

Raman Spectroscopy

Raman Spectra

When an intense beam of light is passed through a liquid or gas, some of the light is scattered by the molecules of the medium. Most of the scattered light has the same frequency as the incident light. This type of scattering which occurs without a change in the incident frequency is termed **Rayleigh scattering**.

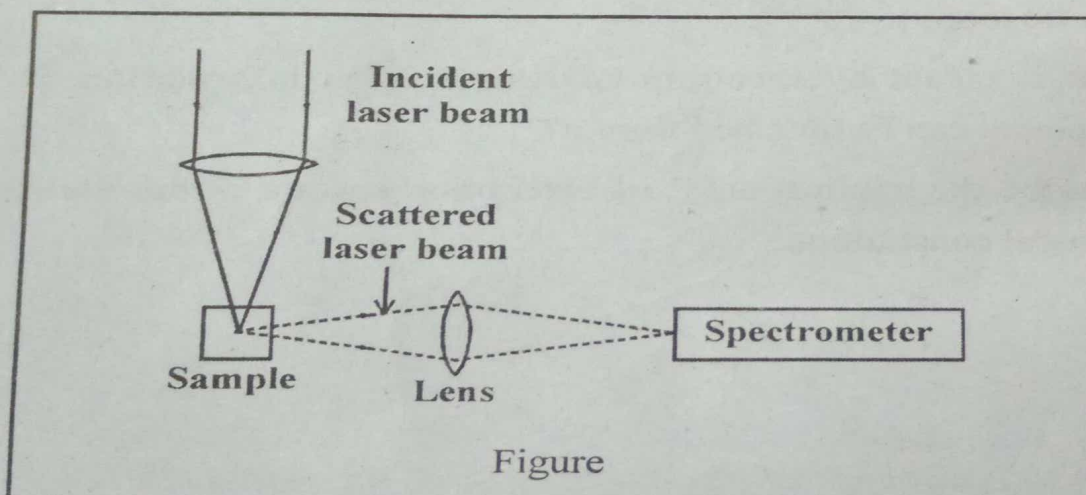
In 1928, Indian physicist Sir C. V Raman discovered that a very small fraction of the scattered light has frequencies higher or lower than the incident frequency. The scattering which occurs with a change in the frequency of the incident radiation is called **Raman scattering**. The phenomenon is called **Raman effect**.

If ν_i is the frequency of the incident beam and ν_s is given by the scattered light then the **Raman frequency** ν_R is given by

$$\nu_R = \nu_i - \nu_s \text{ and } \Delta E = h\nu_R$$

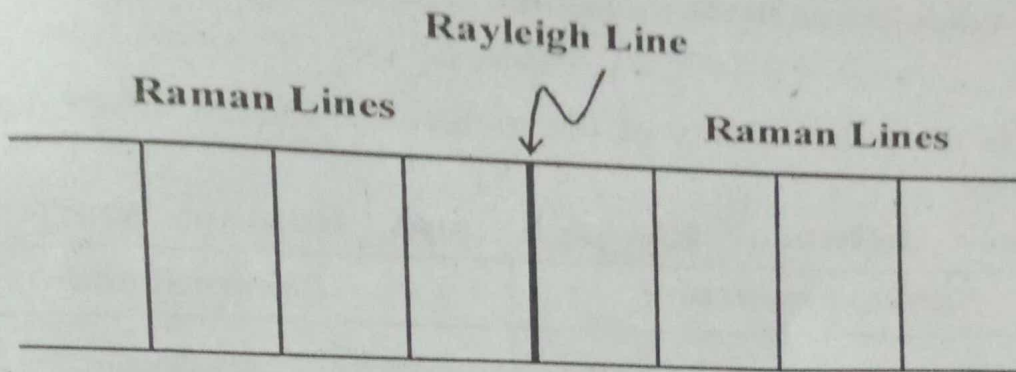
Raman effect occurs because of (i) the dipole moment induced in the molecule by the incident light. Therefore it depends upon the polarizability of the molecule. ii) the rotational and vibrational oscillations of molecule of a compound.

If a vibrational or rotation of molecule is to be active in Raman its polarizability, must change during the vibration or rotation. **This is the basic requirement or condition.**



The spectrum obtained from scattered radiations of a sample can be observed with help of the apparatus shown figure 4.14. Laser beam is now used as incident radiation. Raman originally used ultraviolet light which gave weak spectral lines. The general pattern of spectrum recorded by scattered light is illustrated in figure. The sharp line in the middle corresponds to Rayleigh scattered light and is referred to as **Rayleigh line**. Raman scattered light records a series of lines on either side of the Rayleigh line. These are called **Raman lines** and constitute **Raman spectrum**.

Rayleigh and Raman scattering :



Figure

Let us assume a quantum of $h\nu_i$ of incident light strikes a molecule. If it is scattered elastically, i.e., without energy change, then the frequency of the incident light and that of the scattered light are the same. Such a scattering is called **Rayleigh scattering** or **Tyndall effect**. During Rayleigh scattering atoms and molecules are polarised in the electric field of the light. During this polarisation if the distances between atoms in the molecules do not change then the frequencies of incident and scattered radiations will be same. This is what happens in Rayleigh scattering. Sometimes the inter atomic distances in molecules may vary. Further the molecules are not spherically symmetrical. Thus a condition of anisotropy or polarisability takes place. The consequent vibrational frequencies of the scattering molecules are superimposed on the fundamental frequency of incident radiation. Thus the light is scattered inelastically, i.e., the frequency of the incident light will not be equal to the frequency of the scattered light. Such a scattering is called **Raman scattering**.

