Spectrum

Nature of light:

- The two theories, which explain the nature of light are (i) wave theory, (ii) corpuscular theory.
- The wave theory of light could satisfactorily explain diffraction, refraction etc.
- Corpuscular theory could explain photoelectric effect and Compton effects.
- Wave theory is superior to corpuscular theory.
- Visible light is only a small portion of electromagnetic spectrum.
- All radiant energy is in the form of electromagnetic waves.
- These radiations are associated with electric and magnetic fields.
- The vertical component of the wave (E) indicates the variation of electric field strength.
- The horizontal component of the wave (H) indicates the variation of magnetic field strength.
- The distance between two successive crests or troughs is called the wavelength (λ).
- Wavelength is measured in Angstrom units or nanometres.
- 1 $A^0 = 10^{-8}$ cm = 10^{-10} m; 1 nm = 10^{-9} m = 10 A^0
- The number of waves passing through a given point in one second is called as frequency of the wave.

  $\upsilon = c / \lambda$

  Units of frequency is Hz.
- The velocity of light in air or in vacuum is 3×10^8 ms^{-1} or 3×10^{10} cms^{-1}.
- Frequency x wavelength = velocity; $\upsilon\lambda = c$
- The reciprocal of wavelength is called wave number.

  Wave number $\bar{\upsilon} = \frac{1}{\lambda}$
- The units of wave number is cm^{-1} or m^{-1}.

  $\bar{\upsilon} = \frac{1}{\lambda}$; $\quad \upsilon = \frac{c}{\lambda} \quad \upsilon = c.\bar{\upsilon}$
- 'A' is the amplitude of the wave or intensity of the light.
- The intensity of color depends on amplitude and color of the light depends on frequency. ($I \propto A^2$)

Sources of different radiations:

- High-pressure hydrogen or deuterium discharge tube is the source of ultraviolet rays.
- The wavelength range of ultraviolet rays is 1850 A^0 to 3750 A^0.
- To obtain high energetic U.V. xenon arc lamp or mercury vapour lamp can be used.
- The glass enclosed tungsten filament is the source of visible radiation. Incandescent lamp is the source of I.R. radiation.
- The best source of near infrared radiations is a black body.
- To produce far infrared radiations Nernst glower or globar source is used.
- The wavelength of these radiations is about 14,000 A^0.
- A mixture of Zirconium and Yttrium oxides shaped into a small hollow rod is used in Nernst glower.
- The glower is heated to 1500 °C to 2000 °C.
- The globar source is a rod of sintered silicon carbide, which is heated to 1300 °C to 1700 °C.

Planck's Quantum theory:

- Planck's quantum theory explains black body radiation.
- A hollow sphere coated inside with platinum black and having a pinhole acts as a nearer black body.
- A black body is not only a prefect absorber but also a perfect emitter of radiant energy.
- Black body kept at high temperature give radiations in a wide range of different wavelengths.
- The curves are obtained at different temperatures when the intensity of radiations is plotted against wavelength.
- If the energy is emitted continuously the curve should be as shown by the dotted lines.
- The study of the curves shows that the nature of the radiation depends on temperature.
- At a given temperature, the intensity of radiation increases with wavelength reaches a maximum and then decrease.
- As the temperature increases the peak of the curve shifts to lower wavelengths. (ie. towards left)
- Based on the above observations of black body radiation, Planck proposed quantum theory of radiation. The salient features of the theory are
- The vibrating particle in the black body does not emit energy continuously.
- It is emitted in the form of small discrete packets called quanta.

- The emitted radiant energy is propagated in the form of waves.
- If the vibrating particles oscillates with a frequency v, then the energy associated with a quantum. $E \propto v$;

  E = hv (h = Planck's constant. h = 6.625 x 10^{-27} ergs-sec, h = 6.625 X 10^{-34} J-sec)
- Energy is emitted or absorbed in some simple integral multiples of a quantum i.e. E = 1 hv (or) 2hv (or) 3hv but not fractional multiple of hv.
- This is called quantization of energy.

