Dr.G.G.Pusalkar

F.Y.BSc Notes

Interaction of electromagnetic radiations with matter

Q.1 **What are electromagnetic radiations? Give their characteristics.**

Ans. Electromagnetic radiations are the radiations consisting of waves of energy associated with electric field and magnetic field which act perpendicular to each other and also perpendicular to the direction of propagation of waves.

Characteristics of electromagnetic radiations:-

a) These radiations transmit energy through space.

b) These radiations travel with speed of light in vacuum.

c) These radiations show dual nature – particle and wave nature.

d) These radiations are associated with electrical component and magnetic component.

Q.2 **Define : i) wavelength ii) frequency iii) wave number and give their units.**

Ans. i) **Wave length** (λ) : - The distance between adjacent crest or adjacent troughs is called wavelength. Unit of wavelength : cm, mm , mm, μm, nm , Å

ii) **Frequency** (ν) : The number of waves passing through a given point in one second is called frequency. Unit of frequency: Hz, KHz, MHz, Fresnel

iii) **Wave number** : (: The number of waves per cm or m in vacuum.
Unit of wave number : cm^{-1} m^{-1}

Q.3 **Give the relation between:**

a) nm and cm **b) Angstrom and meter**
c) Megahertz and Hertz **d) Frensel and Hertz**
e) Nanometre and Angstrom **f) Hertz and cycle**

Ans.

a) 1 nm = 10^{-8}cm b) 1Å = 10^{-10}m

c) 1MHz = 10^{6}Hz d) 1 Frensel = 10^{12} Hz

e) 1 nm = 10Å f) 1Hz = 1 cycle sec^{-1}

Q.4 **What is electromagnetic spectrum? Give the range of wavelengths for the following electromagnetic radiations:**
a) X – Ray b) IR c) UV Rays d) Microwaves e) Radio waves

Ans. The set of electromagnetic radiations arranged in increasing order of wavelengths or decreasing order of frequencies is called electromagnetic spectrum. The arrangement of different types of electromagnetic radiations with increase order of their wavelength is ,

Cosmic rays < γ rays < X – Ray < UV rays < visible light < IR < Microwaves < Radio waves.

Electromagnetic radiations	Wavelength range
i) Gamma rays	0.01 nm to 0.1 nm
ii) X - rays	0.1 nm to 10 nm
iii) Visible and Ultraviolet region a) Vacuum ultraviolet b) Ultraviolet c) Visible	 1 – 180 nm 180 – 400 nm 400 – 750 nm
iv) Infrared region a) Near infrared b) Mid infrared c) Far infrared	 780 – 10^3nm 10^3 – 10^4 nm 10^4 – 10^5 nm
v) Microwave region	4 x 10^5 – 2.5 x 10^8nm
vi) Radio frequency region	Above 2.5 x 10^8nm

Q.5 **Explain Planck's Quantum theory of radiation.**

Ans.

Planck Quantum theory of radiation is based on the following postulates:

i) Absorption or emission of radiations by an object does not occur continuously but in small packets of energy called quantas or photons.

ii) The energy associated with each quantum is directly proportional to the frequency of radiation.

ie $E = h\nu$, where ν is frequency of radiation

but, $\nu = \frac{C}{\lambda}$, where C = velocity of light , λ = wavelength of radiation

iii) The object can emit or absorb energy only in an integral (whole number) multiple of a quantum. Ie $E = n h\nu$, where n = 1 , 2 , 3 , 4 ,.....

Q.6 **What is spectroscopy? Explain in brief the various phenomenon observed after interaction of electromagnetic radiation with matter.**

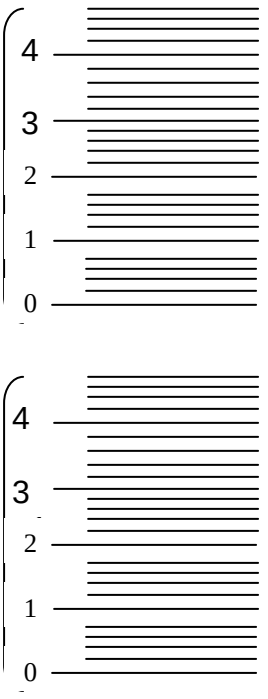
Ans.

