## **BASIC PRINCIPLES OF LASERS**

To explain the process of light amplification in a laser requires an understanding of the energy transition phenomena in the atoms of its active medium. They include: spontaneous emission, stimulated emission/absorption and non-radiative decay.

The theory of quantum mechanics states that the electrons of atoms can take different energy states,  $E_1$ ,  $E_2$ ,  $E_3$ , for example, with  $E_1 < E_2 < E_3$ .

#### **Spontaneous Emission**

By quantum mechanics the lower energy level is more stable than higher energy levels, so electrons tend to occupy the lower level. Those electrons in higher energy levels decay into lower levels, with the emission of EM radiation. This process is called *spontaneous emission*. The radiation emitted is equal to the energy difference between the two levels.

$$\mathbf{E}_2 - \mathbf{E}_1 = \mathbf{h}_0$$

Where  $E_2$  is the upper energy level  $E_1$  is the lower energy level h is Plank's constant  $_0$  is frequency of the radiated EM wave.

#### **Stimulated Emission**

This is crucial if lasing is to occur. Suppose the atoms of the active medium are initially in E2. If external EM waves with frequency  $_0$  that is near the transition frequency between  $E_2$  and E1 is incident on the medium, then there is a finite probability that the incident waves will force the atoms to undergo a transition  $E_2$  to  $E_1$ . Every  $E_2$ - $E_1$  transition gives out an EM wave in the form of a photon. We call this *stimulated emission* since the process is caused by an external excitation. The emitted photon is in phase with the incident photon, has the same wavelength as it and travels in the same direction as the incident photon.

#### **Stimulated Absorption**

If the atom is initially in the ground level E1, the atom will remain in this level until it gets excited. When an EM wave of frequency  $_0$  is incident on the material, there is a finite probability that the atom will absorb the incident energy and jump to energy level E2. This process is called Stimulated Absorption.

#### **Non-Radiative Decay**

Note that the energy difference between the two levels can decay by non-radiative decay. The energy difference can change into kinetic energy or internal energy through collisions with surrounding atoms, molecules or walls.

#### **Population Inversion**

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Normally the population of the lower energy levels is larger than that of the higher levels. The processes of stimulated radiation/absorption and spontaneous emission are going on in the same time, yet even if we ignore the decay factors, stimulated absorption still dominates over stimulated radiation. This means that the incident EM wave cannot be amplified in this case.

Amplification of incident wave is only possible when the population of the upper level is greater than that of the lower level. This case is called Population Inversion. This is a mechanism by which we can add more atoms to the metastable level and hold them there long enough for them to store energy, thereby allowing the production of great numbers of stimulated photons.

We pump atoms into the metastable level at a rate that exceeds the rate at which they leave. A large number of atoms are therefore excited to and held in this level, leaving an almost empty level below it. The atoms stay in this metastable level without de-exciting while the population builds up, giving rise to a population inversion.

In practise laser action cannot be achieved for only two levels, as described above. Three and four level systems work however. An analysis of these systems follows, followed by a description of the pumping schemes for each system.

## Amplification of Light

If population inversion exists,  $N_2 > N_1$ , the incident signal will be amplified. The incident signal has energy equal to the number of photons times the photon energy we have

U(x) = nh . The increase in the signal is given by

$$\frac{dU(x)}{dx} = K[N2(x) - N1(x)]U(x)$$

Where K is a proportionality constant. The solution is

$$U(x) = \exp\left[-K(N1 - N2)x\right]$$

This means that the signal will increase exponentially when there is population inversion. The exponential increase continues until the population inversion reaches a certain point, then the signal saturates, and reaches the steady state.

## **EINSTEIN COEFFICIENTS**

Einstein coefficients are mathematical quantities which are a measure of the probability of absorption or emission of light by an atom or molecule.<sup>[1]</sup> The Einstein A coefficient is related to the rate of spontaneous emission of light and the Einstein B coefficients are related to the absorption and stimulated emission of light.

#### **Einstein Coefficient Relation derivation**

Einstein showed the interaction of radiation with matter with the help of three processes called stimulated absorption, spontaneous emission and stimulated emission

Let us first derive the Einstein coefficient relation on the basis of above theory:

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LASER PHYSICS Let N<sub>1</sub> be the number of atoms per unit volume in the ground state E<sub>1</sub> and these atoms exist in the radiation field of photons of energy

 $E_2 - E_1 = h v$ 

such that energy density of the field is E.

Let  $R_1$  be the rate of absorption of light by  $E_1 \rightarrow E_2$  transitions by the process called stimulated absorption

This rate of absorption  $R_1$  is proportional to the number of atoms  $N_1$  per unit volume in the ground state and proportional to the energy density E of radiations.

That is,

$$R_1 \infty N_1 E$$
  
Or

 $R_1 = B_{12}N_1 E$ (1)

Where B<sub>12</sub> is known as the Einstein's coefficient of stimulated absorption and it represents the probability of absorption of radiation.

Energy density e is defined as the incident energy on an atom as per unit volume in a state.

Now atoms in the higher energy level  $E_2$  can fall to the ground state  $E_1$  automatically after  $10^{-8}$  sec by the process called spontaneous emission.

The rate  $R_2$  of spontaneous emission  $E_2 > E_1$  is independent of energy density E of the radiation field.

 $R_2$  is proportional to number of atoms  $N_2$  in the excited state  $E_2$  thus

$$\begin{array}{l} R_{2} \infty \ N_{2} \\ R_{2} = A_{21} \ N_{2} \end{array} \tag{2}$$

Where A<sub>21</sub> is known as Einstein's coefficient for spontaneous emission and it represents the probability of spontaneous emission.

Atoms can also fall back to the ground state  $E_1$  under the influence of electromagnetic field of incident photon of energy  $E_2-E_1$  = hv by the process called stimulated emission

Rate  $R_3$  for stimulated emission  $E_2$ ->  $E_1$  is proportional to energy density E of the radiation field and proportional to the number of atoms N<sub>2</sub> in the excited state, thus

$$\begin{array}{c} R_{3}\alpha N_{2} E \\ Or \\ R_{3}=B_{21}N_{2} E \end{array}$$
(3)

Where B<sub>21</sub> is known as the Einstein coefficient for stimulated emission and it represents the probability of stimulated emission.

In steady state (at thermal equilibrium), the two emission rates (spontaneous and stimulated) must balance the rate of absorption.

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B.Sc Physics 2017 -2018 ODD Thus,  $\begin{array}{c} \text{UNIT}-\text{I}\\ \text{LASER PHYSICS}\\ R_1{=}R_2{+}R_3 \end{array}$ 

Using equations (1,2, and 3), we get

$$\begin{split} N_1B_{12}E &= N_2A_{21} + N_2B_{21}E \\ Or \\ N_1B_{12}E - N_2B_{21}E &= N_2A_{21} \\ \\ Or \\ (N_1B_{12} - N_2B_{21}) E &= N_2A_{21} \\ Or \\ E &= N_2A_{21}/N_1B_{12} - N_2B_{21} \\ E &= N_2A_{21}/N_2B_{21}[N_1B_{12}/N_2B_{21} - 1] \end{split}$$

[by taking out common  $N_2B_{21}$  from the denominator]

Or  

$$E = A_{21}/B_{21} \{ \frac{1}{N_1}/N_2(B_{12}/B_{21}-1) \}$$
(4)

Einstein proved thermodynamically, that the probability of stimulated absorption is equal to the probability of stimulated emission.thus

 $B_{12} = B_{21}$ 

Then equation(4) becomes

$$E = A_{21}/B_{21}(1/N_1/N_2) \quad (5)$$

From Boltzman's distribution law, the ratio of populations of two levels at temperature T is expressed as

$$N_1/N_2 = e^{(E_2 - E_1)/KT}$$
  
 $N_1/N_2 = e^{hv/KT}$ 

Where K is the Boltzman's constant and h is the Planck's constant.

Substituting value of  $N_1/N_2$  in equation (5) we get

$$E = A_{21}/B_{21}(1/e^{hv/KT}-1)$$
(6)

Now according to Planck's radiation law, the energy density of the black body radiation of frequency v at temperature T is given as

$$E = 8\pi h v^3 / c^3 (1/e^{hv/KT})$$
 (7)

By comparing equations (6 and 7), we get

$$A_{21}/B_{21} = 8\pi hv^3/c^3$$
  
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This is the relation between Einstein's coefficients in laser.

## LASER CONDITIONS

Anything that emits electromagnetic radiation can be turned into a "LASER",

The word "Laser" it stands for "Light Amplification Stimulated Emission of Radiation"

A Laser in the general meaning of the acronym thus produces intense monochromatic electromagnetic radiation in the wavelength region of light (including infrared and a little ultra violet; there are no sharp definitions) that it is coherent to the (monochromatic) input. If you "input" light containing all kinds of frequencies, only one frequency becomes amplified.

A Laser in the specific meaning of everyday usage of the word, however, is more special. It is a device that produces a coherent beam of monochromatic light in one direction only and, at least for semiconductor Lasers, without some input light (but with a "battery" or power source hooked up to it). It is akin to an electronic oscillator that works by internally feeding back parts of the output of an amplifier to the input for a certain frequency.

we considered two basic processes, to which now a third one must be added:

**1. Fundamental absorption**, i.e. the interaction of a photon with an electron in the *valence band* resulting in a electron(C) - hole(V) pair.

**2. Spontaneous emission** of a photon by the (spontaneous and direct) recombination of an electron-hole pair.

**3. Stimulated emission**, as the third and new process, is simply the interaction of a photon with an electron in the *conduction band*. It forces recombination and thus the emission of a second photon.

All three processes are schematically shown in the band diagram below.



An electron in the conduction band absorbs a photon, moves up the amount energy to the conduction band, and comes back to the band edge by giving its surplus energy to phonons.

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This process take place, but is not very strong if we do not have many electrons in the conduction band.

