, an x-ray photon with energy equal to the difference in the electron energy levels is produced. The energy of the x-ray photon is characteristic of the target metal. The different characteristic lines occurred due to the electron transitions between different energy levels as shown in figure 26.9. Electron transitions in an atom, which produce the $K_\alpha$, $K_\beta$ and $L_\alpha$ characteristic x-rays.

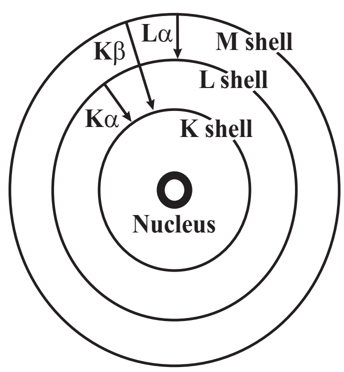



Figure: 26.9.
Electron Transition in atom

## 26.3.3 Properties and Uses of X-rays:

When X-rays strike some minerals, such as zinc sulphide, they make them fluoresce. If a human body part is placed between an X-ray tube and a fluorescent screen, the shadows of its bones can be seen on the screen, because they absorb X-rays more than flesh does. Unusual objects, such as swallowed safety-pins, if they are dense enough, can also be located. X-ray photographs can likewise be taken, with the plate in place of the screen. In this way cracks and flaws can be detected in metal castings. The characteristics lines are most useful in x-ray diffraction for studying the crystallographic structures.

**Self-Assessment Questions:**

1. On what factors the shortest wavelength of X-rays emitted from tube depends?
2. What determines the characteristic wavelength emitted by an X-ray tube?

### 26.4.1 LASER [*Light Amplification by Stimulated Emission of Radiation*]:

The electromagnetic waves experienced in daily life, ranging from the sun, stars, incandescent and fluorescent Lamps are emitted from atoms or molecules **spontaneously**.

- Ordinary natural and artificial, light is released by energy changes on the atomic and molecular level that occur without any outside interference.
- A second type of light exists, when an atom or molecule retains its excess energy until stimulated or induced to emit the energy in the form of light.

***Lasers are designed to produce and amplify this stimulated form of light into intense and focused beams. Compared to conventional sources of ordinary light, the light from a laser is quite intense, monochromatic, and emitted in a unidirectional beam limited by diffraction.***

The special nature of laser light has made laser technology a vital tool in nearly every aspect of everyday life including communications, entertainment, manufacturing, and medicine.

### Stimulated or Induced Absorption:

When an atom absorbs photons of energy $h\nu = E_2 - E_1$ incident on it, in its ground state, the atom reaches in one of its allowed states ***excited state.***

***When an atom induced by the photon (energy packet and do transition to one of its allowed states (excited state) is called Stimulated or induced absorption.***

The life time of an atom in an excited state is $10^{-8}$ seconds as shown in Figure 26.10.

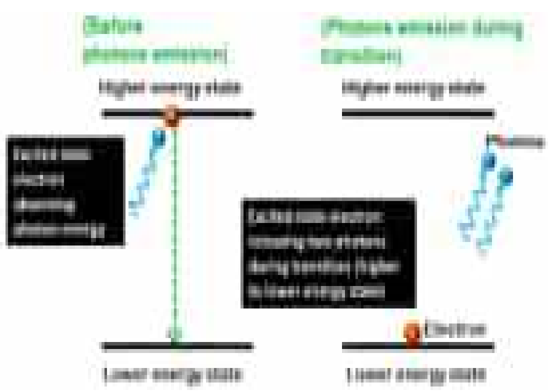


Figure: 26.10. Stimulated Emission

### Spontaneous Emission:

***The process of photon emission by an excited atom with no external influences is called spontaneous emission.***

In excited state the life time of an atom is too short therefore, a probability that the atom in the excited state $E_2$ will go back to the lower state $E_1$ by spontaneously emitting the absorbed radiation ($E=h\nu$) is very high. The emitted radiation is incoherent to the induced energy photon as shown in figure 26.11.