Spectroscopy is a branch in science which deals with the study of atomic and molecular structure of a substance when the given substance interact with the electromagnetic radiations. The most important effect of this interaction is that the energy is absorbed or emitted by matter in discrete amts called quantas.

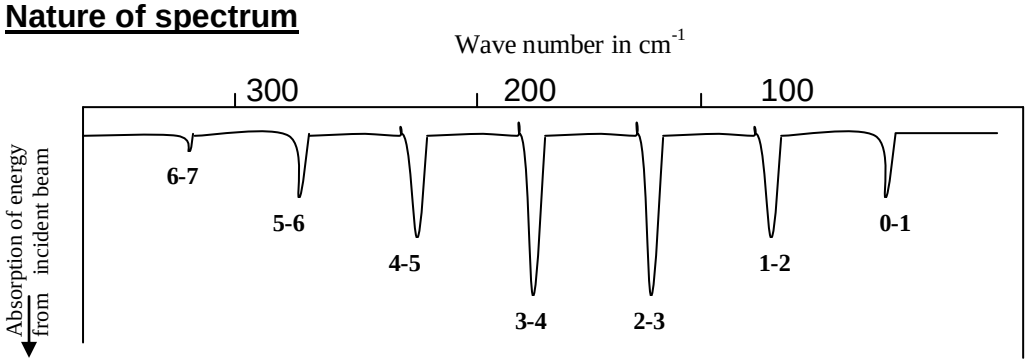
Types of phenomenon:

1)Absorption: It is a process in which the molecules of a substance get excited

	when the incident photons transfer energy to the molecules when the substance is exposed to radiations. **2) Emission** : It is the process of transition of a molecule from high energy level to low energy level (ground state). This phenomenon is observed when the substance is subjected to intense heat or electric discharge. **3) Scattering**: A substance when exposed to electromagnetic radiation may not absorbed the radiation completely but can scattered them. The energy of the scattered radiation may be same or different than of the incident radiation. **4) Fluorescence** : It is a phenomenon observed when the substance exposed to electromagnetic radiation emits the radiations absorbed within $\mathbf{10^{-8}}$ sec. In this process, the exited electrons reach the ground state within $\mathbf{10^{-8}}$**sec** and thus emit the absorbed energy.
Q.7	**Describe the various types of energies associated with the molecules.**
Ans.	A molecule is made up of two or more atoms. The internal energy of a molecule is a combination of translational energy, rotational energy, vibrational energy and electronic energy. **i) <u>Translational energy</u>**: The energy associated with the translational motion of the molecules is called translational energy. A molecule is free to move along x, y, and z axis. The expression for translational energy for such a molecule s given as , 1) – (on the basis of classical theory) m- >mass of molecule, v - > vel. of electron . 2) —— — — — where a,b,c are the dimensions of a rectangular box and 'n' is an integer with values 1,2,3,---- **ii) <u>Rotational energy</u>** : The atoms within a molecule rotates about an imaginary axis which is ⊥ ar to the line joining the nuclei of two atoms. This cause the rotation of the molecule. The expression for rotational energy of the molecule is given by: – where I = Moment of inertia of the molecule ω = angular velocity of the Molecule —— where J = rotational quantum number with values 0.1.2.3.4 I = Moment of inertia of a simple linear molecule iii**) <u>Vibrational energy</u>**: This type of energy is associated with the vibrations of atoms in a molecule about equilibrium positions.The molecular vibrations are of wo types:i) **Linear vibrations** observed in diatomic molecules such as **H_2, O_2, CO etc**.