Stimulated emission is not just the reverse of absorption process. Photons usually interact with electrons in the conduction band by transferring their energy to the electron, which moves the electron to some higher energy level in the band

- Stimulated emission is a resonant process; it only works if the photons have exactly the right energy, corresponding to the energy that is released if the electron makes a transition to some allowed lower level. This also means that the two photons are exactly in phase with each other. For semiconductors, this is pretty much the energy of the band gap, because all conduction band electrons are sitting at the conduction band edge (with some small E, of course), and the only available lower energy level are the free positions occupied by holes at the valence band edge.
- Stimulated emission thus may be seen as a competing process to the fundamental band-band absorption process <u>described before</u>. But while all photons with an energy  $\mathbf{h} > \mathbf{E}_{\mathbf{g}}$  may cause fundamental absorption because there are many unoccupied levels above  $\mathbf{E}_{\mathbf{g}}$ , only photons with  $\mathbf{h} = \mathbf{E}_{\mathbf{g}}$  (give or take some small  $\mathbf{E}$ ) may cause stimulated emission.
- Einstein showed that under "normal" conditions (meaning conditions not too far from thermal equilibrium), fundamental absorption by far exceeds stimulated emission. Of course, Einstein did not show that for semiconductors, but for systems with well defined energy levels - atoms, molecules, whatever.
  - However, for the special case that a sufficiently large number of electrons occupies an excited energy state - this is called **inversion**, - stimulated emission may dominate the electron-photon interaction processes. Then twophotons of identical energy and being exactly in phase come out of the system for one photon going into the system.
  - The kind of inversion we are discussing here should not be mixed up with the inversion that turns n-type Si into p-type or vice versa that we encounterd before. Same word, but different phenomena!
  - These two photons may cause more stimulated emission yielding 4, 8, 16, ... photons, i.e. an avalanche of photons will be produced until the excited electron states are sufficiently depopulated.

In other words: One photon **h** impinging on a material that is in a state of inversion (with the right energy difference **h** between the excited state and the ground state) may, by stimulated emission, cause a lot of photons to come out of the material. Moreover, these

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photons are all in phase, i.e.a strong and coherent beam of light - amplification of light occurs.

**Population inversion**, The redistribution of atomic energy levels that takes place in a system so that **laser** action can occur. The atoms is in temperature equilibrium and the more atoms in low energy states than in higher ones is called Population Inversion

## THRESHOLD CONDITION OF LASER

The lasing **threshold** is the lowest excitation level at which a laser's output is dominated by stimulated emission rather than by spontaneous emission. Below the **threshold**, the laser's output power rises slowly with increasing excitation.

# **OPTICAL FIBER LOSS AND ATTENUATION**

The attenuation of an optical fiber measures the amount of light lost between input and output. Total attenuation is the sum of all losses.

Optical losses of a fiber are usually expressed in **decibels per kilometer (dB/km**). The expression is called the **fiber's attenuation coefficient** and the expression is

$$\alpha = -\frac{10}{z [\rm{km}]} \log \left( \frac{P(z)}{P(0)} \right)$$

where P(z) is the optical power at a position z from the origin, P(0) is the power at the origin.

For a given fiber, these losses are wavelength-dependent which is shown in the figure below. The value of the attenuation factor depends greatly on the fiber material and the manufacturing tolerances, but the figure below shows a typical optical fiber's attenuation spectral distribution.

# **LINE SHAPE FUNCTION**

We consider three different mathematical description of the line shape for an absorptive transition. The transition may be electronic, rotational, or vibrational (i.e. visible, microwave or infrared radiation). In an ideal gas phase experiment where there is no Doppler broadening or lifetime broadening the energy at which transition occurs is unique. This implies that the line is infinitely narrow.

## Scattering

Scattering losses occur when a wave interacts with a particle in a way that removes energy in the directional propagating wave and transfers it to other directions. The light isn't absorbed, just sent in another direction. However, the distinction between scattering and absorption doesn't matter much because the light is lost from the fiber in either case.

There are two main types of scattering: linear scattering and nonlinear scattering.

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For **linear scattering**, the amount of light power that is transferred from a wave is proportional to the power in the wave. It is characterized by having no change in frequency in the scattered wave.

On the other hand, **nonlinear scattering** is accompanied by a frequency shift of the scattered light. Nonlinear scattering is caused by high values of electric field within the fiber (modest to high amount of optical power). Nonlinear scattering causes significant power to be scattered in the forward, backward, or sideways directions.

# THREE LEVEL AND FOUR LEVEL SYSTEMS.

In a simple two-level system, it is not possible to obtain a population inversion with optical pumping because the system can absorb pump light (i.e., gain energy) only as long as population inversion, and thus light amplification, is not achieved. Essentially, the problem is stimulated emission caused by the pump light itself.



Inversion by optical pumping becomes possible when using a three-level system. Pump lightwith a shorter wavelength (higher photon energy) can transfer atoms from the ground state to the highest level. From there, spontaneous emission or a nonradiative process (e.g., involving phonons in a laser crystal) transfers atoms to an intermediate level, called the upper laserlevel. From that level down to the ground state, the laser transition with stimulated emission can occur. With sufficiently high pump intensity, population inversion for the laser transition can be reached as stimulated emission by the pump radiation is prevented by the transfer to the intermediate level.



Laser gain with a much lower excitation level is possible in a four-level system, such as Nd:YAG. Here, the lower level of the laser transition is somewhat above the ground state, and a rapid (most often nonradiative) transfer from there to the ground state keeps the population of the lower laser level very small. Therefore, a moderate population in the third level (the upper laser level), as achieved with a moderate pump intensity, is sufficient for laser amplification.

#### Possible Questions

(1) Write a short notes on (i) Absorption

(ii) Spontaneous emission

(iii) Stimulated emission

(2) Derive the relations between Einstein A and B coefficients.

(3) Explain three level laser system with neat diagram

(4) Write a short notes on (i) Q-Factor (ii) Losses in cavity

(5) Explain in detail various characteristics of LASER.

(6) Explain in detail about two level laser systems.

(7) How will you differentiate laser from other conventional light sources

(8) Write a notes on (i) Pumping (ii) Normal population (iii) Population inversion

(9) Explain in detail about coherence and monochromacity

Questions	opt1	opt2	opt3	opt4	Answer
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	Light Amplification by	Light Amplification by	Light Attenuation by	Light Attenuation by	Light Amplification by
The word Laser is an abbrevation for	Stimulated Emission of	Spontaneous Emission of	Stimulated Emission of	Spontaneous Emission of	Stimulated Emission of
	Radiation	Radiation	Radiation	Radiation	Radiation
The first laser was built in	1972	1960	1988	1994	1960
Ground state of the atom is the minimum energy state and it is the most state.	unstable	discrete	stable	none	stable
Life time of electron in the excited state is very small, of the order of	10 <sup>-8</sup> sec	$10^{-7}$ sec	10 <sup>-5</sup> sec	10 <sup>-3</sup> sec	10 <sup>-8</sup> sec
The characteristics of laser beam is	Monochromatic	Coherent	Intense	All the above	All the above
The photons of energy $h\gamma$ incident to the atoms in the ground state and are taken to the excited state is called	Stimulated emission	Spontaneous emission	Stimulated absorption	Spontaneous absorption	Stimulated absorption
The number of atoms in the excited state becomes greater than the number of atom in the ground state is called as	normal population	optical pumping	pumping	population inversion	population inversion
The life time of atom in the excited state is normally	10 <sup>-6</sup> sec	10 <sup>-12</sup> sec	10 <sup>-8</sup> sec	10 <sup>-3</sup> sec	10 <sup>-8</sup> sec
The life time of atom in the metastable state is normally	10 <sup>-6</sup> sec	10 <sup>-12</sup> sec	10 <sup>-8</sup> sec	10 <sup>-3</sup> sec	10 <sup>-3</sup> sec
The million in the inclusion state is normally	10 500	10 300	10 500	10 300	10 300
levels are called as	metastable state	excited state	stable state	none	metastable state
Under the condition of equilibrium, the no. of atoms absorbing radiation per unit	greater	smaller	equal	none	equal
In optical region $\lambda =$	1000 A°	3000 A°	6000 A°	5000 A°	5000 A°
In micro wave region $\lambda = \dots$	5 cm	15 cm	25 cm	none	none
The numping rate is represented by	0	0 <sup>-1</sup>	0	w <sup>-1</sup>	0
The probability per unit time, where the stome are excited to the upper level is	22	52	6	ω	52
called rate	Normal pumping	Abnormal pumping	Pumping	None	Pumping
The line shape function represents the behaviour of $k\omega$	Amplitude	Frequency	Wavelength	None	Frequency
	Homogeneous&	Homogeneous & non	Heterogeneous & non		Homogeneous & non
Line broadening mechanisms can be classified as	heterogeneous	homogeneous	homogeneous	None	homogeneous
Which of the following is an example of non- homogeneous broadening?	Natural	Collision	Doppler	None	Doppler
Schawlow & Townes suggested plane parallel reflecting surfaces as a	1	2	2	4	2
suitable resonator	1	2	5	4	2
For non degenerate state	$g_n = g_m$	$g_n/g_m$	g <sub>n</sub> -g <sub>m</sub>	$g_n + g_m$	$g_n = g_m$
In transition between two energy states, the atom absorbs or emits a photon of	hv	hv/2	2hv	none	hv
energy is					
I he process by which the atoms in the ground state is taken to the excited state is known as	optical pumping	pumping	induced absorption	induced emission	pumping
The atoms are taken to the higher energy level with the help of light is called	optical pumping	pumping	induced absorption	induced emission	optical pumping
The atoms are taken to the higher energy level with the help of	electrons	chemical reaction	induced absorption	light	light
Population inversion means, the no. of atoms in the excited state is	sama	loss than	graatar than	nono	graatar than
the no. of atoms in the ground state	Same		greater than	none	greater than
The excited atoms return to the lower state without help of any external agency is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission	spontaneous absorption
The excited atoms return to the lower state with help of photon is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission	stimulated emission
The photons produced by stimulated emission is called	Primary photon	secondary photon	spontaneous photon	none	secondary photon
The secondary photon is always with the stimulating photons	out of phase	coherent	in phase	none	in phase
By laser action all the emitted photons are with each other	out of phase	coherent	in phase	none	in phase
In the microwave region wavelength=	.5 cm	15 cm	20 cm	10 cm	10 cm