Selection rules for Raman spectra :

1. Raman spectra are exhibited when there is a change in the polarizability of molecule during rotation or vibration.
2. $\Delta J = 0$ or ± 2 only.
3. $\Delta V = \pm 0 \pm 1 \pm 2 \dots\dots$ (But we can ignore $+ 2 \dots\dots$ since the probability of $\Delta V = \pm 2 \dots$ decreases rapidly and the bands are of low intensity and are weak).

The scattering of light by molecules can be explained by making use of electro magnetic theory. The incident light wave represented by an electric field E induces a dipole moment in the molecules. The induced moment P is given by

$$P = \alpha E$$

Where α is the polarisability of the molecule. Raman effect depends upon polarisability.

Differences between Rayleigh and Raman scattering

<i>Rayleigh scattering</i>	<i>Raman scattering</i>
1. Elastic scattering, i.e., the frequency that of incident light and that of the scattered light are same.	Inelastic scattering. i. e. , the frequency of the incident light and that of the scattered light are different.
2. During the scattering the distance between the atoms in the molecule does not change.	Changes.

Stokes and Anti-Stokes Lines

The difference between the frequency of the incident light and the frequency of the scattered light is called the *Raman frequency*.

$$\text{Thus is } \nu_R = \nu_i - \nu_s$$

The incident radiation may give up energy to the molecule on which it falls. Then the frequency of the incident light will be more than that of the scattered light i.e., $\nu_i < \nu_s$. Then the Raman frequency ν_R is given by

$$\nu_R = \nu_i - \nu_s = \text{Positive}$$

We get lines on the lower frequency side of the incident light. These are called **Stokes lines**.

On the other hand the incident light can also take up energy from the molecule. Then the frequency of the incident light will be less than that of the scattered light i.e., $\nu_i < \nu_s$. Then

$$\nu_R = \nu_i - \nu_s = \text{Negative}$$

We get lines on the higher frequency side. These are called antistokes lines. These stokes and anti-Stokes lines are generally called **Raman lines**.

The intensities of **Raman lines** are in the following decreasing order.

Stokes lines > incident radiations > anti Stokes lines.

This is because the stokes lines result from the absorption of energy of the incident light by the molecules. In this case the molecular energy increases. Therefore Stokes *lines are more intense than the incident light*.

On the other hand the anti-Stokes lines result the emission of energy to the incident light by the molecules. In this case the molecular energy decreases. Therefore anti-Stokes lines are less intense than incident light. *Totally Stokes lines are much more intense than the anti-Stokes lines.*

Differences between Stokes and anti-Stokes lines

Property	Anti-Stokes lines	Stokes lines
1. Sign of Raman frequency $\nu_R = \nu_i - \nu_s$	Negative	Positive
2. Intensity	less intense	more intense

We see that, the intensity of Raman line changes with the frequency of incident radiation and has been found to be Proportional the fourth power of frequency. Hence a light of as, short a wave length as possible should be used in order to get as intense a Raman line as possible.

Polarisation of Raman lines and depolarisation factor

After scattering by any medium light is found to be polarised. i.e., the intensity of the ray with vibrations parallel to the direction of incident light I_h is not same as the intensity of the ray with vibrations perpendicular to the incident light I_v .

Such a polarisation of Raman line may be regarded as due to the differences in the symmetry of molecular vibration and each Raman line can have its own state of polarisation independent of other simultaneously emitted

lines. The state of polarisation of Raman line is measured by a quantity known as depolarisation factor of p .

$$p = \frac{I_h}{I_v} = \frac{\text{Intensity of horizontal light vibrations}}{\text{Intensity of vertical light vibrations}}$$

Important points about depolarisation factor:

1. It varies from zero to 0.86 for the vibrational Raman lines while it has constant value of 0.86 for rotational lines.
2. Low depolarisation factors result in sharp and strong lines. High depolarisation factors result in diffuse and weak lines.

Molecules having similar structures give Raman lines which have the same depolarisation factors.

Difference between the Raman and IR Spectroscopy

Infrared	Raman
1) Infrared spectra are obtained as a result of a absorption of light.	Raman spectra are obtained due to scattering of light.
2) The condition for a vibration to be Infrared active is that there should be change in dipolemoment in that mode of vibration.	The change in polarizability determines whether a vibration is Raman active or not.
3) Since water absorbs infrared radiation almost completely, it can not be used as solvent.	The Water can be used as solvent.
4) Optical systems are made up of alkali halides like NaBr, CsF, LiF etc.	Optical systems are made up of glass or quartz.
5) Dilute solution or small amount of the sample is sufficient.	Concentrated solutions are to be used in order to get intense bands.
6) It cannot be recorded in one exposure. It needs atleast two runs with different prisms to cover the entire region.	Only one exposure is sufficient to get the entire spectrum.
7) Photochemical reactions do not take place as less energetic infrared radiation is the source.	Sometimes photochemical reactions take place.
8) It is both accurate and sensitive.	It is very accurate but less sensitive.
9) The sample may be coloured or colourless.	The sample should be preferably colourless and dust free.