	ii**) Bending vibrations** observed in polyatomic molecules such as **NH_3, SO_2** etc. The expression for vibrational energy on the basis of quantum mechanical approach is given by **$E_{vib} = (\square + ½)\ hv$** where $\square$ is the vibrational frequency and **v** is the vibrational quantum number having value 0,1,2,3..... **iii) <u>Electronic energy</u>**: It is the energy associated with the motion of the electrons with respect to the nuclei of atom (of a molecule) as fixed points. The vibrational and rotational energy of the molecules are added to the electronic energy. The molecular spectroscopy, the translational energy is not quantized as the energy levels are very close to each other, therefore it is neglected. Hence, the total energy of the molecule is the sum of rotational, vibrational and electronic energy. ie. **$E_{total} = E_{trans} + E_{rot} + E_{vib}$**
Q.8	**What are molecular energy levels? With the help of a molecular energy level diagram, give a brief account of rotational, vibrational and electronic energy levels.**
Ans.	The rotational, vibrational and electronic energy levels of a molecule are collectively called as molecular energy levels. All these energy levels are quantized. The transitions can take place between energy levels of same kind. These transitions produce lines of different frequencies which give rise to molecular spectra. **<u>Electronic energy levels</u>**  1)**<u>Rotational energy levels</u>**: These are represented by rotational quantum number **J** which has values **0,1,2,3**…. The energy levels are closely spaced and the energy difference between two consecutive energy levels is **5×10^{-3}eV**. Hence, less energy is required for pure rotational transition, which is achieved by absorption from microwave or from infrared region. 2)**<u>Vibrational energy</u>**: These are represented by a vibrational quantum number **'v'** with values **0,1,2,3,---** the energy gap between two consecutive energy levels is of the order 0.1eV, which is sufficient to cause vibration of atoms by absorbing from

	MIR or NIR region. 3)**<u>Electronic energy levels</u>** : These are represented by the principal quantum number 'n' with values **0,1,2,3**,…etc. The energy gap between two consecutive energy levels is high of the order of several electron volt) hence for an electronic transition to occur absorbing from visible or U.V. region is necessary. The electronic transition is accompanied by rotational as well as vibrational transitions.
Q.9	**Write an informative note on atomic spectroscopy and molecular spectroscopy.**
Ans.	**<u>Atomic spectroscopy</u>**: **i)** It deals with the interaction of electromagnetic rediation with atoms of of an element in ground state. **ii)**It involves the transition of an electron from one energy level to another energy level. During the transition, energy is absorbed or given out in discrete amounts giving rise to a spectrum called atomic spectra. **iii)**The atomic spectra consist of a set of lines of particular wavelength or frequency characteristic of that element. These lines are dark lines against bright back ground (absorbtion spectra) or bright lines against dark background (emission spectra). These lines are observed when white light is passed through cool vapour of an element. **iv)**The study of atomic spectra helps to understand the structural fratures of an atom. **<u>Molecular spetroscopy</u>**: i)It deals with the interaction of electromagnetic radiations with molecules. ii)When a compound is exposed to electromagnetic radiations, following energy chanes are observed in the molecules. a) Electronic energy change which results by the transition of electron from one energy level to another by absorption of radiation from U.V. and visible radiations. b) Vibrational energy change which occurs within the molecules in the same electronic level by absorption of radiations from mid and near infrared region. c) Rotational energy change which involves a change in moment of inertia of the molecule around its center of gravity. This change is caused by absorption of radiations from far infrared or microwave regions.