In microwave region, the stimulated emission rate is the spontaneous rate	equal to	higher than	smaller than	none	higher than
The spontaneous emission is more predominant in the region	optical	IR	UV	microwave	optical
Excited atoms undergo transition to the lower level byemission	spontaneous	stimulated	both a and b	none	both a and b
The population difference between the two levels in a steady stateon the decay time of the upper level	depends	independent	same	none	depends
The probability per unit time, where the atoms are excited to the upper level is calledrate	normal pumping	abnormal pumping	pumping	none	pumping
The pumping power is always upon decay time	same	independence	depends	none	depends
The cavity which does not contain any active medium is calledresonator	active	passive	band pass	low pass	passive
The cavity which contain active medium is calledresonator	active	passive	band pass	low pass	active
The atoms having same central frequency and the same atomic line shape is known as	homogeneous	heterogeneous	non- homogeneous	none	homogeneous
In normal population the no. of atoms in the ground state is than the no. of atoms in the excited state.	less than	greater than	both a & b	none	greater than
In thermal equilibrium the no. of atoms in the ground state is greater than the no. of atoms in the excited state is called	normal population	population inversion	abnormal population	none of these	normal population
In optical region, hw/KT is approximately equal to	10	1000	1500	100	100
In microwave region, hw/KT is approximately equal to	5x10 <sup>-2</sup>	5x10 <sup>-6</sup>	5x10 <sup>-3</sup>	none	none
In threshold condition a is calledgain coefficient	saturated	unsaturated	normal	none	unsaturated
The particular shape of the function g (w) on the phenomenon responsible for the line broadening	same	independence	depends	none	depends
Line broadening mechanism can be classified as	homogeneous & heterogeneous	homogeneous & non homogeneous	heterogeneous & non homogeneous	none	homogeneous & non homogeneous
Laser emits light in direction.	various	1	2	none	1
Laser radiations have degree of coherence.	low	high	medium	very low	high
Time incoherence is a characteristics of a beam of light	single	multiple	Both a and b	None of the above	single
Another name of temporal coherence is coherence	transverse	spatial	longitudinal	none of these	longitudinal
is a best example of an optically pumped rare earth laser system	calcium ion	erbium ion	uranium ion	neodymium ion	neodymium ion
The fluorescent quantum efficiency was found to be near	zero	less than unity	unity	greater than unity	unity
The point at which the strength of the beam has dropped to 1/e times its value at the centre is called	inner edge	half edge	full edge	outer edge	outer edge
Rayleigh range begins to spread linearly with distance because of effect	interference	dispersion	diffraction	refraction	diffraction
Who determine the equation $2d \sin \theta = m\lambda$	Heisenberg	Bragg	Planck	None	Bragg

#### **TYPES OF LASERS AND OUTPUT MODULATION METHODS**

Lasers are classified into 4 types based on the type of laser medium used:

- 1] Solid-state laser
- 2] Gas laser
- 3] Liquid laser
- 4] Semiconductor laser

#### 1] SOLID STATE LASERS

Solid-state lasers are lasers based on solid-state gain media such as crystals or glasses doped with rare earth or transition metal ions, or semiconductor lasers. (Although semiconductor lasers are of course also solid-state devices, they are often not included in the term solid-state lasers.) Ion-doped solid-state lasers (also sometimes called doped insulator lasers) can be made in the form of bulk lasers, fiber lasers, or other types of waveguide lasers. Solid-state lasers may generate output powers between a few milliwatts and (in high-power versions) many kilowatts.





#### **Optical Pumping and Energy Storage**

Many solid-state lasers are optically pumped with flash lamps or arc lamps. Such pump sources are relatively cheap and can provide very high powers. However, they lead to a fairly low power efficiency, moderate lifetime, and strong thermal effects such as thermal lensing in the gain medium. For such reasons, laser diodes are very often used for pumping solid-state lasers. Such diode-pumped solid-state lasers (DPSS lasers, also called all-solidstate lasers) have many advantages, in particular a compact setup, long lifetime, and often very good beam quality. Therefore, their share of the market is rapidly rising.

The laser transitions of rare-earth or transition-metal-doped crystals or glasses are normally

weakly allowed transitions, i.e., transitions with very low oscillator strength, which leads to long radiative upper-state lifetimes and consequently to good energy storage, with upper-state lifetimes of microseconds to milliseconds. Although this is beneficial for nanosecond pulse generation (see below), it can also lead to unwanted spiking phenomena in continuouswave lasers, e.g. when the pump source is switched on.

## **Pulse Generation**

The long upper-state lifetimes makes solid-state lasers very suitable for Q switching: the laser crystal can easily store an amount of energy which, when released in the form of a nanosecond pulse, leads to a peak power which is orders of magnitude above the achievable average power. Bulk lasers can thus easily achieve mill joule pulse energies and megawatt peak powers.

In mode-locked operation, solid-state lasers can generate ultra short pulses with durations measured in picoseconds or femto seconds (minimum: 5 fs, achieved with Ti sapphire lasers). With passive mode locking, they have a tendency for Q-switching instabilities, if these are not suppressed with suitable measures.

## Wavelength Tuning

In terms of their potential for wavelength tuning, different types of solid-state lasers differ considerably. Most rare-earth-doped laser crystals, such as Nd:YAG and Nd:YVO<sub>4</sub>, have a fairly small gain bandwidth of the order of 1 nm or less, so that tuning is possible only within a rather limited range. On the other hand, tuning ranges of tens of nanometers and more are possible with rare-earth-doped glasses, and particularly with transition-metal-doped crystals such as Ti:sapphire, Cr:LiSAF and Cr:ZnSe (vibronic lasers).

## **Types of Solid-state Lasers**

Examples of different types of solid-state lasers are:

- Small diode-pumped Nd:YAG (YAG lasers) or Nd:YVO<sub>4</sub> lasers (vanadate lasers) often operate with output powers between a few milli watts (for miniature setups) and a few watts. Q-switched versions generate pulses with durations of a few nanoseconds, micro joule pulse energies and peak powers of many kilowatts. Intra cavity frequency doubling can be used for green output.
- Single-frequency operation, typically achieved with unidirectional ring lasers (e.g. NPROs = non planar ring oscillators) or microchip lasers, allows for operation with very small line width in the lower kilohertz region.
- Larger lasers in side-pumped or end-pumped configurations (see above), having the geometry of rod lasers, slab lasers or thin-disk lasers, are suitable for output powers up to several kilowatts. Particularly thin-disk lasers can still offer very high beam quality, and also a high power efficiency.
- Q-switched Nd:YAG lasers are still widely used in lamp-pumped versions. Pulsed pumping allows for high pulse energies, whereas the average output powers are often moderate (e.g. a few watts). The cost of such lamp-pumped lasers is lower than for diode-pumped versions with similar output powers.
- ➢ Fiber lasers are a special kind of solid-state lasers, with a high potential for high average output power, high power efficiency, high beam quality, and broad wavelength y..

#### 2] RUBY LASER

A ruby laser is a solid-state laser that uses a synthetic ruby crystal as its gain medium. The first working laser was a ruby laser made by Theodore H. "Ted" Maiman at Hughes Research Laboratories on May 16, 1960.

Ruby lasers produce pulses of visible light at a wavelength of 694.3 nm, which is a deep red colour. Typical ruby laser pulse lengths are on the order of a millisecond.

#### Design

A ruby laser most often consists of a ruby rod that must be pumped with very high energy, usually from a flashtube, to achieve a population inversion. The rod is often placed between two mirrors, forming an optical cavity, which oscillate the light produced by the ruby's fluorescence, causing stimulated emission. Ruby is one of the few solid state lasers that produce light in the visible range of the spectrum, lasing at 694.3 nanometers, in a deep red colour, with a very narrow line width of 0.53 nm

The ruby laser is a three level solid state laser. The active laser medium (laser gain/amplification medium) is a synthetic ruby rod that is energized through optical pumping, typically by a xenon flashtube. Ruby has very broad and powerful absorption bands in the visual spectrum, at 400 and 550 nm, and a very long fluorescence lifetime of 3 milliseconds. This allows for very high energy pumping, since the pulse duration can be much longer than with other materials. While ruby has a very wide absorption profile, its conversion efficiency is much lower than other mediums.

In early examples, the rod's ends had to be polished with great precision, such that the ends of the rod were flat to within a quarter of a wavelength of the output light and parallel to each other within a few seconds of arc. The finely polished ends of the rod were silvered; one end completely, the other only partially. The rod, with its reflective ends, then acts as a Fabry–Pérot etalon (or a Gires-Tournois etalon). Modern lasers often use rods with antireflection coatings, or with the ends cut and polished at Brewster's angle instead. This eliminates the reflections from the ends of the rod. External dielectric mirrors then are used to form the optical cavity. Curved mirrors are typically used to relax the alignment tolerances and to form a stable resonator, often compensating for thermal lensing of the rod.

Ruby also absorbs some of the light at its lasing wavelength. To overcome this absorption, the entire length of the rod needs to be pumped, leaving no shaded areas near the mountings. The active part of the ruby is the dopant, which consists of chromium ions suspended in a sapphire crystal. The dopant often comprises around 0.05% of the crystal, and is responsible for all of the absorption and emission of radiation. Depending on the concentration of the dopant, synthetic ruby usually comes in either pink or red.

#### Applications

One of the first applications for the ruby laser was in range finding. By 1964, ruby lasers with rotating prism q-switches became the standard for military rangefinders, until the introduction of more efficient Nd: YAG rangefinders a decade later. Ruby lasers were used mainly in research. The ruby laser was the first laser used to optically pump tunable dye lasers and is particularly well suited to excite laser dyes emitting in the near infrared. Ruby lasers are rarely used in industry, mainly due to low efficiency and low repetition rates. One of the main industrial uses is drilling holes through diamond.