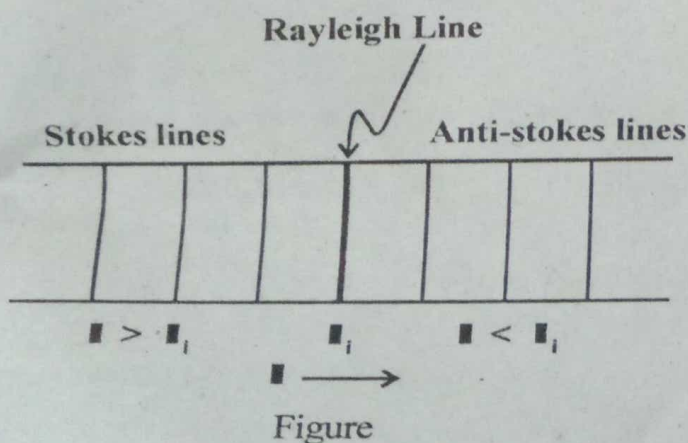
IR (vibrational) and Raman spectroscopy are complimentary to each other

We find that informations which are not available from IR spectroscopy are available from Raman spectroscopy. This is because a given vibrational mode which in a molecule may lead to fluctuating changes in dipole. This will give IR spectrum. But it may not necessarily lead to changes in the polarisability so it will not give Raman spectrum. Similarly some other vibrations symmetrically substituted $C = C$, $C \equiv C$, etc and symmetric vibrations of CO_2 . The polarisability is the capacity to become a dipole. A change in this polarisability leads to Raman spectra. But the dipole involved in an associated IR absorption signal. In molecules like benzene which have high symmetry the IR-active vibrations that lead to dipole changes and those that lead to changes in the polarisability are **mutually exclusive**. This, the two techniques are complementary to each other. E.g., in indene the vibrations which absorb weakly in Raman absorb strongly in IR and vice versa.

Advantages of Raman spectra over IR spectra :

1. Raman spectroscopy is more sensitive. Sample sizes as small as some milligrams can be employed.
2. The sample preparation is easier. (Powders or solutions can be used).
3. Water can be used as a solvent. This point assumes importance because several drug analyses in body fluids and study of amino acids and organo metallic complexes have to be conducted in aqueous solutions only. These are not possible in IR spectroscopy.

Structure of Raman Spectrum :



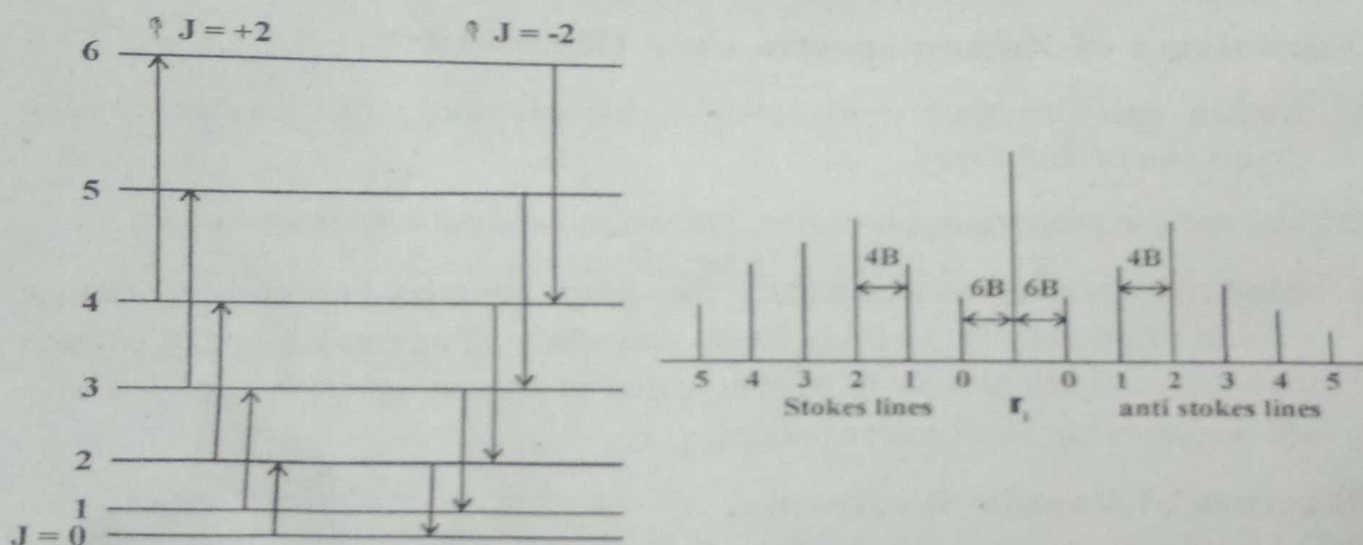
When a monochromatic beam of light is used the Raman spectrum will consist of (i) a line resulting from Rayleigh scattering (R) (ii) intense Stokes lines on the lower frequency side (S) and (iii) very weak anti-stokes lines on the higher frequency side (A) (Figure).