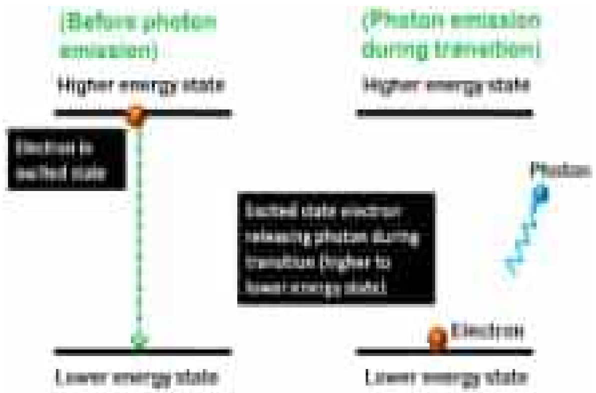



Figure: 26.11. Spontaneous Emission

## Stimulated Emission:

In this process, if the atom in an excited state $E_2$, the action of external radiation with a frequency $h\nu = E_2 - E_1$, forced (induced, stimulated) a transition to the ground state with the emission of one photon with the same energy.

***Radiation, which occurs as a result of external exposure, is called induced or stimulated. In the stimulated emission two photons are involved: the primary photon, causing the emission of radiation by an excited atom and the secondary photon emitted by the atom.***

These two identical photons will be exactly in phase and coherent. If a cascade of stimulated or induced emission occurs, the number of identical photons increases, the ***light amplification in*** the acronym laser. The beam is *coherent* because all photons are in phase, the beam is *monochromatic* because the photons all have the same *wavelength*, and the beam is parallel because the photons all move in same *direction* as shown in figure 26.12.

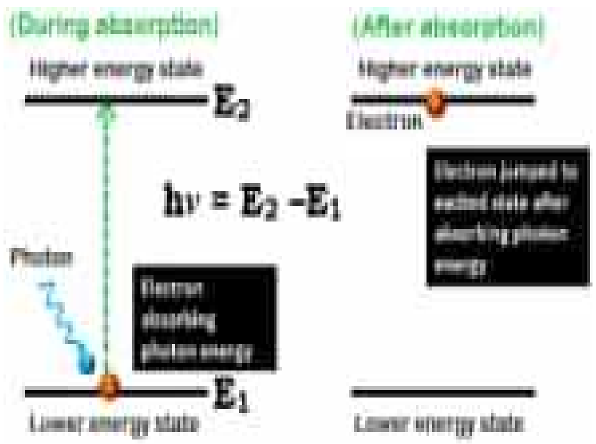



Figure: 26.12. Stimulated Emission

## Metastable States and Population Inversion:

***Population inversion*** is a key to produce laser light. The process of achieving a greater population in a higher energy state compared to a lower energy state. The population inversion is required for laser operation.

***Population inversion cannot be achieved in a two-energy level system, at normal conditions; the number of electrons in the lower energy state ($E_1$) is always greater as compared to the number of electrons in the higher energy state ($E_2$).***

**DO YOU KNOW?**

In addition to induced absorption and spontaneous emission, a third interaction between an atom and a photon (energy) was first proposed by Albert Einstein in 1917 called stimulated emission.

## Metastable States:

Consider a system consisting of three energy levels $E_1$, $E_2$, $E_3$. We assume that the energy level of $E_1$ is less than $E_2$ and $E_3$, the energy level of $E_2$ is greater than $E_1$ and less than $E_3$, and the energy level of $E_3$ is greater than $E_1$ and $E_2$. The energy level $E_2$ is sometimes referred to as **Metastable state** having a life time of $10^{-3}$ seconds. When we supply light energy which is equal to the energy difference of $E_3$ and $E_1$, the electrons in the lower energy state ($E_1$) gains sufficient energy and jumps into the higher energy state ($E_3$). This process of supplying energy is called **optical pumping** as shown in figure 26.13.

Figure: 26.13. Optical Pumping

We also use other methods to excite ground state electrons such as electric discharge and chemical reactions. The flow of electrons from $E_1$ to $E_3$ is called pump transition. Because of the shorter lifetime, only a small number of electrons accumulate in the energy state $E_3$. The electrons undergo a radiation less transition from $E_3$ to $E_2$. In the Metastable state $E_2$ the electrons will remain there for longer period because of its longer lifetime. Hence the number of electrons coming in the state $E_2$ is greater than the number of electrons leaving out. As result, a large number of electrons accumulate in Metastable state. After the population inversion is achieved the Metastable state $E_2$ is exposed to beam of photons which causes induced (stimulated emission). The whole process for population inversion is shown in figure 26.14 for three level systems.