Ruby lasers have declined in use with the discovery of better lasing media. They are still used in a number of applications where short pulses of red light are required. Holographers around the world produce holographic portraits with ruby lasers, in sizes up to a meter square. Because of its high pulsed power and good coherence length, the red 694 nm laser light is preferred to the 532 nm green light of frequency-doubled Nd: YAG, which often requires multiple pulses for large holograms. Many non-destructive testing labs use ruby lasers to create holograms of large objects such as aircraft tires to look for weaknesses in the lining. Ruby lasers were used extensively in tattoo and hair removal, but are being replaced by alexandrite and Nd:YAG lasers in this application.

## 3] Nd-YAG Laser

## Definition

Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid state laser in which Nd: YAG is used as a laser medium.

#### Construction

Nd:YAG laser consists of three important elements: an energy source, active medium, and optical resonator.



Fig---: Schematic of Nd: YAG Laser

#### Working

Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. The light energy sources such as flashtubes or laser diodes are used to supply energy to the active medium.

In Nd:YAG laser, the lower energy state electrons in the neodymium ions are excited to the higher energy state to achieve population inversion.

Consider a Nd:YAG crystal active medium consisting of four energy levels  $E_1$ ,  $E_2$ ,  $E_3$ , and  $E_4$  with N number of electrons. The number of electrons in the energy states  $E_1$ ,  $E_2$ ,  $E_3$ , and  $E_4$  will be  $N_1$ ,  $N_2$ ,  $N_3$ , and  $N_4$ .

Let us assume that the energy levels will be  $E_1 < E_2 < E_3 < E_4$ . The energy level  $E_1$  is known as ground state,  $E_2$  is the next higher energy state or excited state,  $E_3$  is the metastable state or excited state and  $E_4$  is the pump state or excited state. Let us assume that initially, the population will be  $N_1 > N_2 > N_3 > N_4$ . When flashtube or laser diode supplies light energy to the active medium (Nd:YAG crystal), the lower energy state  $(E_1)$  electrons in the neodymium ions gains enough energy and moves to the pump state or higher energy state  $E_4$ .

![](_page_15_Figure_4.jpeg)

The lifetime of pump state or higher energy state  $E_4$  is very small (230 microseconds ( $\mu$ s)) so the electrons in the energy state  $E_4$  do not stay for long period. After a short period, the electrons will fall into the next lower energy state or metastable state  $E_3$  by releasing non-radiation energy (releasing energy without emitting photons).

The lifetime of metastable state  $E_3$  is high as compared to the lifetime of pump state  $E_4$ . Therefore, the electrons reach  $E_3$  much faster than they leave  $E_3$ . This results in an increase in the number of electrons in the metastable  $E_3$  and hence population inversion is achieved.

After some period, the electrons in the metastable state  $E_3$  will fall into the next lower energy state  $E_2$  by releasing photons or light. The emission of photons in this manner is called spontaneous emission.

![](_page_15_Figure_8.jpeg)

Physics and Radio-Electronics

The lifetime of energy state  $E_2$  is very small just like the energy state  $E_4$ . Therefore, after a short period, the electrons in the energy state  $E_2$  will fall back to the ground state  $E_1$  by releasing radiation less energy.

When photon emitted due to spontaneous emission is interacted with the other metastable state electron, it stimulates that electron and makes it fall into the lower energy state by releasing the photon. As a result, two photons are released. The emission of photons in this manner is called stimulated emission of radiation.

![](_page_16_Figure_5.jpeg)

Physics and Radio-Electronics

When these two photons again interacted with the metastable state electrons, four photons are released. Likewise, millions of photons are emitted. Thus, optical gain is achieved.

Spontaneous emission is a natural process but stimulated emission is not a natural process. To achieve stimulated emission, we need to supply external photons or light to the active medium.

The Nd:YAG active medium generates photons or light due to spontaneous emission. The light or photons generated in the active medium will bounce back and forth between the two mirrors. This stimulates other electrons to fall into the lower energy state by releasing photons or light. Likewise, millions of electrons are stimulated to emit photons.

The light generated within the active medium is reflected many times between the mirrors before it escapes through the partially reflecting mirror.

# Advantages

- Low power consumption
- Nd:YAG laser offers high gain.
- Nd:YAG laser has good thermal properties.
- Nd:YAG laser has good mechanical properties.
- The efficiency of Nd:YAG laser is very high as compared to the ruby laser.

## Applications

## Military

Nd:YAG lasers are used in laser designators and laser rangefinders. A laser designator is a laser light source, which is used to target objects for attacking. A laser rangefinder is a rangefinder, which uses a laser light to determine the distance to an object.

#### Medicine

Nd: YAG lasers are used to correct posterior capsular opacification (a condition that may occur after a cataract surgery). Nd:YAG lasers are used to remove skin cancers.

## Manufacturing

Nd:YAG lasers are used for etching or marking a variety of plastics and metals. Nd:YAG lasers are used for cutting and welding steel.

## 4] GAS LASERS

#### **HELIUM-NEON LASER**

The most common and inexpensive gas laser, the helium-neon laser is usually constructed to operate in the red at 632.8 nm. It can also be constructed to produce laser action in the green at 543.5 nm and in the infrared at 1523 nm.

One of the excited levels of helium at 20.61 eV is very close to a level in neon at 20.66 eV, so close in fact that upon collision of helium and a neon atom, the energy can be transferred from the helium to the neon atom.

Helium-neon lasers are common in the introductory physics laboratories, but they can still be dangerous! According to Garmire, an unfocused 1-mW He-Ne laser has brightness equal to sunshine on a clear day  $(0.1 \text{ watt/cm}^2)$  and is just as dangerous to stare at directly.

![](_page_17_Figure_15.jpeg)

![](_page_18_Figure_3.jpeg)

The helium gas in the laser tube provides the pumping medium to attain the necessary population inversion for laser action.

The collimation of the beam is accomplished by mirrors on each end of the evacuated glass tube which contains about 85% helium and 15% neon gas at 1/300 atmospheres pressure (Metrologic). These mirrors could be both flat, but this requires great precision in alignment, so the common laboratory He-Ne lasers are manufactured with the semiconfocal mirror arrangement shown.

![](_page_18_Figure_6.jpeg)

#### **CARBON-DI-OXIDE LASER**

The CO<sub>2</sub> laser (carbon dioxide laser) is a laser based on a gas mixture as the gain medium, which contains carbon dioxide (CO<sub>2</sub>), helium (He), nitrogen (N<sub>2</sub>), and possibly some hydrogen (H<sub>2</sub>), water vapour and/or xenon (Xe). Such a laser is electrically pumped via a gas discharge, which can be operated with DC current, with AC current (e.g. 20–50 kHz) or in the radio frequency (RF) domain. Nitrogen molecules are excited by the discharge into a metastable vibrational level and transfer their excitation energy to the CO<sub>2</sub> molecules when colliding with them. Helium serves to depopulate the lower laser level and to remove the heat. Other constituents such as hydrogen or water vapour can help (particularly in sealed-tube lasers) to reoxidize carbon monoxide (formed in the discharge) to carbon dioxide.

![](_page_19_Figure_0.jpeg)

Figure 1: Schematic setup of a sealed-tube carbon dioxide laser.

The gas tube has Brewster windows and is water-cooled.CO<sub>2</sub> lasers typically emit at a wavelength of 10.6  $\mu$ m, but there are other lines in the region of 9–11  $\mu$ m (particularly at 9.6  $\mu$ m). In most cases, average powers are between some tens of watts and many kilowatts. The power conversion efficiency can be well above 10%, i.e., it is higher than for most lamppumped solid-state lasers, but lower than for many diode-pumped lasers.

## Applications

 $CO_2$  lasers are widely used for material processing, in particular for cutting plastic materials, wood, die boards, etc., exhibiting high absorption at 10.6 µm, and requiring moderate power levels of 20–200 W cutting and welding metals such as stainless steel, aluminum or copper, applying multi-kilowatt powers laser marking of various materials.

Other applications include laser surgery (including ophthalmology) and range finding.

 $CO_2$  lasers used for material processing (e.g. welding and cutting of metals, or laser marking) are in competition with solid-state lasers (particularly YAG lasers and fiber lasers) operating in the 1-µm wavelength regime. These shorter wavelengths have the advantages of more efficient absorption in a metallic work piece, and the potential for beam delivery via fiber cables (there are no optical fibers for high-power 10-µm laser beams). The potentially smaller beam parameter product of 1-µm lasers can also be advantageous. However, the latter potential normally cannot be realized with high-power lamp-pumped lasers, and diode-pumped lasers tend to be more expensive. For these reasons,  $CO_2$  lasers still dominate the cutting and welding business, particularly for parts with a thickness greater than a few millimeters. This may change in the future due to the development of high-power thin-disk lasers and advanced fiber cables in combination with techniques which exploit the high beam quality of such lasers.

Due to their high powers and high drive voltages,  $CO_2$  lasers raise serious issues of laser safety. However, their long operation wavelength makes them relatively eye-safe at low intensities.

#### SEMICONDUCTOR LASER

Semiconductor lasers are said to be "the laser of the future". The reasons are: they are compact, they have the potential of mass production, they can be easily integrated, their properties are in rapid improvement, they are becoming more and more powerful and efficient and they have found a widespread use as pumps for solid–state lasers.

The majority of semiconductor materials are based on a combination of elements in the third group of the Periodic Table (such as Al, Ga, In) and the fifth group (such as N, P, As, Sb) hence referred to as the III-V compounds. Examples include GaAs, AlGaAs, InGaAs and InGaAsP alloys. The cw laser emission wavelengths are normally within 630~1600 nm,

but recently InGaN semiconductor lasers were found to generate cw 410 nm blue light at room temperature. The semiconductor lasers that can generate blue-green light uses materials which are the combination of elements of the second group (such as Cd and Zn) and the sixth group (S, Se).