The absorbed energy is used for raising the molecules from lower rotational and vibrational quantum levels to the higher ones causing Stokes lines. Or, the energy may be emitted by the molecules when they drop down from higher rotational and vibrational levels to the lower ones causing anti-Stokes lines. These rotational and vibrational Raman spectra are the counterparts of the absorption spectra in the far IR (microwave) and near IR regions. But Raman spectra are studied with visible or UV light.

A study of Raman spectrum :

Relation between frequency ν_R of a rotational Raman spectra and rotational quantum level J .

The selection rule for Rotational Raman spectra is $\Delta J = 0, \pm 2$. When $\Delta J = 0$ Rayleigh scattering takes place. i.e., the scattered light and incident light will have the same frequency. The transition $\Delta J = +2$ gives Stokes lines (longer wave lengths). The transition $\Delta J = -2$ gives anti-Stokes lines (shorter wave lengths).



Figure

For these transitions the Raman shift (Raman frequency) is given by.

$$\nu_R = \pm 2B(2J+3) \text{ where } J = 0, 1, 2, \dots \text{ and } B = \frac{8}{8\pi^2 I c}$$

The frequency of the corresponding lines will be

$$\nu_S = \nu_i \pm \nu_R$$

Where ν_i is the frequency of the exciting radiation. The corresponding Raman spectrum is given figure.

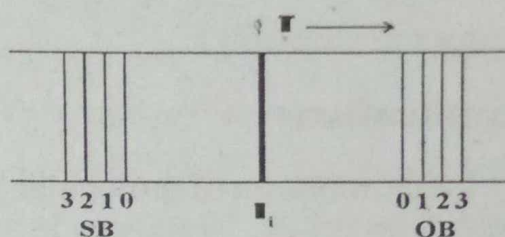
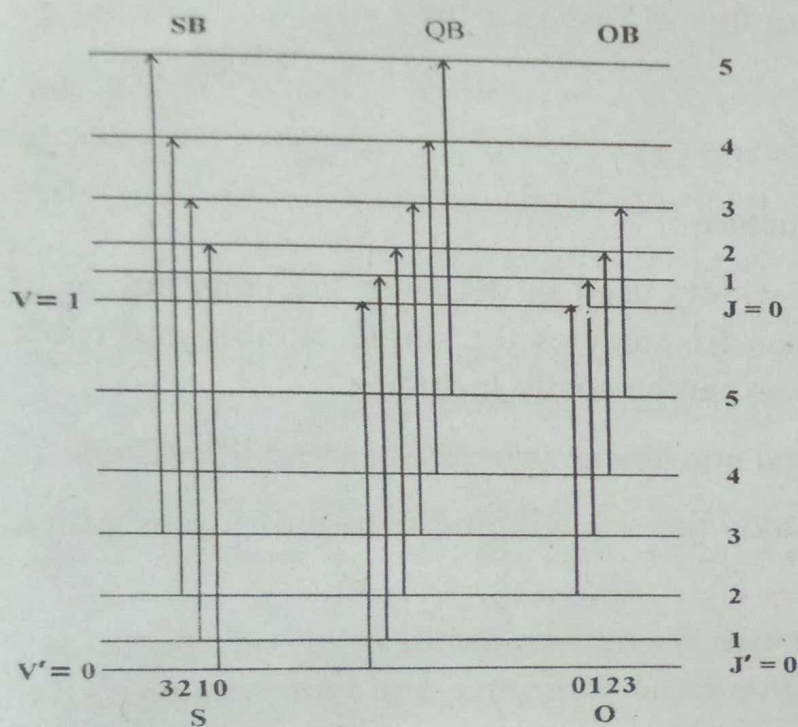
From the figure it can be seen that the frequency separation, of successive lines is $4B \text{ cm}^{-1}$. Separation of the first line from the exciting line (incident light) is $6B \text{ cm}^{-1}$.

Rotational vibrational Raman spectra

The selection rule for a diatomic molecule is

$$\Delta V = +1 \text{ and}$$

$$\Delta J = 0, \pm 2.$$



OB = O Branch

SB = S Branch

QB = Q Branch

Figure

Since the majority of the molecules are in the ground vibrational state at room temperature, it is enough if we consider the vibrational change from $V=0$ to $V=1$. We get lines in three branches. $\Delta J=0$ Q branch; $\Delta J = \pm 2$ S Branch and $\Delta J = -2$ O Branch. For the vibrational change $V=0$ to $V=1$, the accompanying Raman rotational changes are shown in figure.

Here $\bar{\nu}$ measures the distance from the exciting $\bar{\nu}_i$. Q Branch exhibits an intense narrow unresolved line at $\bar{\nu}_i$. S and O branches from weak wings which extend to lower and higher wave numbers respectively from $\bar{\nu}_i$.