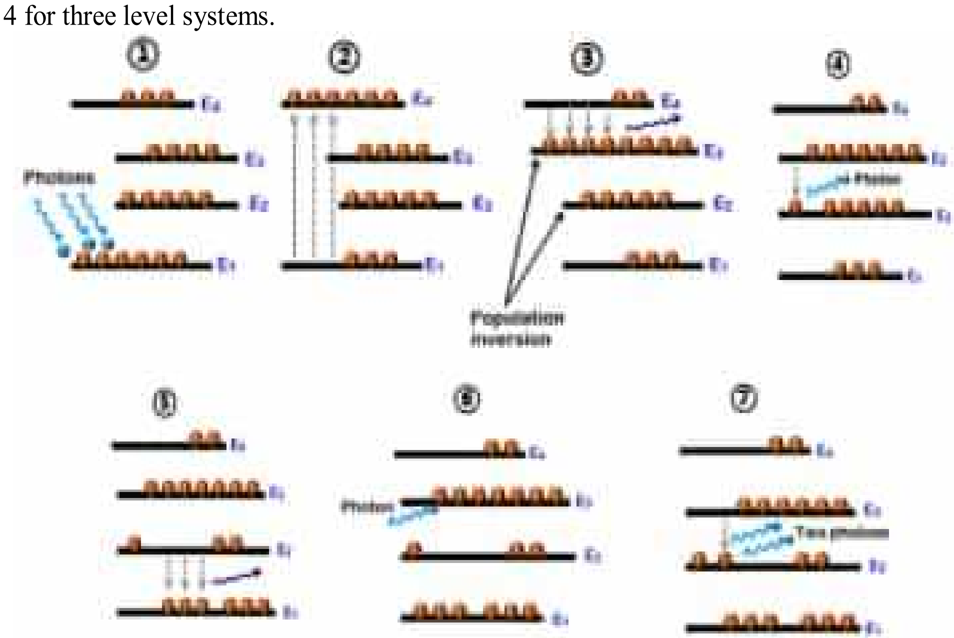


Figure: 26.14. Population Inversion

### 26.4.2 He – Ne Gas Laser:

The helium-neon laser was the first continuous wave (CW) laser ever constructed. It was built in 1961 by **Ali Javan**, **Bennett**, and **Herriott** at Bell Telephone Laboratories. He-Ne lasers are commonly used in school laboratories and in older barcode readers. The schematic diagram of He-Ne laser is shown in figure 26.15.

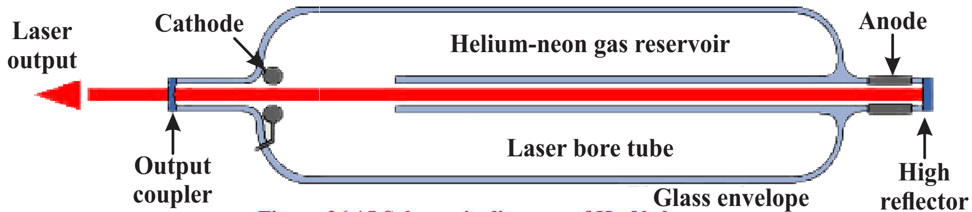



Figure 26.15 Schematic diagram of He-Ne laser

## Helium-neon laser construction:

The helium-neon laser consists of three essential components:

### Pump Source (high voltage power supply):

The pump energy of the laser is provided by an electrical discharge of several hundred Volts between an anode and cathode at each end of the glass tube. A current of 5 to 100 mA is typical for laser operation.

### Gain Medium (laser glass tube or discharge glass tube):

Figure 26.15 shows a gas discharge tube contains a low-pressure mixture of helium-neon in a ratio between 5:1 and 20:1 bound in a glass tube. The partial pressure of helium is 1 mbar whereas that of neon is 0.1 mbar.

### Resonating Cavity:

The glass tube (containing a mixture of helium and neon gas) is placed between two parallel mirrors. These two mirrors are silvered or optically coated. Each mirror is silvered differently. The left side mirror is partially silvered and is known as output coupler whereas the right side mirror is fully silvered and is known as the high reflector or fully reflecting mirror. The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows some part of the light to produce the laser beam.