UNIT – II

**TYPES OF LASERS** 

The principle of semiconductor laser is very different from  $CO_2$  and Nd:YAG lasers. It is based on "Recombination Radiation". We can explain this principle by referring to the following figure.

![](_page_20_Figure_4.jpeg)

Principles of semiconductor lasers

The semiconductor materials have valence band V and conduction band C, the energy level of conduction band is Eg (Eg>0) higher than that of valence band. To make things simple, we start our analysis supposing the temperature to be 0 K. It can be proved that the conclusions we draw under 0 K applies to normal temperatures.

Under this assumption for non degenerate semiconductor, initially the conduction band is completely empty and the valence band is completely filled. Now we excite some electrons from valence band to conduction band, after about 1 ps, electrons in the conduction band drop to the lowest unoccupied levels of this band, we name the upper boundary of the electron energy levels in the conduction band the quasi-Fermi level  $E_{fc}$ . Meanwhile holes appear in the valence band and electrons near the top of the valence band drop to the lowest energy levels of the unoccupied valence energy levels, leave on the top of the valence band an empty part. We call the new upper boundary energy level of the valence band quasi-Fermi level  $E_{fv}$ . When electrons in the conduction band run into the valence band, they will combine with the holes, in the same time they emit photons. This is the recombination radiation. Our task is to make this recombination radiation to lase. Then several conditions must be met.

First for the radiation to be amplified, the light energy hn must satisfy:

$$E_{fc}$$
 -  $E_{fv}$  <sup>3</sup> hn <sup>3</sup> Eg

From this relation we have  $E_{fc} - E_{fv} \cdot E_g$ . This decides the critical condition. The value of  $E_{fc}$  and  $E_{fv}$  is influenced by the pumping process, i.e., by the intensity (N) of the electrons being raised to the conduction band. When N is increased,  $E_{fc}$  increases and  $E_{fv}$  decreases. The N satisfies  $E_{fc} - E_{fv} = Eg$  is named N<sub>tr</sub>. We inject carriers into the semiconductor material to make the free electron intensity to be larger than N<sub>th</sub>, then the semiconductor exhibits a net gain. We put this active medium in a suitable cavity, laser action occurs when this net gain overcome losses. The pumping of semiconductor lasers can be realized by the beam of another laser, or by an electron beam, but the most convenient way is by using electrical UNIT – II TYPES OF LASERS

current that flows through the semiconductor junctions. This uses the semiconductor laser in the form of diode.

The early semiconductor lasers are Homojunction Lasers, which can operate cw only at cryogenic temperatures (like T=77K). Homojunction means the laser devices use the same material for both the p and n sides of the junction. The homojunction lasers were replaced by double-heterostructure (DH) lasers which can operate at room temperatures. The active medium of DH laser is sandwiched between p and n materials, the p and n materials differ from the active material.

The dimension of semiconductor laser is very small, a typical value is 100 mm \* 200 mm \* 50 mm. The power conversion efficiency is a few percent for the low power units and can reach 30% for laser arrays. The output power increases with the volume of the active layers, linear or stacked diode laser arrays can generate up to 20W cw and peak power up to 100W in quasi-CW operation. A problem with the semiconductor laser is its relatively large divergence angle (typical value 1~30 degrees), but its defects are being improved quickly. Lower power diode laser systems, of a few mW, are used in CD players, optical storage systems, laser printers and communications. Diode lasers with Power 0.5W/diode are available, when they are packed into arrays, they can generate power of several kW. As we mentioned before, semiconductor lasers are developing quickly, the cost will be greatly reduced when they can be mass produced. A very important application of diode lasers is for pumping other high energy laser systems such as Nd: YAG lasers.

#### **APPLICATION OF LASER**

Lasers are sources of light with very special properties, as discussed in the article on laser light. For that reason, there is a great variety of laser applications. The following sections give a brief overview.

#### Manufacturing

Lasers are widely used in manufacturing, e.g. for cutting, drilling, welding, cladding, treatment, marking, hardening, ablating, surface engraving. soldering. micromachining, pulsed laser deposition, lithography, alignment, etc. In most cases, relatively high optical intensities are applied to a small spot, leading to intense heating, plasma generation. Essential aspects possibly evapouration and are the high spatial coherence of laser light, allowing for strong focusing, and often also the potential for generating intense pulses.

Laser processing methods have many advantages, compared with mechanical approaches. They allow the fabrication of very fine structures with high quality, avoiding mechanical stress such as caused by mechanical drills and blades. A laser beam with high beam quality can be used to drill very fine and deep holes, e.g. for injection nozzles. A high processing speed is often achieved, e.g. in the fabrication of filter sieves. Further, the lifetime limitation of mechanical tools is removed. It can also be advantageous to process materials without touching them.

#### **Medical Applications**

There is a wide range of medical applications. Often these relate to the outer parts of the human body, which are easily reached with light; examples are eye surgery and vision

correction (LASIK), dentistry, dermatology (e.g. photodynamic therapy of cancer), and various kinds of cosmetic treatment such as tattoo removal and hair removal.

Lasers are also used for surgery (e.g. of the prostate), exploiting the possibility to cut tissues while causing minimal bleeding.

Very different types of lasers are required for medical applications, depending on the optical wavelength, output power, pulse format, etc. In many cases, the laser wavelength is chosen such that certain substances (e.g. pigments in tattoos or caries in teeth) absorb light more strongly than surrounding tissue, so that they can be more precisely targeted.

Medical lasers are not always used for therapy. Some of them rather assist the diagnosis, e.g. via methods of ocular imaging, laser microscopy or spectroscopy (see below).

#### Metrology

Lasers are widely used in optical metrology, e.g. for extremely precise position measurements and optical surface profiling with interferometers, for long-distance range finding and navigation.

Laser scanners are based on collimated laser beams, which can read e.g. bar codes or other graphics over some distance. It is also possible to scan three-dimensional objects, e.g. in the context of crime scene investigation (CSI).

Optical sampling is a technique applied for the characterization of fast electronic microcircuits, microwave photonics, terahertz science, etc.

Lasers also allow for extremely precise time measurements and are therefore essential component of optical clocks which are beginning to outperform the currently used cesium atomic clocks.

Fiber-optic sensors, often probed with laser light, allow for the distributed measurement of temperature, stress, and other quantities e.g. in oil pipelines and wings of airplanes.

#### **Data Storage**

Optical data storage e.g. in compact disks (CDs), DVDs, Blu-ray Discs and magnetooptical disks, nearly always relies on a laser source, which has a high spatial coherence and can thus be used to address very tiny spots in the recording medium, allowing a very high density data storage. Another case is holography, where the temporal coherence can also be important.

#### Communications

Optical fiber communication, extensively used particularly for long-distance optical data transmission, mostly relies on laser light in optical glass fibers. Free-space optical communications, e.g. for inter-satellite communications, is based on higher-power lasers, generating collimated laser beams which propagate over large distances with small beam divergence.

#### Displays

Laser projection displays containing RGB sources can be used for cinemas, home videos, flight simulators, etc., and are often superior to other displays concerning possible screen dimensions, resolution and colour saturation. However, further reductions in manufacturing costs will be essential for deep market penetration.

#### Spectroscopy

Laser spectroscopy is used in many different forms and in a wide range of applications. For example, atmospheric physics and pollution monitoring profits from trace gas sensing with differential absorption LIDAR technology. Solid materials can be analyzed with laser-induced breakdown spectroscopy. Laser spectroscopy also plays a role in medicine (e.g. cancer detection), biology, and various types of fundamental research, partly related to metrology (see above).

#### Microscopy

Laser microscopes and setups for optical coherence tomography (OCT) provide images of, e.g., biological samples with very high resolution, often in three dimensions. It is also possible to realize functional imaging.

#### **Various Scientific Applications**

Laser cooling makes it possible to bring clouds of atoms or ions to extremely low temperatures. This has applications in fundamental research and also for industrial purposes.

Particularly in biological and medical research, optical tweezers can be used for trapping and manipulating small particles, such as bacteria or parts of living cells.

Laser guide stars are used in astronomical observatories in combination with adaptive optics for atmospheric correction. They allow substantially increased image resolution even in cases where a sufficiently close-by natural guide star is not available.

#### **Energy Technology**

In the future, high-power laser systems might play a role in electricity generation. Laser-induced nuclear fusion is investigated as an alternative to other types of fusion reactors. High-power lasers can also be used for isotope separation.

## **Military Applications**

There are a variety of military laser applications. In relatively few cases, lasers are used as weapons; the "laser sword" has become popular in movies, but not in practice. Some high-power lasers are currently developed for potential use as directed energy weapons on the battle field, or for destroying missiles, projectiles and mines.

In other cases, lasers function as target designators or laser sights (essentially laser pointers emitting visible or invisible laser beams), or as irritating or blinding (normally not directly destroying) countermeasures e.g. against heat-seeking anti-aircraft missiles. It is also possible to blind soldiers temporarily or permanently with laser beams, although the latter is forbidden by rules of war.

There are also many laser applications which are not specific for military use, e.g. in areas such as range finding, LIDAR, and optical communications.

#### **DYE LASERS**

A dye laser is a laser which uses an organic dye as the lasing medium, usually as a liquid solution. Compared to gases and most solid state lasing media, a dye can usually be used for a much wider range of wavelengths. The wide bandwidth makes them particularly suitable for tunable lasers and pulsed lasers. Moreover, the dye can be replaced by another type in order to generate different wavelengths with the same laser, although this usually requires replacing other optical components in the laser as well.

#### UNIT – II TYPES OF LASERS

Dye lasers were independently discovered by P. P. Sorokin and F. P. Schäfer (and colleagues) in 1966. In addition to the usual liquid state, dye lasers are also available as solid state dye lasers (SSDL). SSDL use dye-doped organic matrices as gain medium.

