# B.Sc. (Sem. - 4) Physics

# Course: US04CPHY21

# Electromagnetic Theory and Spectroscopy

# UNIT-3 Lecture 1

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# Atomic Spectra

# UNIT - 3 Atomic Spectra - Topics

- Investigation of Spectra
- Production of Spectra
- Types of Spectra
- Wave Number
- Shortcomings of Bohr theory
- Criticism and limitations of old quantum mechanical models
- The Spinning Electron
- Space Quantization
- Quantum Numbers and their Physical Interpretation
- Fine structure of Hydrogen atom
- Spectral terms and their notations
- Positronium
- Mesonic atoms
- L-S Coupling
- J-J Coupling
- Experimental study of Zeeman Effect
- Classical Interpretation of Normal Zeeman Effect
- Vector model and normal Zeeman effect
- Paschen-Back effect
- Stark Effect

# UNIT - 3 Atomic Spectra – Reference Books

**Text Books:**

1. Introduction to Electrodynamics
   David J Griffiths, (4th Edition) Prentice-Hall of India Private Ltd.
2. Elements of Spectroscopy
   S L Gupta, V Kumar, R C Sharma
   (24th Edition) Pragati Prakashan

**Reference Books:**

1. Electricity and Magnetism
   A S Mahajan and A A Rangwala
   Tata McGraw Hill Publishing Company Ltd
2. Molecular structure and Spectroscopy
   G Aruldhas, Prentice-Hall of India Private Limited

# UNIT - 3 Atomic Spectra

## Topics of the discussion

Investigation of Spectra
Production of Spectra
Types of Spectra
Wave Number
Shortcomings of Bohr theory

# Spectroscopy - Importance

- Spectroscopy-important branch of sciences
  - [Chemistry, Physics, Astronomy, etc.]
- Due to development of Spectroscopy it is possible
  - **Development of Atomic Physics and Molecular Physics**
  - **Development of Theoretical and Experimental Physics**
  - **Understanding of Periodic Table**
  - **Understanding of the type of Chemical Bonds**
  - **It is possible to predict something about Earth and Sun (its environment etc.)**

# What is a Spectrum ?

- Spectrum:

*When light dispersed through the prism is focused on a screen, then the formation of a regular array of colors on the screen is observed. This regular arrangement of colors is named as spectrum.*

# What is Spectroscopy?

- It is a study of spectrum.
- Spectroscopy is used as a tool for studying the structures of atoms and molecules.
- *The branch of science concerned with the investigation and measurement of spectra produced when matter interacts with or emits electromagnetic radiation.*

# Investigation of Spectra

# Investigation of Spectra

- **Two Methods:**

**[1] Refraction Method**

- For the separation of components of light *Prisms* are employed

- Advantage: *High intensity*

# Investigation of Spectra

## [2] Diffraction Method

For the separation of components of light *Grating* are employed

- **Advantage:** *High resolving power*

# Investigation of Spectra

**Comparison**

- **Refraction Method**
  - For the separation of components of light *Prisms* are employed
  - Advantage: *High intensity*
- **Diffraction Method**
  - For the separation of components of light *Grating* are employed
  - Advantage: *High resolving power*

# Methods/Instruments used

# Method/Instruments used

| | |
|---|---|
| Far Infrared (IR) Spectrum | Thermopiles and bolometer |
| Below 13000 $A^0$ | Photographic films |
| 30,000 $A^0$ to 3600 $A^0$ | Lenses, Prisms , windows of glass |
| Up to 1800 $A^0$ | Quartz |
| 1800 $A^0$ to 1250 $A^0$ | Fluorite |
| Below 1250 $A^0$ | Refraction grating |

# Production of Spectra

## Production of Spectra - BASIC Principle:

Normal atom excited so that electron jump from normal orbit to outer orbit.