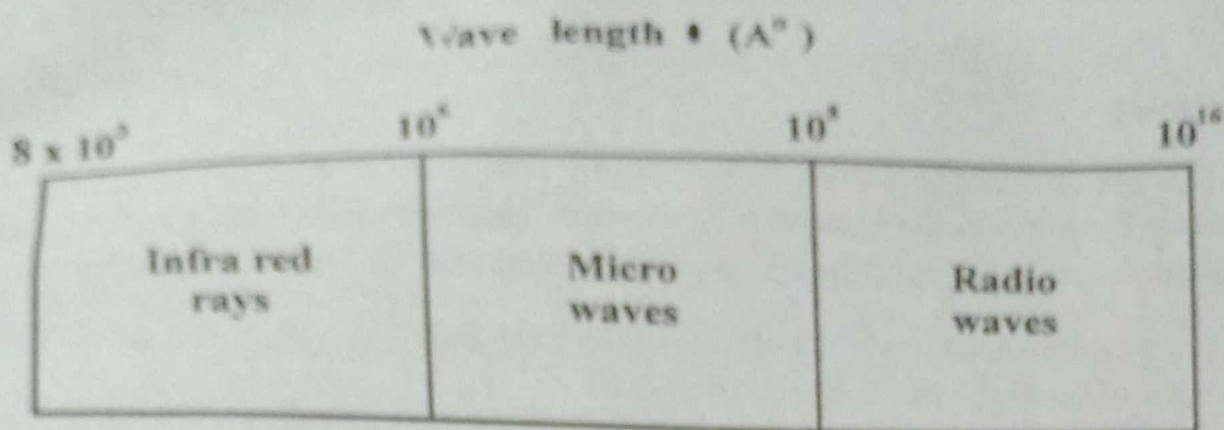
Mutual exclusion principle

CO_2 has one strong band in its Raman spectrum at 1389cm^{-1} and two strong bands in its IR absorption spectrum at 668 and 2342cm^{-1} . None of these occurs both in Raman and in IR spectrum. This is because CO_2 has a centre of symmetry. According to the law of mutual exclusion which states that, for molecules with a centre of symmetry, transitions that are allowed in the IR are forbidden in Raman and vice versa. This law also implies that transition may occur both in Raman and in IR if the molecule has no centre of symmetry. This is shown in the case of water. All the vibrations are simultaneously active in Raman and IR spectra, showing that H_2O has a bent structure and has no centre of symmetry).

Applications

1. Determination of molecular structure :
 - a) Raman spectra have been widely used in deciding the constitution of organic compounds since Raman frequencies for single, double and triple bonds are available. Hence these can be easily located.
 - b) Similarly linear structures and non-linear structures can be identified.
2. Using Raman spectra we can study the strength and nature of forces which are present in the crystals.
3. Centres of vibrational bands which do not appear in infra-red spectra are produced in Raman spectra. Thus force constants, and moments of inertia can be calculated from Raman spectra.
4. In inorganic chemistry we can determine the chemical constitution and the nature of the valence bands. Isomers show different Raman lines. It is used in the study of complex compounds, mixed molecules and water of crystallisation.
5. In organic chemistry aliphatic and aromatic compounds have different Raman spectra. Structure of organic compounds and isomerism can be studied with Raman spectra.
6. In physical chemistry, amorphous states and crystalline states, electrolytic dissociation, hydrolysis etc., may be studied.

Microwave spectroscopy



Definition

The microwave spectroscopy explores that part of the electromagnetic spectrum which is extending from 100 (3 x 10¹²Hz) to 1 centimeter (3 x 10¹⁰ Hz). This region of electromagnetic spectrum is designated as the *microwave region*. This lies between the far infrared and conventional radio frequency regions. Spectroscopic applications and microwaves consist almost exclusively of absorption works, rather than of the emission type. In most of the cases, absorption of microwave energy represents changes of the absorbing molecule from one rotational level to another. Therefore, *the microwave spectroscopy deals with the pure adiatinal motion of molecules and is also known as rotational spectroscopy*. The condition for observing resonance in that region is that a molecule must possess *permanent dipole moment*. When a molecule having dipole moment rotates, it generates an electric field which can interact with the electric component of the microwave radiation. During the interaction, energy can be absorbed or emitted and thus the rotation of the molecule gives rise to a spectrum. If molecules are not having dipole moments, interaction is not possible and these molecules are said to be "*microwave inactive*". Examples of such molecules are H₂, Cl₂, etc. On the other hand, the molecules like HCl, CH₃Cl, etc., are having dipole moments and their interaction will give rise to a spectrum. Such molecules are said to be "*microwave active*". Generally, the microwave spectra obtained in most of the molecules are *absorption spectra*.

Differences between Infrared and Microwave Spectroscopy

The main differences between infrared and microwave spectroscopy are as follows :

1. The absorption spectrum in the microwave region is characteristic of the absorbing molecule as a whole, whereas spectrum in the infrared region is characteristic of the functional groups present in the absorbing molecule.
2. The resolution of the lines in microwave spectrum is very much greater than that obtained by the infrared method.
3. In microwave spectroscopy, the substance must be in gaseous state. On the other hand, in the infrared spectrum the substance may be in the solid, liquid or gaseous state.
4. In microwave spectroscopy, the spectra observed are nearly always absorption spectra. But in the infrared spectroscopy the spectra observed may be absorption or emission spectra.