#### Construction

A dye laser consists of an organic dye mixed with a solvent, which may be circulated through a dye cell, or streamed through open air using a dye jet. A high energy source of light is needed to "pump" the liquid beyond its lasing threshold. A fast discharge flash lamp or an external laser is usually used for this purpose. Mirrors are also needed to oscillate the light produced by the dye's fluorescence, which is amplified with each pass through the liquid. The output mirror is normally around 80% reflective, while all other mirrors are usually more than 99% reflective. The dye solution is usually circulated at high speeds, to help avoid triplet absorption and to decrease degradation of the dye. A prism or diffraction grating is usually mounted in the beam path, to allow tuning of the beam.

Because the liquid medium of a dye laser can fit any shape, there are a multitude of different configurations that can be used. A Fabry–Pérot laser cavity is usually used for flash lamp pumped lasers, which consists of two mirrors, which may be flat or curved, mounted parallel to each other with the laser medium in between. The dye cell is usually side-pumped, with one or more flash lamps running parallel to the dye cell in a reflector cavity. The reflector cavity is often water cooled, to prevent thermal shock in the dye caused by the large amounts of near-infrared radiation which the flash lamp produces. Axial pumped lasers have a hollow, annular-shaped flash lamp that surrounds the dye cell, which has lower inductance for a shorter flash, and improved transfer efficiency. Coaxial pumped lasers have an annular dye cell that surrounds the flash lamp, for even better transfer efficiency, but have a lower gain due to diffraction losses. Flash pumped lasers can only be used for pulsed output.

![](_page_24_Figure_7.jpeg)

A ring dye laser. P-pump laser beam; G-gain dye jet; A-saturable absorber dye jet; M0, M1, M2-planar mirrors; OC–output coupler; CM1 to CM4-curved mirrors.

A ring laser design is often chosen for continuous operation, although a Fabry–Pérot design is sometimes used. In a ring laser, the mirrors of the laser are positioned to allow the beam to travel in a circular path. The dye cell, or cuvette, is usually very small. Sometimes a dye jet is used to help avoid reflection losses. The dye is usually pumped with an external laser, such as a nitrogen, excimer, or frequency doubled Nd: YAG laser. The liquid is circulated at very high speeds, to prevent triplet absorption from cutting off the beam. Unlike Fabry–Pérot cavities, a ring laser does not generate standing waves which cause spatial hole burning, a phenomenon where energy becomes trapped in unused portions of the medium between the crests of the wave. This leads to a better gain from the lasing medium.

#### Operation

The dyes used in these lasers contain rather large organic molecules which fluoresce. The incoming light excites the dye molecules into the state of being ready to emit stimulated radiation, the singlet state. In this state, the molecules emit light via fluorescence, and the dye is transparent to the lasing wavelength. Within a microsecond, or less, the molecules will change to their triplet state. In the triplet state, light is emitted via phosphorescence, and the molecules absorb the lasing wavelength, making the dye opaque. Liquid dyes also have an extremely high lasing threshold. Flash lamp pumped lasers need a flash with an extremely short duration, to deliver the large amounts of energy necessary to bring the dye past threshold before triplet absorption overcomes singlet emission. Dye lasers with an external pump laser can direct enough energy of the proper wavelength into the dye with a relatively small amount of input energy, but the dye must be circulated at high speeds to keep the triplet molecules out of the beam path.

Since organic dyes tend to decompose under the influence of light, the dye solution is normally circulated from a large reservoir. The dye solution can be flowing through a cuvette, i.e., a glass container, or be as a dye jet, i.e., as a sheet-like stream in open air from a specially-shaped nozzle. With a dye jet, one avoids reflection losses from the glass surfaces and contamination of the walls of the cuvette. These advantages come at the cost of a morecomplicated alignment.

Liquid dyes have very high gain as laser media. The beam only needs to make a few passes through the liquid to reach full design power, and hence, the high transmittance of the output coupler. The high gain also leads to high losses, because reflection from the dye cell walls, or flash lamp reflector, will dramatically reduce the amount of energy available to the beam. Pump cavities are often coated, anodized, or otherwise made of a material that will not reflect at the lasing wavelength while reflecting at the pump wavelength.

#### Narrow line width dye lasers

Dye lasers emission is inherently broad. However, tunable narrow line width emission has been central to the success of the dye laser. In order to produce narrow bandwidth tuning these lasers use many types of cavities and resonators which include gratings, prisms, multiple-prism grating arrangements, and etalons.

The first narrow line width dye laser, introduced by Hänsch, used a Galilean telescope as beam expander to illuminate the diffraction grating. Next were the grazing-incidence grating designs and the multiple-prism grating configurations. The various resonators and oscillator designs developed for dye lasers have been successfully adapted to other laser types such as the diode laser. The physics of narrow-line width multiple-prism grating lasers was explained by Duarte and Piper.

#### **Chemicals used**

Some of the laser dyes

are rhodamine, fluorescein, coumarin, stilbene, umbelliferone, tetracene, malachite green, and others. While some dyes are actually used in food colouring, most dyes are very toxic, and often carcinogenic. Many dyes, such as rhodamine 6G, (in its chloride form), can be very corrosive to all metals except stainless steel.

A wide variety of solvents can be used, although some dyes will dissolve better in some solvents than in others. Some of the solvents used are water, glycol, ethanol, methanol, hexane, cyclohexane, cyclodextrin, and many others. Solvents are often highly toxic, and can sometimes be absorbed directly through the skin, or through inhaled vapours. Many solvents are also extremely flammable.

Adamantane is added to some dyes to prolong their life.

Cycloheptatriene and cyclooctatetraene (COT) can be added as triplet quenchers for rhodamine G, increasing the laser output power. Output power of 1.4 kilowatt at 585 nm was achieved using Rhodamine 6G with COT in methanol-water solution.

## Applications

Dye lasers are very versatile. In addition to their recognized wavelength agility these lasers can offer very large pulsed energies or very high average powers. Flash lamp-pumped dye lasers have been shown to yield hundreds of Joules per pulse and copper-laser-pumped dye lasers are known to yield average powers in the kilowatt regime.

Dye lasers are used in many applications including:

- astronomy (as laser guide stars),
- atomic vapour laser isotope separation
- manufacturing
- medicine
- spectroscopy

In laser medicine these lasers are applied in several areas, including dermatology where they are used to make skin tone more even. The wide range of wavelengths possible allows very close matching to the absorption lines of certain tissues, such as melanin or hemoglobin, while the narrow bandwidth obtainable helps reduce the possibility of damage to the surrounding tissue. They are used to treat port-wine stains and other blood vessel disorders, scars and kidney stones. They can be matched to a variety of inks for tattoo removal, as well as a number of other applications.

In spectroscopy, dye lasers can be used to study the absorption and emission spectra of various materials. Their tunability, (from the near-infrared to the near-ultraviolet), narrow bandwidth, and high intensity allows a much greater diversity than other light sources. The variety of pulse widths, from ultra-short, femto-second pulses to continuous-wave operation, makes them suitable for a wide range of applications, from the study of fluorescent lifetimes and semiconductor properties to lunar laser ranging experiments.

#### **Possible Questions**

- (1) Explain the working of He-Ne laser.
- (2) Explain the principle and working of semiconductor laser.
- (3) Describe about the working of Ruby Laser.
- (4) Explain the principle and working of He-Ne laser.
- (5) Explain the working of Ruby laser.
- (6) Explain the working of Nd:YAG laser.
- (7) Explain the working of chemical laser.
- (8) Explain about the semiconductor lasers and features of semiconductors.
- (9) Explain the principle and working of Nd Glass laser.

Questions	opt1	opt2	opt3	opt4	Answer
UNIT-II					
In which type of lasers, atomic transitions have been used	ruby	He-Ne	dye	CO <sub>2</sub>	He-Ne
In He –Ne laser action, which atoms assists in the pumping process	Ne	Не	Both a & b	none	Не
In medicine, the lasers are used for and cauterizing	cutting	welding	drilling	none	cutting
The carbon dioxide laser is operated in mode	no flow	fast flow	slow axial flow	All the above	all the above
Lasers are found to be very effective in cutting types of material.	different	same	invariant	identical	different
The hologram contains in the form of the pattern	Interference	diffraction	scattering	refraction	Interference
The reference beam of the balancing of the plate would be proportional to -	E <sub>0ê</sub> <sup>3</sup>	$ E_{0\hat{e}}^2$	E <sub>0</sub> I	$E_0^2$	$ E_{0\hat{e}}^2$
The virtual image produced by a hologram appears in complete	4	2	3	6	3
With the help of laser the astronomers have been able to extend range of observation.	CO <sub>2</sub> laser	ruby laser	dye laser	He-Ne laser	ruby laser
Who determine the equation $2d \sin \theta = m\lambda$	Heisenberg	Bragg	Planck	None	Bragg
Who discovered ruby laser?	Theodore Maiman	Brillouin	Raman	None	Theodore Maiman
contains in the form of the interference pattern	maser	laser	hologram	none	hologram
The first working laser was made by Theodore Maiman in	1950	1955	1960	1965	1960
The first laser diode was demonstrated by	Robert N. Hall	Donald Herriot	Ali Javan	William R. Bennett	Robert N. Hall
The first laser diode was demonstrated by Robert N. Hall in	1959	1960	1961	1962	1962
lasers are powered by a chemical reaction involving an excited dimer.	He-Ne	Excimer	Ruby	Dye	Excimer
The efficiency of a CO <sub>2</sub> laser is over	5%	10%	15%	20%	10%
Elastic and inelastic scatterings are referred as	Hyper and Hyper Raman Rayleigh	Raman and stokes	Rayleigh and stokes	Rayleigh and anti stokes	Hyper and Hyper Raman Rayleigh
The ruby laser was first demonstrated in the year of	1967	1987	1950	1960	1960
Nd:YAG is an level laser system.	two	four	three	none	four