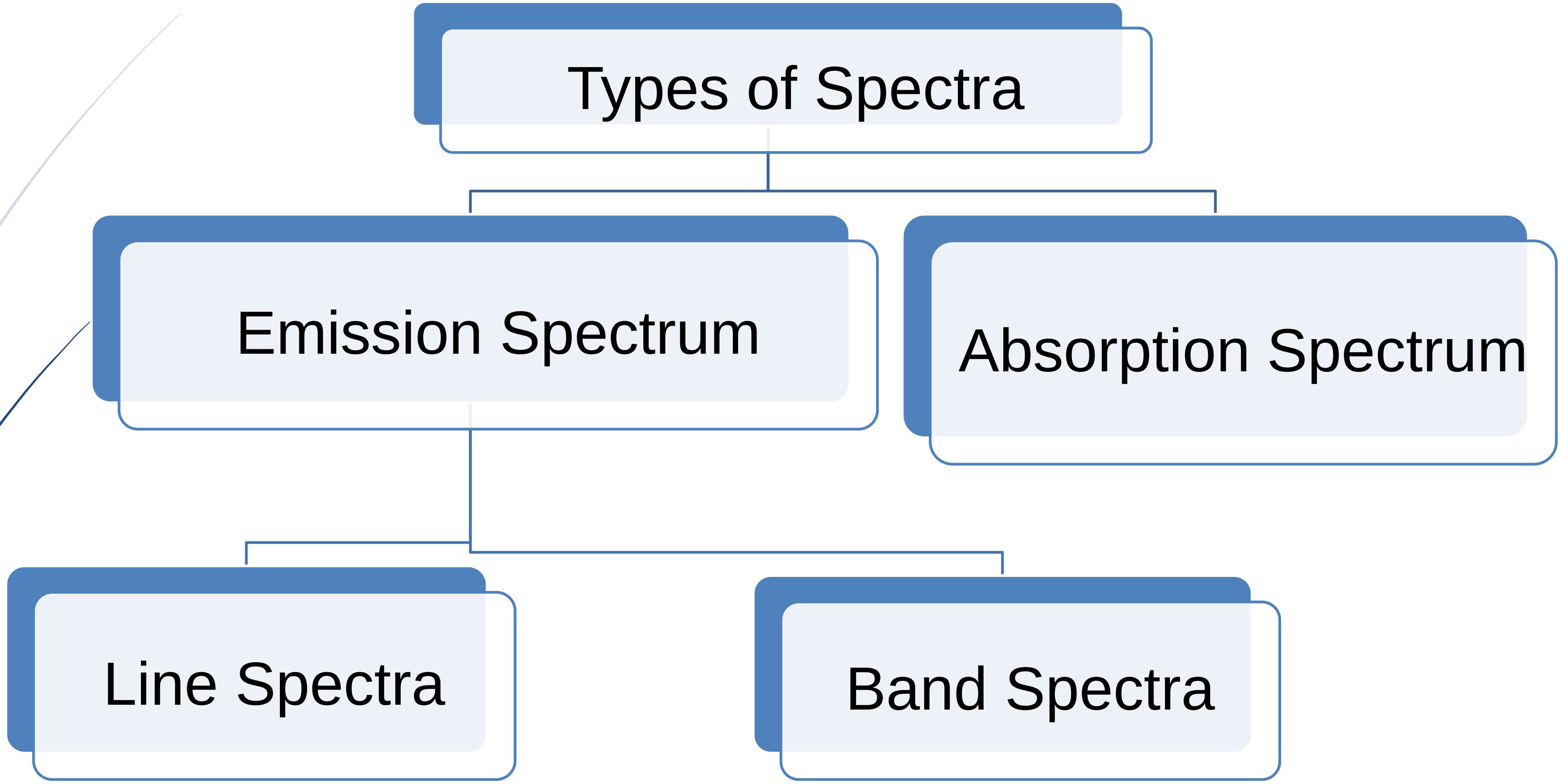
Transition of electron from upper level to lower orbit emit the light.

In each transition a definite amount of energy is absorbed or released.

The intensity of spectral line depends on the probability of the transition.

# Production of Spectra

| Temperature Radiation Method | Luminescence Method |
| --- | --- |
| | (a)Electroluminescence Method |
| | (b) Chemiluminescence Method |
| | (c) Photoluminescence Method |


Types of Spectra
Emission Spectrum
Absorption Spectrum
Line Spectra
Band Spectra

# Types of Spectra

Emission Spectrum

Absorption Spectrum

# Comparison

**Emission Spectrum**

- The emission spectrum is obtained due to emission of radiation from the substances.

**Absorption Spectrum**

- The absorption spectrum is obtained when the substance absorbs the radiation.

The differences between them are given below.

| Emission Spectrum | Absorption Spectrum |
|---|---|
| White lines are formed on the black background. | Black lines are formed on the white background. |

The differences between them are given below.

| Emission Spectrum | Absorption Spectrum |
|---|---|
| Formed when atoms or molecules are de-excited from higher energy level to lower energy level. | Formed when atoms or molecules are excited from lower energy level to higher energy levels. |

*Types of Spectra*

- Continuous Spectrum
- Discontinuous Spectrum

# Continuous Spectra-Characteristics

| | |
|---|---|
| 1 | Continuous Spectrum contain wide range of continuous wavelength lines which are not separable. |
| 2 | ❑ **The intensity is not uniformly distributed** over the entire observed spectrum.<br><br>❑ The **intensity is maximum at a particular wavelength** and **decrease on both sides of the point of maximum intensity**. |

# Continuous Spectra-Characteristics

| | |
|---|---|
| 3 | ❑ **The point of maximum intensity shifts towards violet (higher frequency side) of the spectrum as the temperature of the solid is increased.**<br>❑ This is known as **Wein's displacement law**.<br>❑ $\lambda_m T = \text{constant}$ |

## Continuous Spectra-Characteristics

| | |
|---|---|
| 4 | The general appearance of a continuous spectrum is **independent of the material of the source of radiation** so long as the material is in position of emitting continuous spectra. |

# Continuous Spectra-Characteristics

- When white light from sun or any incandescent body or lamp is passed through a prism, it disperses into its component colors and a spectrum is obtained known as Continuous Spectrum.
  - Examples:
  - Spectrum of sunlight,
  - Incandescent solids and liquids, bulb light,
  - Tube light.