**DO YOU KNOW?**

The three important components of any laser device are:

1. Active medium (medium in which the population inversion can be achieved)
2. Pumping source (usually light or electric current to achieve population inversion)
3. 3. Optical resonator (a feedback system, which consists of an active medium kept in between a 100% mirror and a partial mirror)

### Laser Operation:

This electrical excitation raises the helium atom into a meta-stable state with energy 20.61 eV above the ground state. Neon has a meta-stable state with energy 20.66 eV above its ground state. Collision of the excited helium atoms with the ground-state neon atoms results in transfer of energy to the neon atoms, exciting neon electrons. The difference between the energy states of the two atoms is in the order of 0.05eV, which is supplied by kinetic energy. The number of neon atoms in the excited states builds up as further collisions between helium and neon atoms occur, causing a population inversion. Spontaneous and stimulated emission results in emission of 632.82 nm wavelength light.

### 26.4.3 Properties and Uses of Lasers:

#### Properties of Laser:

The properties of laser light are very strange as compared to conventional light. The factors that make laser light prominent are: Monochromatic, Highly Intense or Brightness Coherence and Directionality

1. **Monochromatic:**

A single color or wavelength light is called monochromatic. The light emitted from ordinary light sources has different wavelengths, or colors. However, laser light has a single wavelength or color.

2. **Highly Intense or Brightness:**

The characteristics of coherence and directionality of the laser makes laser light highly intense as compared to conventional light. It is the power emitted per unit surface area per unit solid angle. A one milli watt He-Ne laser is more intense than the sun intensity.

3. **Coherence:**

Two or more waves of same frequency are said to be coherent in nature if they have constant phase difference. A predictable correlation of the amplitude and phase at any one point with another point is called coherence. In laser light the property of coherence occurs between any two or more light waves. Where as in conventional light, the property of coherence exhibits between a source and its virtual source.

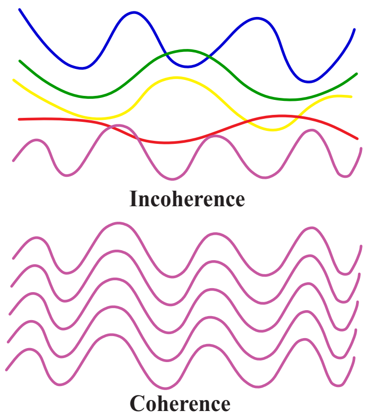


**Figure 26.16: Incoherence and Coherence**

4. **Directionality or Divergence:**

The light ray coming from laser light travels in a single direction. However, an ordinary light source travels in all directions. For example, on travelling a distance of 1 Km the torch light spreads 1 km distance. But the laser light spreads only few centimeters distance even it travels lacks kilometer distance.

#### Uses of Lasers:

Lasers are widely used in many fields some of them are:

1. **Tools:**
   - Cutting tools are typically precise, and also simple to automate. They do not require sharpening, unlike that of knives.
   - Robot-guided lasers are widely used for the cutting of pieces of cloth.
   - Laser tools are used in corneal surgery, restoring a detached retina of eye, and removing kidney stones.
2. **Communication:**
   - Lasers are used in Barcode scanners to convert a printed barcode into a number.
   - A semiconductor laser beam helps to convert the printed pattern of data into numbers in a CD/DVD.
   - In Photonics, lasers are used in fibre optic cables.
3. **Defence:**
   - In defence field, the military employs laser-guided guns and missiles.

- Laser range-finders use high-resolution scanning to find the distance and speed from an object that is located beyond the point-blank range.

4. **Medicine:**
   - In medicine, the laser beam is used as part of phototherapy for many procedures.
   - The development of laser technology in recent decades has enabled the creation of a new field of medicine laser surgery.
   - Lasers have uses in dermatology, ophthalmology, urology, rheumatology and dentistry.
5. **Holography:**
   - Holography is a true three-dimensional image recording on film by lasers. Holograms are used for amusement, decoration on novelty items and magazine covers.

### 26.4.3 Safe Handling of Lasers:

Lasers come in various shapes and forms. They have many uses in teaching, research, manufacturing, medicine, dentistry, communications, and shop checkouts and most commonly at work in the office. In fact, some applications may be so well engineered that users are not even aware that the equipment contains a laser.