Nd:YAG lasers are mostly used in applications.	military	range finding	target destination	All the above	all the above
In Nd Glass lasers, type of glasses are used.	oxide glasses	halide glasses	chalcogenide glasses	All the above	all the above
What is the lifetime of ns state of Ne?	100ns	50ns	150ns	200ns	100ns
What kind of mirrors are used in co2 lasers?	Si coated with Al	Ni coated with Al	Fe coated with Al	none	Si coated with Al
What is the voltage used in co2 laser?	10-30kV	20-30kV	10-20kV	around 50kV	10-30kV
What is the Current used in co2 laser?		30mA	50mA	70mA	100mA
What kind of pumping is used in semiconductor laser? Is the ruby laser is CW or pulsed?	electrical CW	optical pumping pulsed	thermal both	none	electrical pulsed
Solid state masers have noise level than hat of ammonium laser.	higher	stable	lower	unstable	lower
Solid state maser uses as an active element.	chromium	nickel	aluminium	copper	chromium
The image of a 3 dimensional object is recorded on a dimensional photography plate.	1	2	3	both a & b	2
Holography means	complete decoding	partial recording	complete recording	partial decoding	complete recording
Holography works under the principle of	interference	diffraction	dispersion	refraction	interference
Light waves with degree of coherence is required in holography.	medium	low	high	none of these	high
The fine structure of interference fringes required photographic emulsion with a special resolution	high	low	medium	none of these	high
A major drawback of conventional holographic process is requirement of in the image construction.	incoherent illumination	coherent illumination	incoherent emission	coherent emission	coherent illumination
Volume hologram is a grating.	1-D	2-D	3-D	none of these	3-D
Rainbow hologram can be viewed with a source.	white light	red light	green light	both a and b	white light
Volume hologram, the colour light will be at a particular angle by hologram.	reflected	refracted	diffracted	scattered	refracted

Three level maser system has its chief disadvantage that	it can operate only in bursts	it can operate only in low temperature	it can operate only in low pressure	none of these	it can operate only in bursts
is a pulsed laser.	1 level	2 level	3 level	4 level	2 level
The conduction for gases remains absorptive is	n1> n2	n1 <n2< td=""><td>n1=n2</td><td>both a and b</td><td>n1&gt;n2</td></n2<>	n1=n2	both a and b	n1>n2
A continuous maser operation is possible in a	1 level	2 level	3 level	none of these	3 level
The absorption transition will continue as long as the gas remains	absorptive	refractive	reflective	dispersive	absorptive
In three level maser is used.	separation in space	frequency separation	amplitude separation	none of these	frequency separation
The basic element of the early maser was	gaseous ammonia	liquid ammonia	gaseous nitrogen	liquid nitrogen	gaseous ammonia
The ammonia molecule in structure.	linear	tetrahedral	hexagonal	octahedral	tetrahedral
The energy of a symmetric state in ammonia molecule is	1/√2 (ψ1+ψ2)	<sup>1</sup> / <sub>2</sub> (ψ1+ψ2)	½(ψ1-ψ2)	1/√2 (ψ1-ψ2)	1/√2 (ψ1+ψ2)
The antisymmetric state has energy than the symmetric state.	higher	lower	stable	none of the above	higher
The wavelength of radiation in ammonia maser is	1cm	1.25 cm	1.30 cm	1.5 cm	1.25 cm
An example for two level maser system is	fibre maser	He-Ne maser	ammonia maser	CO <sub>2</sub> maser	ammonia maser
Ammonia maser is maser system.	2 level	3 level	4 level	none of these	2 level
For efficient maser action it is imperative that a cavity losses are asas possible.	high	small	medium	none of these	small
The losses depend upon the of the cavity.	intensity	energy stored	energy lost	Q-factor	Q-factor
Ammonia masers have power output.	very low	very high	medium	none of these	very low
Ammonium masers have power output around watt.	10 <sup>-3</sup>	10 <sup>+3</sup>	10 <sup>-9</sup>	10 <sup>+9</sup>	10 <sup>-9</sup>
The splitting of state increases with field.	increasing	decreasing	stable	none of these	increasing

The coherence of maser radiation produces a line width	broad	narrow	medium	none of these	narrow
What is the lifetime of electron hole pair in a semiconductor laser?	1-5ns	1-10ns	1-3ns	none	1-10ns
What is the active material in dye lasers?	methanol	glycerol	both a and b	none	both a and b
What is the concentration of dye molecules?	1 part in 1000	1 part in 100	1 part in 10000	none	1 part in 10000
The lifetime of lower vibrational level of S1 is about	1ns	3ns	4ns	7ns	1ns
The lifetime of higher vibrational level of S1 is about	10(-10)s	10(-12)s	10(-19)s	10(-15)s	10(-12)s

## **APPLICATIONS OF LASER**

#### Spectroscopy

Most types of laser are an inherently pure source of light; they emit nearmonochromatic light with a very well defined range of wavelengths. By careful design of the laser components, the purity of the laser light can be improved more than the purity of any other light source. This makes the laser a very useful source for spectroscopy.

The high intensity of light that can be achieved in a small, well collimated beam can also be used to induce a nonlinear optical effect in a sample, which makes techniques such as Raman spectroscopy possible.

#### **Heat Treatment**

Heat treating with lasers allows selective surface hardening against wear with little or no distortion of the component. Because this eliminates much part reworking that is currently done, the laser system's capital cost is recovered in a short time.

Typically, irradiances between 500-5000  $W/cm^2$  satisfy the thermodynamic constraints and allow the rapid surface heating and minimal total heat input required.

#### Lunar laser ranging

When the Apollo astronauts visited the moon, they planted retroreflector arrays to make possible the Lunar Laser Ranging Experiment. The time taken for the beam to be reflected back to Earth measured to determine the distance between the Earth and Moon with high accuracy.

#### Photochemistry

Extremely brief pulses of light - as short as picoseconds or femtoseconds  $(10^{-12} - 10^{-15} \text{ seconds})$ . The pulses can be used to initiate and analyze chemical reactions, a technique known as photochemistry. The short pulses can be used to probe the process of the reaction at a very high temporal resolution, This method is particularly useful in biochemistry, where it is used to analyse details of protein folding and function.

#### Laser scanner

Laser barcode scanners are ideal for applications that require high speed reading of linear codes or stacked symbols.

#### Laser cooling

A technique that has recent success is laser cooling. where a number of atoms are confined in a specially shaped arrangement of electric and magnetic fields.

#### **Nuclear fusion**

The most powerful and complex arrangements of multiple lasers and optical amplifiers are used to produce extremely high intensity pulses of light of extremely short duration,

These pulses are arranged such that they impact pellets of tritium– deuterium simultaneously from all directions, the squeezing effect of the impacts will induce atomic fusion in the pellets.

## Microscopy

Confocal laser scanning microscopy and Two-photon excitation microscopy make use of lasers to obtain blur-free images of thick specimens at various depths. Laser capture micro size to procure specific cell populations from a tissue section under microscopic visualization.

#### Military

Military uses of lasers include applications such as target designation and ranging, defensive countermeasures, communications and directed energy weapons.

#### Medical

- Cosmetic surgery (removing tattoos, scars, stretch marks, sunspots, wrinkles, birthmarks, and hairs): see laser hair removal.
- Laser types used in dermatology include ruby(694 nm), alexandrite (755 nm), pulsed diode array (810 nm), Nd:YAG (1064 nm), Ho:YAG (2090 nm), and Er:YAG (2940 nm).
- Eye surgery and refractive surgery
- Soft tissue surgery: CO<sub>2</sub>, Er:YAG laser
- Laser scalpel (General surgery, gynecological, urology, laparoscopic)
- To removal of tumors, especially of the brain and spinal cord.

## **APPLICATION OF LASER IN INDUSTRY**

#### Laser cutting

It is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated. A typical commercial laser for cutting materials involved a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas,<sup>[1]</sup> leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

#### Laser beam welding (LBW)

It is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications using automation, such as in the automotive industry. It is based on keyhole or penetration mode welding.

#### Laser drilling

It is the process of creating thru-holes, referred to as "popped" holes or "percussion drilled" holes, by repeatedly pulsing focused laser energy on a material. The diameter of

these holes can be as small as 0.002 inches. If larger holes are required, the laser is moved around the circumference of the "popped" hole until the desired diameter is created; this technique is called "trepanning".

## Laser marking

It is used to engrave an object. it is also used to leave marks on an object, which also includes colour change due to chemical/molecular alteration, charring, foaming, melting, ablation, and more. It involve tool bits which contact the engraving surface and wear out,

## Laser hardening

It is a surface hardening process. It is used exclusively on ferrous materials suitable for hardening including, steels and cast iron with a carbon content of more than 0.2 percent.

To harden the work piece, the laser beam usually warms the outer layer to just under the melting temperature (about 900 to 1400 degrees Celsius). Once the desired temperature is reached, the laser beam starts moving. As the laser beam moves, it continuously warms the surface in the processing direction. The high temperature causes the iron atoms to change their position within the metal lattice. As soon as the laser beam moves away, the hot layer is cooled very rapidly by the surrounding material. Rapid cooling prevents the metal lattice from returning to its original structure,

# MEDICAL APPLICATIONS - LASER AS DIAGNOSTIC AND THERAPEUTIC TOOL

## **Therapeutic Tool**

This includes the use of lasers as surgical tools for tissue cutting, welding, and coagulation, as well as the use of optics to initiate cell-damaging photochemical reactions for the treatment of diseases such as cancer.

In addition, optics, spectroscopy, and imaging provide unique tools that may allow real-time diagnostics of the efficacy of clinical procedures.

## HOLOGRAM

A hologram is a physical structure that diffracts light into an image. The term 'hologram' can refer to both the encoded material and the resulting image.

A holographic image can be seen by looking into an illuminated holographic print or by shining a laser through a hologram and projecting the image onto a screen.

## Recording of hologram.

The recording of hologram is based on the phenomenon of interference. It requires a laser source, a plane mirror or beam splitter, an object and a photographic plate. A laser beam from the laser source is incident on a plane mirror or beam splitter. As the name suggests, the function of the beam splitter is to split the laser beam. One part of splitted beam, after reflection from the beam splitter, strikes on the photographic plate. This beam is called **reference beam.** While other part of splitted beam (transmitted from beam splitter) strikes on the photographic plate after suffering reflection from the various points of object. This beam is called object beam.