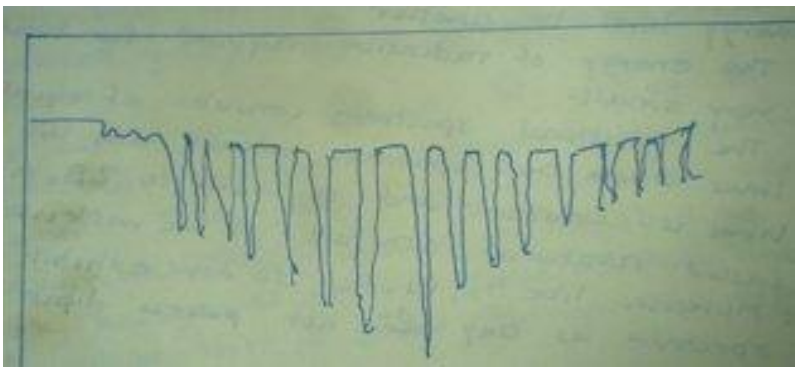
	iii)The molecular spectra is a complex spectra. It consists of several lines due to energy chamges in rotational, vibrational and electronic levles. The set of lines therefore appears like a band and is called band spectra.
Q.10	**Explain in brief the follwoing types of molecular spectra:** a) **Rotational spectra b) IR spectra c) Raman spectra d) NMR spectra e) CSr spectra**
Ans.	a)**<u>Rotational spectra</u>**: i) It is observed in molecules with permanent dipole moments eg.CO, H_2O,When such a gaseous molecule is exposed to radiations from far infrared or microwave region, the molecules undergo rotational motion. As a result, there is a transition of molecule from one rotational energy level to another. ii)The energy of radiation required for transition is very small iii)The rotational spectrum consists of equally spaced lines where the spacing between any two successive lines is constant and is equal to $2B_0m^{-1,}$ where B_0 is called rotational constant of the molecule. iv)Molecules like N_2, O_2, H_2 do not exhibit rotational spectrum as they do not possesses dipole moment. **<u>Nature of spectrum</u>** 
	b)**<u>IR spectra</u>** **i)**This spectra arise due to vibrations caused in the molecule when the molecule absorbs the energy of radiation from near infrred region. For such absorption to occur the dipole moment of inertia of the molecule must change during the corse of vibration. **ii)**The absorption of radiation by the molecule from near IR region causes a transition from one vibrational energy level to another within the same electronic level. At the same time, there is also a transition observed in the rotational energy level of the molecule. Hence, the IR spectra is called vibrational –rotational spectra.

iii) Nature of spectra

Wave length cm^{-1}

y

Absor
n of



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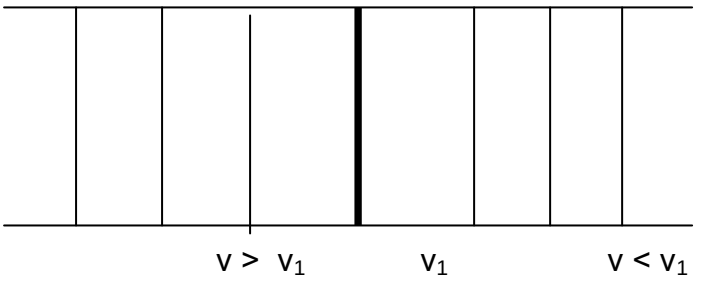
c)**Raman Spectra**

i)It is observed in the visible region ie** = 12,500 – 25000 cm^{-1}

ii) It is a type of vibrational-rotational spectra

iii) It is based on the principle that when a sample is exposed to monochromatic radiations of visible region and scattering of light is observed at right angle to the direction of incident beam, the frequency of the scattered radiation is equal to that of incident beam as well as higher and lower from the incident beam. The lines observed are called Raman lines and the spectra is Raman spectra.