THEORY OF MICROWAVE SPECTROSCOPY

We are aware of the simple fact that rotational energy, along with all other forms of molecular energy, is quantised. It means that rotational energy has certain permitted energy values. These are generally known as rotational energy levels. They may be calculated for any molecule by solving the Schrodinger equation for the system represented by that molecule. For simple molecules the mathematics involved is simple whereas for complex molecules the mathematics involved is tedious and gross approximations have to be used.

We will now discuss for a simple molecule.

Diatomic molecule as a rigid rotator

A rotating diatomic molecule whose nuclei are supposed to be separated by a definite mean distance may be treated as a rigid rotator with free axis of rotation. In order to provide a suitable model for the interpretation of pure rotational spectra, consider a diatomic molecule in which masses m_1 and m_2 of atoms A and B are joined by a rigid bar whose length is r and is given by

$$r = r_1 + r_2 \quad (4)$$

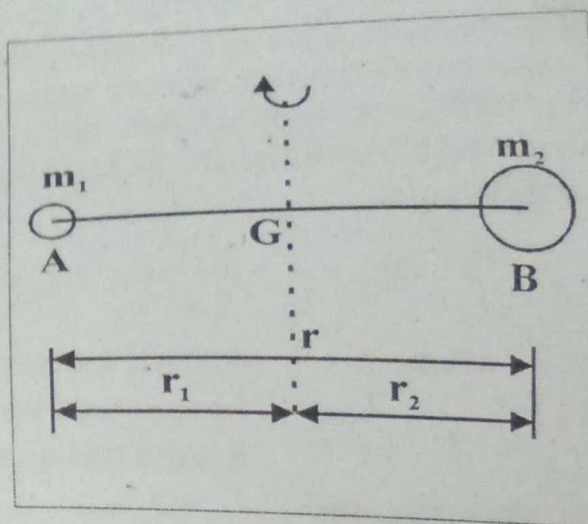
where r_1 and r_2 are the distance of atoms A and B from the centre

of gravity G of the molecule AB about which the molecule rotates end-over-end as shown in Fig. 24. In this case, the moment of inertia about G is defined by

$$I = m_1 r_1^2 + m_2 r_2^2 \quad (5)$$

As the system is balanced about its centre of gravity G , one may write

$$m_1 r_1 = m_2 r_2 \quad (6)$$



On substituting equation (6) in (5), we obtain the following expression :

$$I = m_2 r_2 r_1 + m_1 r_1 r_2; \quad I = r_1 r_2 (m_1 + m_2) \quad (7)$$

But, from equations (5) and (6), we have

$$m_1 r_1 = m_2 r_2 = m_2 (r - r_1) \quad (8)$$

On solving equations (7) and (8), we get

$$r_1 = \frac{m_2}{m_1 + m_2} r \quad \text{and} \quad r_2 = \frac{m_1}{m_1 + m_2} r \quad (9)$$

On putting these values of r_1 and r_2 in equation (5), we get

$$\begin{aligned} I &= \frac{m_1 m_2^2}{(m_1 + m_2)^2} r^2 + \frac{m_1^2 m_2}{(m_1 + m_2)^2} r^2 \\ I &= \frac{m_1 m_2^2 + m_1^2 m_2}{(m_1 + m_2)^2} r^2 = \frac{m_1 m_2 (m_1 + m_2)}{(m_1 + m_2)^2} r^2 \\ I &= \frac{m_1 m_2}{m_1 + m_2} r^2 = \mu r^2 \end{aligned} \quad (10)$$

where μ is the reduced mass of the diatomic molecule and its value is

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \quad (11)$$

Equation (10) defines moment of inertia in terms of atomic masses and bond length.

A rotating molecule having a permanent dipole or magnetic moment generates an electric field which can interact with the electric component of the microwave region. If it is assumed that a diatomic molecule behaves like a rigid rotator, the rotational energy levels may in principle be calculated by solving the Schrodinger's equation for the system represented by that molecule.

$$E_J = \frac{h^2}{8\pi^2 I} J(J+1) \text{ Joules, where } J = 0, 1, 2, \quad (12)$$

where h = Planck's constant,

I = Moment of Inertia,

J = Rotational quantum number ; it takes integral values from zero upwards, and

In rotational region, spectra are generally expressed in terms of wave numbers. Thus

$$\begin{aligned} \epsilon_J &= \frac{E_J}{hc} = \frac{h^2}{8\pi^2 I hc} J(J+1) \text{ cm}^{-1} \\ &= BJ(J+1) \text{ cm}^{-1} \end{aligned} \quad (13)$$