**Laser beam hazards:**

The health effects that could occur due to exposure to a laser beam are damage to the skin and eyes. Skin effects include erythema, elastosis (photoageing), and immediate pigment darkening (tanning), burns and skin cancer. Eye effects include photokeratitis, photoconjunctivitis, cataracts, photoretinal damage and burns. The nature of safety measures which are generally taken to avoid the hazards or damages can caused by the lasers are adopted and procedure according to the use and intensity of the laser. Following are some general safety protocols which have to be taken into consideration while working with las ers.

- Only **trained, authorized personnel** may operate lasers, Authorization is received from the authorized laser user and the Laser Safety Officer.
- **NEVER** put yourself into any position where your eyes approach the axis of a laser beam (even with eye protection on).
- **Keep beam paths below or above** standing or sitting eye level. Do not direct them towards other people.
- **Do not damage laser protective housings**, or malfunctioned the interlocks on these housings.
- **Eliminate all reflective material** from the vicinity of the beam paths.
- **Never use viewing instruments** to look directly into a laser beam. If this is necessary, install an appropriate filter into the optical element assembly.
- **Keep ambient light levels as high** as operations will permit.
- **Do not work alone** when performing high power laser operations.

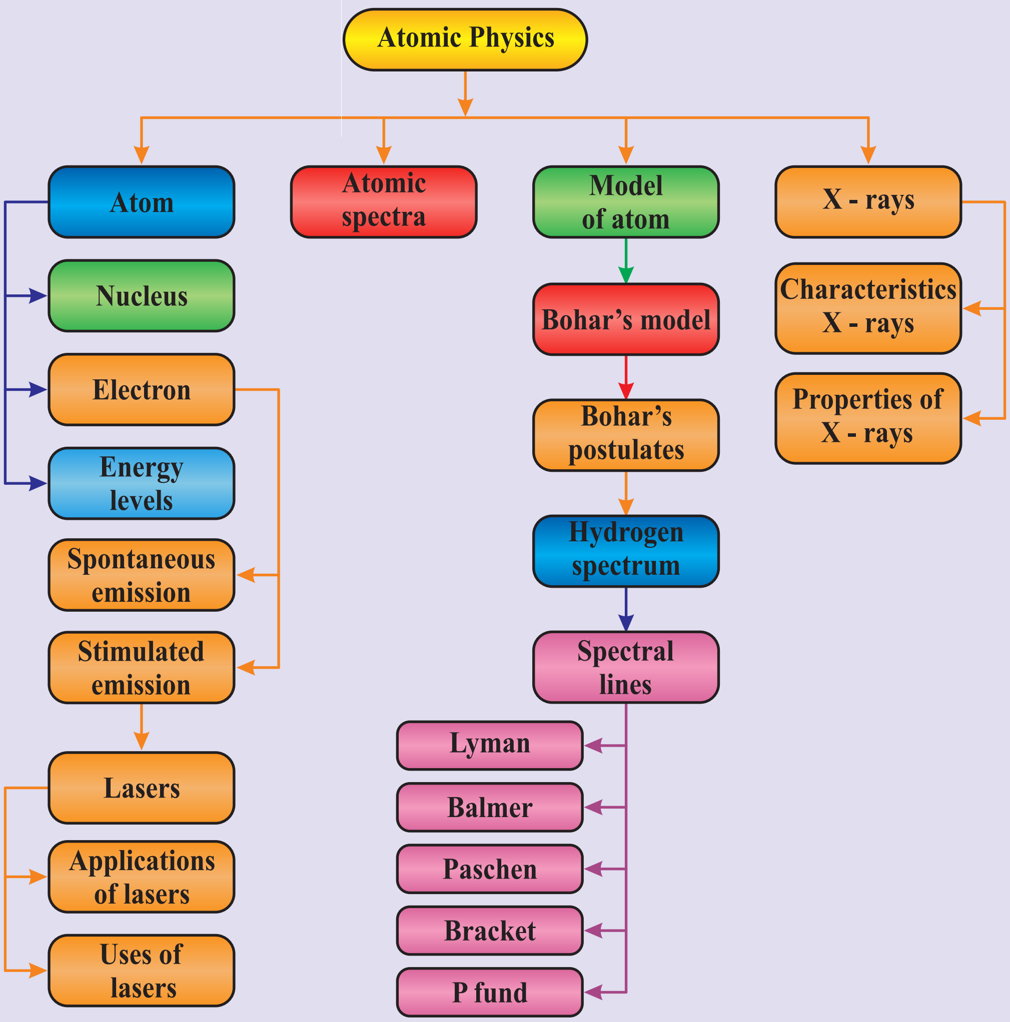
**Self-Assessment Questions:**

1. How bright is a laser beam when viewed from the side?
2. How do you focus regular light to make it a laser beam?
3. Why do we call laser as a non-material knife?