Ray length 1000

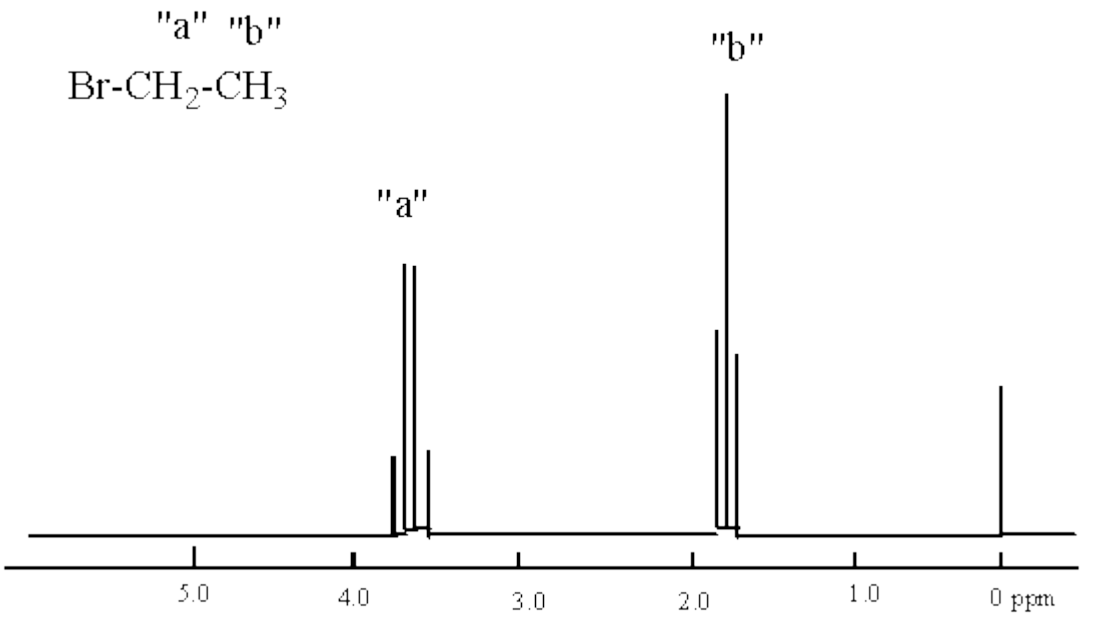


d) **Electronic spectra**

This type of spectra is observed when the compound is exposed to radiations from visible and U.V. region. The spectra arises due to transition of electron from one electronic energy level to another. Such a transition also brings about vibrational level changes, which also results in rotational level changes. Thus for a given electronic transition , a set of bands is observed, which is called band system. A complete set of band system due to different electronic transitions gives the electronic band system.

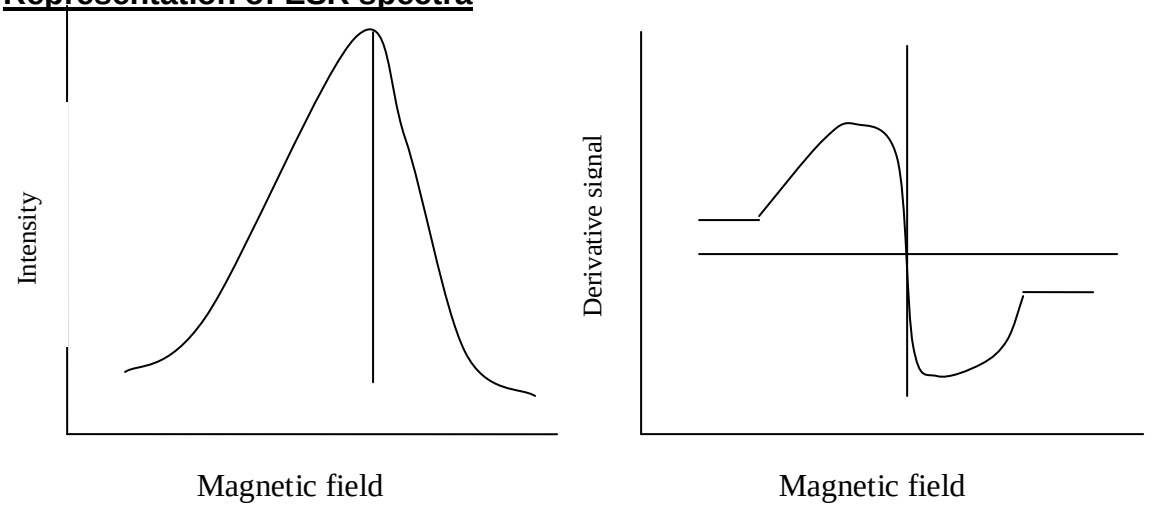
e)**<u>NMR spectra</u>**:

This type of spectra is observed when the nucleus of an atom containing odd number of protons and neutrons is subjected to external magnetic field and simultaneously exposed to radiation in radiofrequency region. A proton inside the nucleus behaves like a tiny magnet, spinning around its own axis with a definite magnetic moment. When such a nucleus is subjected to varying magnetic field by keeping the frequency of electromagnetic radiation constant, the proton will resonate at a particular value of magnetic field and will absorb the radiation. This will change the spin of the proton and change in orientation will be observed. This method of recording spectra is called NMR spectra.



f) **Electron spin resonance or electron paramagnetic resonance spectra (ESR or EPR)**

This spectra is given by substances with unpaired electrons. The substances include stable paramagnetic molecules like NO, O_2 , NO_2 , transition metal ions and free radicals. An electron spins around its own axis and behaves like a tiny magnet when it revolves around the nucleus. It has two magnetic moments- one associated with its spin and the other associated with its motion around the nucleus. The total magnetic moment is the vector sum of two magnetic moments. When a species with an unpaired electron is subjected to external magnetic field, the electron energy level splits into two non degenerate energy levels. The lower energy level have spin magnetic moment aligned with the field , while the higher energy level will have spin magnetic moment opposing the field . when under this condition , the substance is exposed to radiations from microwave region, the

	transition of electron will take place between two states by absorption of radiation. When the energy of radiation becomes equal to the energy difference between the two states, when this happens , resonance absorption takes place giving rise to ESR spectrum for the system. **Representation of ESR spectra** 
Q.11	**What is selection rule?**
Ans.	The electronic, vibrational and rotational spectra of a molecule is observed when transitions occur between energy levels. However, such transition can take place between definite energy levels and not just between any two energy levels. Thus there are certain restrictions on transitions taking place between energy levels which are governed by certain rules called selection rules. These rules specify the change in quantum numbers accompanying a particular transition for pure rotational transitions, the selection rule is $\Delta J = \pm 1$, where J is rotational quantum number. For pure vibrational transition , the selection rule is $\Delta V = \pm 1$, where V is vibrational quantum number. Transitions on the basis of selection rules are classified into two types: 1)**Allowed transitions**: These types of transition follow selection rule 2)**Forbidden transitions**: These types of transition do not follow selection rule The selection rules are derived by taking into consideration a large number of approximations, hence they are not obeyed strictly.
Q.12	**Give the applications of the following spectroscopic techniques** **a) Microwave b) IR c) Visible d) UV-Visible e) Radiofrequency f) ESR**
Ans:	a) **Microwave spectra** i) Determination of abundance of isotope.

	ii) Determination of bond length. iii) Determination of structure of molecule. b) **Infrared spectra**: i) Detection of functional groups of organic compounds. ii) Conformational studies. iii) Determination of geometry of molecule. c) **Visible spectra**: i) Determination of geometry of molecule. ii) Study of isomers. iii) Study of degree of hydrolysis. iv) Constitution of organic compounds. d) **UV-Visible spectra** i) Qualitative analysis. ii) Idenification of unknown compounds. iii) Extent of conjugation and identification of configuration of geometrical isomers. e**) Radiofrequency spectra** i) Identification of structural isomers ii) Detection of hydrogen bonding, aromaticity, bond character etc. iii) Structural diagnoses. f) **ESR spectra** i) Structural determination. ii) Study of reaction velocities and mechanism.