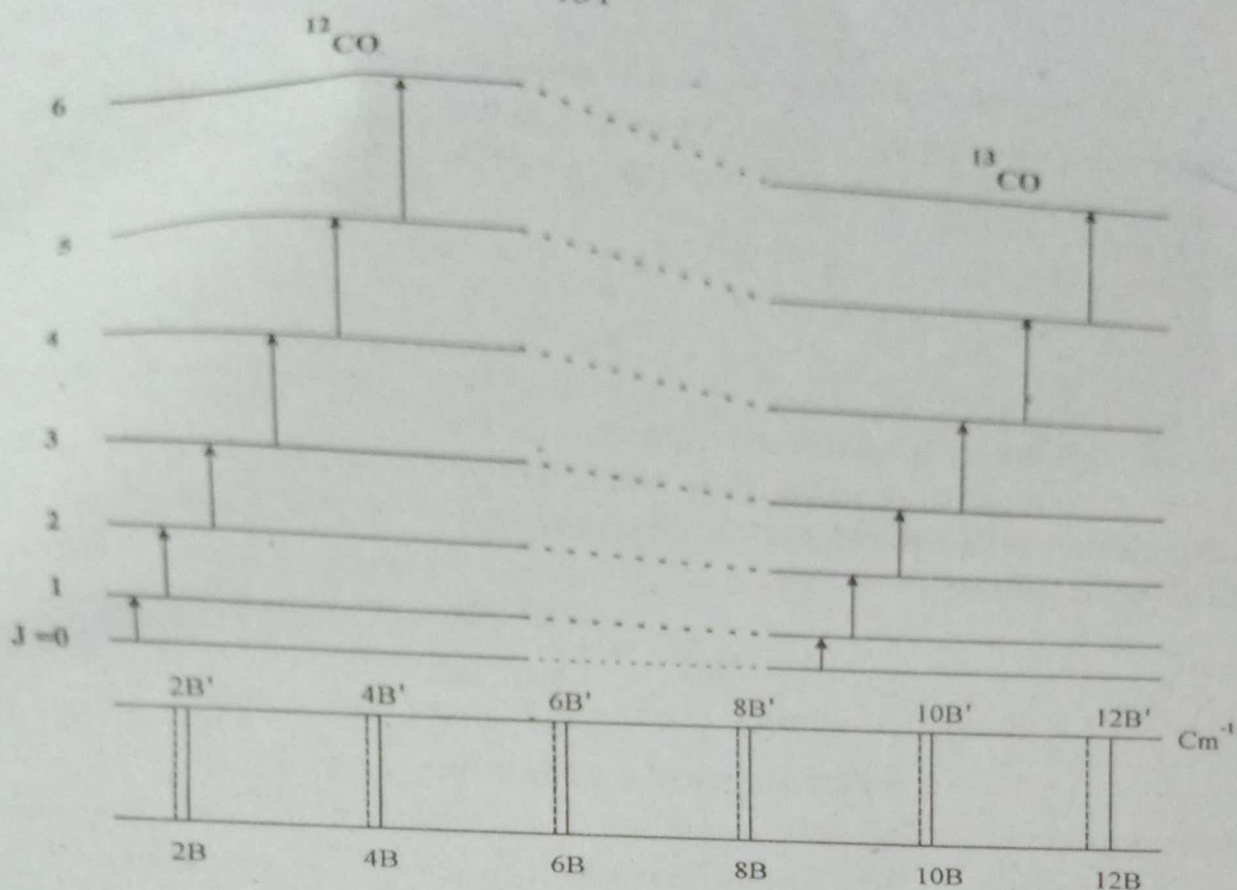
where $B = \frac{h}{8\pi^2 Ic}$; B is called the rotational constant.

EFFECT OF ISOTOPIC SUBSTITUTION

When a particular atom in a molecule is replaced by its isotope an element identical in every way except for its atomic mass-the resulting substance is identical chemically with the original. In particular there is no appreciable change in internuclear distance on isotopic substitution,

There is, however, a change in total mass and hence in the moment of inertia and B value for the molecule.

Considering carbon monoxide as an example, we see that ongoing from $^{12}\text{C}^{16}\text{O}$ to $^{13}\text{C}^{16}\text{O}$ there is a mass increase and hence a decrease in the B value. If we designate the ^{13}C molecule with a prime we have $B > B'$. This Change will be reflected in the rotational energy levels of the molecule and Fig. shows, much exaggerated, the relative lowering of the ^{13}C levels with respect to those of ^{12}C . Plainly, as shown by the diagram at the foot of this figure, the spectrum of the heavier species will show a smaller separation between the lines ($2B'$) than that of the lighter one ($2B$). Again the effect has been much exaggerated for clarity, and the transitions due to the heavier molecule are shown on the right half of the diagram.



The effect of isotopic substitution on the energy levels and hence rotational spectrum of a diatomic molecule such as carbon monoxide

Observation of this decreased separation has led to the evaluation of precise atomic weights. Gilliam et al., as already stated, found the first rotational absorption of $^{12}\text{C}^{16}\text{O}$ to be at 3.84235 cm^{-1} , while that of $^{13}\text{C}^{16}\text{O}$ was at 3.67337 cm^{-1} . The values of B determined from these figures are :

$$B = 1.92118 \text{ cm}^{-1} \quad \text{and} \quad B' = 1.83669 \text{ cm}^{-1}$$

where the prime refers to the heavier molecule. We have immediately :

$$\frac{B}{B'} = \frac{h}{8\pi^2 I c} \cdot \frac{8\pi^2 I' c}{h} = \frac{I'}{I} = \frac{\mu'}{\mu} = 1.046$$

where μ is the reduced mass.

CALCULATION OF INDIVIDUAL BOND LENGTHS IN POLYATOMIC MOLECULES

Study of rotational spectra helps in determining the bond lengths of various bonds in a molecule. Consider a diatomic molecule AB with bond length (or internuclear distance) r . The molecule can rotate about its axis passing through its centre of gravity c .