# Discontinuous Spectra

# Line Spectra-Characteristics

- LINE-spectra consists of discrete wavelengths distributed throughout the spectra. The wavelengths of the lines are the characteristics of the elements concerned.
- The line spectra are produced by atoms i.e. **atomic spectra**.

# Line Spectra-Characteristics

- Examples:

- Vapour in flame
- Metallic arc and spark

# Line Spectra-Characteristics

| | |
|---|---|
| 1 | The wavelengths of the lines are the characteristics of the elements concerned. |
| 2 | **The lines are regularly arranged and differ in intensity.** |
| 3 | Shows multiple character and possess fine and hyperfine structure. |
| 4 | Dark line on a bright background or bright lines on a dark background are observed. |
| 5 | Lines can be grouped in series. |

# Band Spectra-Characteristics

# Band Spectra-Characteristics

- Band spectra are produced when the emitting substance is in the molecular state.
- They are called **Molecular Spectra**.

# Band Spectra-Characteristics

- Strips of graded intensity showing a continuous spectrum but divided into bands.
- Examples: the carbon arc with metallic salts
- $CO_2$ and $N_2$ gases in vacuum tubes etc.

# Band Spectra-Characteristics

| | |
|---|---|
| 1 | The bands are observed in a dark region and they are arranged in a regular sequence forming a groups of bands. |
| 2 | A regular arrangement of groups of bands form a **band system.** |

# Band Spectra-Characteristics

| | |
|---|---|
| 3 | Each band system contains several lines separated from one another.<br>The lines are closer on one side and wider on other side |
| 4 | The lines in a bands are characteristic of molecules and depend upon the mode of oscillations. |
| 5 | The appearance is changed as the type of the molecule is changed. |

# Absorption Spectra

- An element can absorb light at specific wavelengths
- An absorption spectrum can be obtained by passing a continuous radiation spectrum through a vapor of the gas
- The absorption spectrum consists of a series of dark lines superimposed on the otherwise continuous spectrum
- The dark lines of the absorption spectrum coincide with the bright lines of the emission spectrum

# Absorption Spectra

- **Examples :**

1. The continuous absorption spectrum is obtaining by putting a pure red glass in the path of the light having continuous spectrum. **The red glass absorbs every radiation except red.**

2. By putting the **sodium vapor** in the path of continuous light, two famous dark sodium lines ($D_1$ and $D_2$) are obtained on the bright background.

# Absorption Spectra - Applications

- The continuous spectrum emitted by the Sun passes through the cooler gases of the Sun’s atmosphere.
- The various absorption lines can be used to identify elements in the solar atmosphere led to the discover of helium

# Wave Number

- Frequency ($\nu$) is more fundamental than wavelength ($\lambda$) but **is not directly measures in the laboratory**.
- Therefore, for theoretical purpose, frequency is computed from the relation
- $c = \lambda \nu \rightarrow \nu = c / \lambda$
- Unit vibrations/sec

# Wave Number

- **In spectroscopy,** Wave Number defined as
- Unit cm$^{-1}$

$$\bar{\upsilon} = \frac{1}{\lambda}$$

- Number of waves per unit length
- **Advantage:**
- **No need to involve speed of light (c) and so they retain all the accuracy of spectroscopy.**

# Wave Number

- **Wave number energy equivalence Using Plank's relation**

$$\Delta E = h\upsilon = h\frac{c}{\lambda} = hc\bar{\upsilon}$$

$$For\,change\,in\,energy$$

$$corresponding\,to\,1m^{-1}$$

$$\Delta E = 6.62\times10^{34}\times3\times10^{8}\times1$$

$$\Delta E = 1.986\times10^{-25}\;joule/molecule$$

# Wave Number

- **Wave number energy equivalence Using Plank's relation**

$$\Delta E = h\,\upsilon = h\,\frac{c}{\lambda} = h\,c\,\bar{\upsilon}$$

$$For\ change\ in\ energy$$

$$corresponding\ to\ 1\,cm^{-1}$$

$$\Delta E = 6.62 \times 10^{34} \times 3 \times 10^{8} \times 100$$

$$\Delta E = 1.986 \times 10^{-23}\ joule/molecule$$

## Wave Number

$$\text{For change in energy}$$

$$\text{corresponding to } 1\ \text{cm}^{-1}\ \textit{is}$$

$$\Delta E = 1.986 \times 10^{-23}\ \text{joule/molecule}$$

$$\therefore \Delta E = \frac{1.986 \times 10^{-23}}{1.6 \times 10^{-19}}$$

$$\Delta E = 1.239 \times 10^{-4}\ \text{eV}$$

## Wave Number

$$A\ one\ \ mole\ \ contains\ \ molecules$$

$$equal\,to\,the\,Avegrado\,No$$

$$and\,1\,J = 4.18\,cal,\,hence$$

$$\Delta E = \frac{1.986\times 10^{-23}\times 6.023\times 10^{23}}{4.18}$$

$$= 2.858\ cal\,/\,molecule$$

$$1eV\ = 23.06\,kcal\,/\,mole$$

# Thanks