Einstein's generalization of Planck's quantum theory:

- Planck's quantum theory was extended to all types of electromagnetic radiations by Einstein.
- According to Einstein energy is released in the form of photons and they continue to exist as photons till they are absorbed by another body.
- According to Max Planck, energy is emitted in the form of packets and propagated in the form of waves.
- According to Einstein, both emission and propagation of energy take place in the form of photons.
- Einstein explained photoelectric effect with the help of his generalized quantum theory.
- Emission of electrons from the metal surface when it is exposed to light is called photoelectric effect.
- Such emitted electrons are called photoelectrons.
- According to Einstein electron is ejected from a metal when it is struck by a photon which has sufficient energy.
- If the photon has insufficient energy it cannot eject the electron and photo electric effect is not observed.
- Photon of violet light has higher energy than that of red light. It is observed that violet light is able to eject electrons from potassium but red light has no effect.
- When the photon having energy $h\nu$, strikes the metal surface, some part of it is utilised to eject electron and the remaining part is utilised to increase the K.E. of photo electron.
- If the frequency of incident radiation increased, K.E. of photoelectrons increase.
- If the intensity of incident radiation increases rate of photoelectric emission increases.

$$hv = W + K.E$$

hv = energy of striking photon; W = energy required to eject the electron (work function);

K.E. = kinetic energy of the emitted electron.

Light spectra:

- Spectrum: It is the pattern of lines produced on the photographic plate, by the dispersion of a beam when it is passed through the prism.
- Spectrometer: It is the device used to record the spectrum.
- Spectrograph It consists of source of light, Prism and photographic plate.
- Spectra are of 2 types: 1. Emission spectrum 2. Absorption spectrum

Emission Spectrum:

- When the substances are in the excited state they emit light. Spectrum obtained with this emitted light is called emission spectrum.
- Emission spectrum is obtained by heating the substances on a flame or by passing electric discharge through the gases.
- Emission spectrum consists of bright lines on dark background.

Absorption spectrum:

- It is due to absorption of light.
- When the substances are in the ground state, they absorb radiation and go to excited state, the spectrum so obtained is called absorption spectrum.
- Absorption spectrum consists of dark lines on bright background.
- In the absorption spectrum lines are formed at same wavelengths as those of emission spectrum.
- Emission spectrum or absorption spectrum is of two types.

Continuous spectrum or band spectrum:

- In this spectrum formation of lines is continuous.
- Each color fades in to the next color as in rainbow.
- A beam of white light when passed through a prism, it gives a continuous spectrum of seven colors i.e. VIBGYOR.
- Incandescent lamp or hot solids at high temperatures will give continuous spectrum.

Discontinuous spectrum or line spectrum:

- Line spectrum consists of sharp, distinct and well defined lines.

- Gases or vapours of elements when heated in a flame or by passing electric discharge through them, line spectrum is obtained.
- Line spectrum is given by atoms and so it is called atomic spectrum.
- Each element has it's own characteristic line spectrum, by which the element can be identified.

Band spectrum:

- It consists of series of bands where each band is a group of lines merged together.
- Band spectrum is given by molecules and so it is called molecular spectrum.

Hydrogen spectrum:

- It consists of number of lines.
- They can be classified into various series.
- Only one such series is visible to the naked eye and is termed as the visible region of hydrogen spectrum i.e. Balmer series.
- The wavelength or wave number of various lines in the visible region can be expressed by an equation.

  (Reydberg – Ritz equation) : $\bar{\upsilon} = \frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

  Where $n_1 = 2$ which is constant for all the lines in Balmer series; $n_2 = 3, 4, 5.....$

Series in hydrogen spectrum:

Name of series	n_1(lower orbit)	n_2(higher orbit)	Spectral region
Lyman series	1	2, 3, 4, 5...	ultraviolet
Balmer series	2	3,4,5,6...	visible
Paschen series	3	4,5,6,7...	near infrared
Brackett series	4	5,6,7...	infrared
Pfund series	5	6,7,8...	far infrared

- The other series in the hydrogen spectrum are invisible.
- The wavelength or wavenumber of all the lines in all the series can be calculated by using Rydberg's equation or Rydberg-Ritz equation.