## SUMMARY

- ✓ Atomic spectra deal with the spectrum of frequencies of electromagnetic radiation emitted or absorbed by an electron during transitions between different levels of energy within an atom.
- ✓ An optical spectrum is obtained, when light passes through a prism or a diffraction-grating.
- ✓ A line of particular frequency or wavelength emitted or absorbed by atoms is called spectral line.
- ✓ The spectra for each element are unique because each element contains differing numbers of electrons and thus different energy levels.
- ✓ Niels Bohr explained the atom of hydrogen. Hydrogen atom consist of proton and electron revolving around the nucleus
- ✓ According to Bohr's the radii of Hydrogen atom have the quantized values $r = \frac{n^2 \varepsilon_0 h^2}{\pi m e^2}$ or $r = r_0 n^2$ where $r_0 = 5.29 \times 10^{-11} m = 0.53 A^0$ is called Bohr's first orbit.
- ✓ X-Rays are powerful electromagnetic rays of higher energy and can pass through most objects, including the body.
- ✓ X-rays are produced when fast electrons, or cathode rays, strike a target, such as the walls or anode of a low-pressure discharge tube.
- ✓ The light from a laser is quite intense, monochromatic, and one directional.
- ✓ The process of photon emission by an excited atom with no external influences is called spontaneous emission.
- ✓ Radiation which occurs as a result of external exposure is called induced or stimulated emission.
- ✓ Metastable state is a particular excited state of an atom, nucleus, or other system that has a longer lifetime than the ordinary excited states.
- ✓ The process of making the population of atoms in the higher energy state (Excited state) more than that of lower energy state (ground state) is known as population inversion.
- ✓ A process in which light is used to raise (pump) electrons from a lower energy level in an atom or molecule to a higher energy level is called optical pumping.
- ✓ The helium-neon laser was the first continuous wave (CW) laser ever constructed.
- ✓ Laser light is Monochromatic, Highly Intense, Coherence and single directional.
- ✓ Lasers are widely used in tools, communication, defence, medicine and holography.
- ✓ The health effects that could occur due to exposure to a laser beam are damage to the skin and eyes.
- ✓ The nature of safety measures which are generally taken to avoid the hazards or damages can caused by the lasers are adopted and procedure according to the use and intensity of the laser.

# CONCEPT MAP



Atomic Physics
Atom
Atomic spectra
Model of atom
X - rays
Nucleus
Bohar's model
Characteristics X - rays
Electron
Bohar's postulates
Properties of X - rays
Energy levels
Hydrogen spectrum
Spontaneous emission
Stimulated emission
Spectral lines
Lasers
Lyman
Balmer
Applications of lasers
Paschen
Bracket
Uses of lasers
P fund

# EXERCISE

## Section (A): Multiple Choice Questions (MCQs)

**Choose the correct answer:**

1. Atomic spectra are also known as:
   (a) Discrete spectra (b) Line spectra
   (c) Emission spectrum (d) Continuous spectra
2. The ratio of kinetic energy to total energy for an electron in a Bohr orbit is:
   (a) 1:1 (b) 2:3 (c) 1:2 (d) 2:1
3. The Bohr radius increases as the principal quantum number:
   (a) increases (b) decreases
   (c) remains constant (d) oscillates
4. Laser beams consist of:
   (a) Highly coherent electrons (b) Highly coherent photons
   (c) Highly coherent phonons (d) Highly coherent neutrons
5. The ruby laser is an example of:
   (a) Optical pumping (b) Electrical pumping
   (c) Chemical pumping (d) Thermal pumping
6. Laser action requires a medium with at least:
   (a) Three energy levels (b) Four energy levels
   (c) Two energy levels (d) Five energy levels
7. Population inversion occurs in:
   (a) Active medium (b) Passive medium
   (c) Gaseous medium (d) Vapour medium
8. X-rays transfer __________ to metals.
   (a) Energy (b) Force (c) Pressure (d) Momentum
9. X-rays are deflected by:
   (a) Magnetic fields (b) Electric fields
   (c) Gravitational fields (d) No fields
10. Doubling the voltage of an X-ray tube:
    (a) Halves the intensity (b) Keeps the intensity unchanged
    (c) Doubles the intensity (d) Quadruples the intensity