As the molecule rotates in this manner, its moment of inertia $I_m = Rr^2$ (14) where R is the reduced mass. R is related to the masses of A and B as

$$\frac{1}{R} = \frac{1}{m_A} + \frac{1}{m_B} \quad \text{or} \quad R = \frac{m_A m_B}{(m_A + m_B)}$$

The rotations of the molecule are governed by specific quantum restrictions relating to its angular momentum such that the energy difference between permitted rotational energy level ΔE is given by

$$\Delta E = \frac{h^2 \Delta J}{4\pi^2 I_m} \quad (14)$$

where ΔJ is change in rotational quantum number with values 1,2,3.....etc.

$$\text{Since } E = h\nu ; \Delta E = h\Delta\nu \quad (15)$$

From equation (14) and (15) we get

$$h\Delta\nu = \frac{h^2 \Delta J}{4\pi^2 I_m} \quad \text{or} \quad \Delta\nu = \frac{h\Delta J}{4\pi^2 I_m} \quad (16)$$

When $\Delta J = 1$ that is spacing between successive lines is considered; equation (16) becomes

$$\Delta\nu = \frac{h}{4\pi^2 I_m} \quad (17)$$

Knowing the spacing of equidistant lines, Δw , from the rotational spectrum of a compound, $\Delta\nu$ can be calculated from the formula

$$\Delta\nu = \frac{c}{\Delta\lambda} = c\Delta w \quad (18)$$

where c is the velocity of electromagnetic radiation ($c = 2.998 \times 10^8 \text{ ms}^{-1}$)

Combining (17) and (18) we get

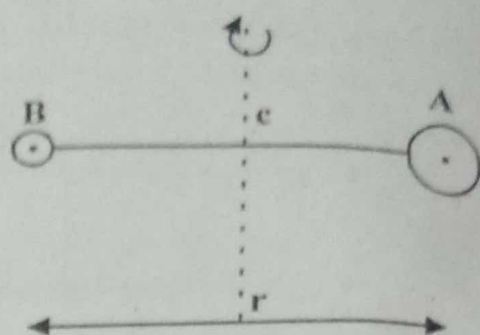
$$c\Delta w = \frac{h}{4\pi^2 I_m} \quad (19)$$

$$\text{Now } I_m = \frac{h}{4\pi^2 c\Delta w} \quad (20)$$

Since $I_m = Rr^2$ from eqn (14)

$$r = \sqrt{\frac{I_m}{R}} \quad (21)$$

I_m is calculated from equation (20) and R is the reduced mass. Thus the bond distance r is calculated from equation (21).



Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy is a type electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern and the position of the beam combined with the intensity of the detected signal to produce an image.

In the most common SEM mode, secondary electrons beam are detected using an Everhart – Thornley detector. SEM can achieve resolution better than 1 nano meter.

Applications of scanning electron microscope

- i. It is used to detect the surface structure.
- ii. In addition to topographical, morphological and compositional informations of surface area of the sample.
- iii. SEM can examine the surface contaminations reveal spatial variations in chemical composition of the crystalline structure.
- iv. SEM can be as essentials research tool in fields such as life science, biology, gemology, medical, metallurgy and forensic science.
- v. It is used to analyze the production line of miniscule products and assembly of microchips for computer.

Transmission Electron Microscopy (TEM)

It is a microscope technique in which a beam of electrons is transmitted through a specimen to form an image. The specimen is most often an ultrathin section less than 100 nm thick or a suspension on a grid. Transmission electron microscopes are capable of imaging at a significantly higher resolution than light microscope.

Applications of scanning electron microscope

- i. TEM applications signals in cancer research virology and material science as well as pollution.
- ii. Nano technology and semi conductor research TEM is highly used.

- iii. TEM is to provide high magnification images of the internal structure of the sample.
- iv. It is also used to investigate the crystalline structure of an object.
- v. It is used to detect the contamination of the sample.

University Questions

1. Write short notes on Raman effect.
2. Explain clearly the term Raman frequency.
3. What is the requirement for a vibration to be Raman active ? / What is the important condition for Raman scattering?
4. Give the difference between Raman and Rayleigh scattering.
5. What do you understand by the term Raman active vibration?
6. Distinguish clearly between Stokes or Anti-stokes lines
7. Explain depolarisation factor in Raman spectroscopy.
8. How is Raman spectra of a molecule studied?
9. Give a comparative account of Raman and IR spectroscopy.
10. Bring out differences between Infra Red and Raman spectra.
11. Why are homonuclear diatomic molecules Infrared and Raman active.
12. Explain why the symmetric vibrations of CO_2 molecule is IR in active and Raman active.
13. Show which of the various modes of vibration in (i) CO_2 molecules and (ii) H_2O molecules are Raman active.
[Hint : CO_2 symmetric stretching vibrational mode : H_2O All the three modes of vibrations]
14. Explain with an example how vibrational spectroscopy and Raman spectroscopy are complimentary to each other ? With an example, illustrate the complimentary nature of IR and Raman spectroscopy.
15. "Raman spectra are more advantageous than infrared spectra " - Explain.