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

- The value of R = 1,09,677 cm^{-1} is valid only for the lines in the hydrogen spectrum.
- For a spectral line of one electron species like He^+, Li^{2+} the value of R = 1,09,677 x Z^2 cm^{-1}.
- The first line in Balmer series is called Hα line and its wavelength is 6563 A^0.
- The second line is called Hβ line and its wavelength is 4861 A^0.
- The spectral lines get closer when the n_2 value is increased.

Hydrogen spectrum – Bohr's explanation:

- When hydrogen gas is heated or exposed to light energy or subjected to electric discharge different atoms absorb different amounts of energy and electrons are excited to different higher energy levels.
- The bright light emitted when passed through a prism and received on a photographic plate and is recorded as the atomic spectrum of hydrogen.
- The hydrogen spectrum is the simplest of all the atomic spectra. It is line spectrum and emission spectrum.
- It contains a number of series of lines.
- The electrons in the excited atoms may be completely knocked out of the atom if the absorbed energy is greater than or equal to 13.58 eV which is the ionization potential of hydrogen atom.
- If the energy available is less than 13.58 eV the electron absorbs only a certain quantum of energy and the electron jumps to higher orbit.
- The electron in higher quantum state tends to emit energy and come back to the lower energy level.
- This may happen in a single step or in multiple steps.
- If electron jumps from any higher orbit to 1st orbit Lyman series is formed in u.v. region.

Electron transitions: $\infty \rightarrow 1$

$7 \rightarrow 1$

$6 \rightarrow 1$

$5 \rightarrow 1$ so on.

- If electron jumps back from any higher orbit to 2nd orbit Balmer series is formed in visible region.
- Electron transitions: $\infty \rightarrow 2$; $7 \rightarrow 2$, $6 \rightarrow 2$……
- If electron jumps back from any higher orbit to 3rd orbit Paschen series is formed in near I.R. region.
- Electron transitions: $\infty \rightarrow 3$; $7 \rightarrow 3$, $6 \rightarrow 3$; and so on.
- If electron jumps back from any higher orbit to 4^{th} orbit, Bracket series is formed in the I.R. region.
- Electron transitions: $\infty \rightarrow 4$; $7 \rightarrow 4$, $6 \rightarrow 4$ and so on.
- If electron jumps back from any higher orbit to 5^{th} orbit.
- Electron transitions: $\infty \rightarrow 5$; $7 \rightarrow 5$, $6 \rightarrow 5$
- If electron jumps back from infinite state to corresponding lower orbit, spectral line is called limiting line or limiting series

  Rydberg's equation for limiting line is $\bar{v} = R\left(\frac{1}{n_1^2} - \frac{1}{\infty^2}\right) = \frac{R}{n_1^2}$
- In a given series the line of longest wavelength is 1^{st} line ($2 \rightarrow 1$) and the line of shortest wavelength is limiting line.
- In all the five series of H - spectrum, the line of longest wavelength is 1^{st} line of Pfund series ($6 \rightarrow 5$) and the line of shortest wavelength is limiting line of Lyman series(∞ to 1)
- No.of possible spectral lines= $\frac{n(n+1)}{2}$; $n = n_2 - n_1$
- As the value of 'n' increases
  - i) the total energy of electron increases
  - ii) the energy difference between the successive orbits decreases
  - iii) P.E increases and K.E. decreases
  - iv) radius of orbits increases
  - v) velocity of electron decreases

Merits of Bohr's theory:

- He could explain the spectra of H - atom and other single electron species like He^+, Li^{2+} etc.
- He could determine frequency, wavelength, wave number of lines in H - spectrum.
- He could calculate the value of Rydberg constant (R).
- He could determine energy and velocity of electron and radius of orbits.
- He could explain the stability of atoms that is why, electrons are not falling into the nucleus and atoms

are not collapsed.

Demerit's of Bohr's theory:

- Bohr failed to explain spectra of multi electron species.
- He failed to explain fine structure of the H - spectrum.
- He failed to consider the wave number of electron.
- Bohr's theory contradicts Hisenberg's uncertainty principle.