## Section (B): CRQs (Short Answered Questions):

1. Why do different elements have different spectra?
2. In the Bohr model, how many times larger is the radius of the fifth Bohr orbit compared to that of the first Bohr orbit?
3. What is the difference between X-Rays and Gamma Rays?
4. Sate the properties of X-Rays, which makes it possible to detect cracks in bones.

5. What is the energy of a photon that, when absorbed by a hydrogen atom, could cause an electronic transition from (a) the n =3 state to the n = 5 state and (b) the n = 5 state to the n = 8 state?
6. What are the (a) wavelength range and (b) frequency range of the Lyman series and the Balmer series?
7. Distinguish between spontaneous and stimulated emission.
8. Explain why population inversion is necessary in a laser?
9. In an optically pumped laser, the light that causes optical pumping is always shorter in wavelength than the laser beam. Explain
10. A hydrogen atom is in its first excited state (n = 2). Calculate (a) the kinetic energy of the electron, (b) the potential energy of the system, and (c) the total energy of the system.

**Section (C): ERQs (Long Answered Questions):**

1. What are the postulates of Bohr's Model of hydrogen atom? Discuss the importance of this model to explain various series of line spectra in hydrogen atom. Do any of the assumptions of the Bohr's theory of hydrogen atom contradict with the classical Physics? Derive the expression for total energy of electron in nth Bohr orbit and show that- $E_n \propto 1/n^2$.
2. How X-rays are produced? State the purpose of cooling fins in the X-ray tube.
3. Explain why X-rays are appropriate in study of crystalline structure material? Write some main properties of X-rays.
4. What is Laser? Write the characteristics of Laser light. Can a two-level system be used for the production of Laser? Why?
5. What is pumping? What are the different methods of pumping? Explain optical pumping.
6. What is the principle of Laser? Write the construction and working of Helium-neon laser.
7. Give some important properties of lasers. Also write the uses of lasers in the field of medicine, defense and communication.
8. What is wave number? Derive the expression $\frac{1}{\lambda} = R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$.
9. Derive the expression for Bohr's radius and develop a general relation for radii of quantized orbits of hydrogen atom.

**Section (D):** **Numerical:**

1. Calculate the energy of an electron in the n = 2 orbit of a hydrogen atom according to the Bohr model. **(Ans. $-5.447 \times 10^{-19}$ $J$)**
2. Calculate the speed of the electron if it orbits in(a) the smallest allowed orbit and (b) the second smallest orbit? (c)If the electron moves to larger orbits, does its speed increase, decrease, or stay the same? **(Ans. (a) $2.19 \times 10^{6} m/s$ (b) $1.09 \times 10^{6} m/s$ (c) the speed of the electron will decrease)**
3. What are the (a) energy, (b) magnitude of the momentum, and (c) wavelength of the photon emitted when a hydrogen atom undergoes a transition from a state with n = 3 to a state with n = 1? **(Ans. (a) 12.1 eV (b) 6.45 X $10^{-27}$ N.s (c) 102 nm)**
4. What is the energy of the photon emitted by hydrogen atom when the hydrogen atom changes directly from the n = 5 state to the n = 2 state? **(Ans. 2.85 eV)**
5. How much work must be done to pull apart the electron and the proton that make up the hydrogen atom if the atom is initially in (a) its ground state and (b) the state with n =3? **(Ans. (a) 13.6 eV (b) 1.51 eV)**
6. (a) What is the wavelength of light for the least energetic photon emitted in the Balmer series of the hydrogen atom spectrum lines?
   (b) What is the wavelength of the series limit? **((a) 659 nm (b) 366 nm)**
7. A laser emits light with a wavelength of 632.8 nm and has a power output of 55 mW. Calculate the energy of one photon emitted by this laser. **(Ans. 3.14 X $10^{-19}$ J)**
8. Calculate the wavelength of X-rays if the energy of one photon emitted by the X-ray machine is 1.9878×10−15 joules. **(Ans. 0.1 nm)**