The object beam reflected from the object interferes with the reference beam when both the beams reach the photographic plate. The superposition of these two beams produces an interference pattern (in the form of dark and bright fringes) and this pattern is recorded on the photographic plate. The photographic plate with recorded interference pattern is called hologram. Photographic plate is also known as Gabor zone plate in honour of Denis Gabor who developed the phenomenon of holography.

Each and every part of the hologram receives light from various points of the object. Thus, even if hologram is broken into parts, each part is capable of reconstructing the whole object.

![](_page_35_Figure_4.jpeg)

Figure: Recording process in holography

#### **Reconstruction of image.**

In the reconstruction process, the hologram is illuminated by laser beam and this beam is called reconstruction beam. This beam is identical to reference beam used in construction of hologram.

The hologram acts a diffraction grating. This reconstruction beam will undergo phenomenon of diffraction during passage through the hologram. The reconstruction beam after passing through the hologram produces a real as well as virtual image of the object.

![](_page_35_Figure_9.jpeg)

![](_page_35_Figure_10.jpeg)

Karpagam Acadamy of Higher Education
One of the diffracted beams emerging from the hologram appears to diverge from an apparent object when project back. Thus, virtual image is formed behind the hologram at the original site of the object and real image in front of the hologram. Thus an observer sees light waves diverging from the virtual image and the image is identical to the object. If the observer moves round the virtual image then other sides of the object which were not noticed earlier would be observed. Therefore, the virtual image exhibits all the true three dimensional characteristics. The real image can be recorded on a photographic plate.

### **APPLICATION OF HOLOGRAPHY**

### **Holographic Interferometry**

It is used in numerous laboratories for non-destructive testing. It visually reveals structural faults without damaging the specimen. It is also used to quantitatively determine 3D deformation fields in deformed solid objects. We use this method in our laboratory for research (holography in research ) and for teaching (EMA 611 Advanced mechanical testing of materials). holography links .

### **Bubble Chamber Holography**

It has been performed at the Enrico Fermi National Laboratory. Three-dimensional tracks in a 15-foot deep bubble chamber were recorded. The creation and annihilation of matter and antimatter can be seen through these holograms.

#### **Holographic Optical Elements (HOE)**

It is used to perform the same functions as lenses, mirrors, gratings, diffusers, etc. They can also combine several functions together not possible with conventional optical elements.

#### **Biomedical Applications Of Holography**

It is actively pursued in the U.S. and Europe. Holograms are made inside live organs through optical fibers, providing more details than any previous alternate techniques.

#### **Holographic Scanners**

It used in store check-out counters for reading the bar codes. A rotating computergenerated hologram is responsible for both the scanning and the detecting of the scattered light.

HOLOSTORE is a holographic computer memory system being manufactured to replace your disc drive. It will have thousands time more memory capacity and no mechanical movements.

### **APPLICATIONS OF HOLOGRAPHY**

#### Art

Early on, artists saw the potential of holography as a medium and gained access to science laboratories to create their work. Holographic art is often the result of collaborations between scientists and artists, although some holographers would regard themselves as both an artist and a scientist.

A small but active group of artists still use holography as their main medium, and many more artists integrate holographic elements into their work. Some are associated with novel holographic techniques; for example, artist Matt Brand employed computational mirror design to eliminate image distortion from specular holography.

#### Data storage

Holography can be put to a variety of uses other than recording images. Holographic data storage is a technique that can store information at high density inside crystals or photopolymers. The ability to store large amounts of information in some kind of media is of great importance, as many electronic products incorporate storage devices. As current storage techniques such as Blu-ray Disc reach the limit of possible data density (due to the diffraction-limited size of the writing beams), holographic storage has the potential to become the next generation of popular storage media. The advantage of this type of data storage is that the volume of the recording media is used instead of just the surface. Currently available SLMs can produce about 1000 different images a second at  $1024 \times 1024$ -bit resolution.

#### **Dynamic holography**

In static holography, recording, developing and reconstructing occur sequentially, and a permanent hologram is produced. There also exist holographic materials that do not need the developing process and can record a hologram in a very short time. This allows one to use holography to perform some simple operations in an all-optical way. Examples of applications of such real-time holograms include phase-conjugate mirrors ("time-reversal" of light), optical cache memories, image processing (pattern recognition of time-varying images), and optical computing.

#### Holographic interferometry

Holographic interferometry (HI) is a technique that enables static and dynamic displacements of objects with optically rough surfaces to be measured to optical interferometric precision (i.e. to fractions of a wavelength of light). It can also be used to detect optical-path-length variations in transparent media, which enables, for example, fluid flow to be visualized and analyzed. It can also be used to generate contours representing the form of the surface. It has been widely used to measure stress, strain, and vibration in engineering structures.

#### Sensors or biosensors

The hologram is made with a modified material that interacts with certain molecules generating a change in the fringe periodicity or refractive index, therefore, the colour of the holographic reflection.

#### Security

Security holograms are very difficult to forge, because they are replicated from a master hologram that requires expensive, specialized and technologically advanced equipment. They are used widely in many currencies.

#### **Other applications**

Holographic scanners are in use in post offices, larger shipping firms, and automated conveyor systems to determine the three-dimensional size of a package. Holograms produced stress-strain reporters due to its elasticity and compressibility, the pressure and force applied are correlated to the reflected wavelength .

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#### **Possible Questions**

- (1) Give the applications of laser in medical field.
- (2) Explain Reconstruction of Holography.
- (3) Explain Q-switching.
- (4) Discuss the absorption of X-rays and give the properties of X-rays?
- (5) Explain Q-Switching.
- (6) Write a note on mode locking.
- (7) Describe different types of X-ray spectra. How are they explained?
- (8) Derive Bragg's law for X-ray diffraction in crystals and how it is verified?
- (9) Explain in details the production of continuous and characteristic of X-rays.
- (10) Explain in brief about the electron spin resonance spectroscopy.

Questions	opt1	opt2	opt3	opt4	Answer
	Light Amplification	Light Amplification	Light Attenuation by	Light Attenuation by	Light Amplification
The word Laser is an abbrevation for	by Stimulated	by Spontaneous	Stimulated Emission	Spontaneous	by Stimulated
The word Easer is an aborevation for	Emission of	Emission of	of Radiation	Emission of	Emission of
	Radiation	Radiation	of Radiation	Radiation	Radiation
The first laser was built in	1972	1960	1988	1994	1960
Ground state of the atom is the minimum energy state and it is the most state.	unstable	discrete	stable	none	stable
Life time of electron in the excited state is very small, of the order of	$10^{-8}$ sec	$10^{-7}$ sec	$10^{-5}$ sec	$10^{-3}$ sec	$10^{-8}$ sec
The characteristics of laser beam is	Monochromatic	Coherent	Intense	All the above	All the above
The photons of energy $h\gamma$ incident to the atoms in the ground state and are taken to the	Stimulated	Spontaneous	Stimulated	Spontaneous	Stimulated
excited state is called	emission	emission	absorption	absorption	absorption
The number of atoms in the excited state becomes greater than the number of atom in the	normal nonulation	ontical numning	numning	population	population
ground state is called as	normai population	optical pumping	pumping	inversion	inversion
The life time of atom in the excited state is normally	10 <sup>-6</sup> sec	10 <sup>-12</sup> sec	10 <sup>-8</sup> sec	10 <sup>-3</sup> sec	10 <sup>-8</sup> sec
The life time of atom in the metastable state is normally	$10^{-6}$ sec	$10^{-12}$ sec	$10^{-8} \sec$	$10^{-3}$ sec	$10^{-3}$ sec
The excited energy levels have greater life times for atoms $10^{-3}$ sec. Such energy levels are called as	metastable state	excited state	stable state	none	metastable state
Under the condition of equilibrium, the no. of atoms absorbing radiation per unit time is to the no. of atoms emitting radiation per unit time	greater	smaller	equal	none	equal
In optical region, $\lambda =$	1000 A <sup>o</sup>	3000 A <sup>o</sup>	6000 A <sup>o</sup>	5000 A <sup>o</sup>	5000 A <sup>o</sup>
In micro wave region, $\lambda =$	5 cm	15 cm	25 cm	none	none
The pumping rate is represented by	Ω	$\Omega^{-1}$	ω	ω <sup>-1</sup>	Ω
The probability per unit time, where the atoms are excited to the upper level is called rate	Normal pumping	Abnormal pumping	Pumping	None	Pumping
The line shape function represents the behaviour of ko	Amplitude	Frequency	Wavelength	None	Frequency
Line broadening mechanisms can be classified as	Homogeneous&	Homogeneous &	Heterogeneous &	None	Homogeneous &
Which of the following is an example of non-homogeneous broadening?	Natural	Collision	Doppler	None	Doppler
Schawlow & Towned suggestednlane parallel reflecting surfaces as a	1 vaturar	Comsion	Боррісі	None	Doppier
suitable resonator	1	2	3	4	2
For non degenerate state	$g_n = g_m$	$g_n/g_m$	g <sub>n</sub> -g <sub>m</sub>	$g_n + g_m$	$g_n = g_m$
In transition between two energy states, the atom absorbs or emits a photon of energy is	hν	hv/2	2hv	none	hv
The process by which the atoms in the ground state is taken to the excited state is known as	optical pumping	pumping	induced absorption	induced emission	pumping
The atoms are taken to the higher energy level with the help of light is called	optical pumping	pumping	induced absorption	induced emission	optical pumping
The atoms are taken to the higher energy level with the help of	electrons	chemical reaction	induced absorption	light	light
Population inversion means, the no. of atoms in the excited state is the no. of		1 +1			
atoms in the ground state	same	less than	greater than	none	greater than
The excited atoms return to the lower state without help of any external agency is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission	spontaneous absorption
The excited atoms return to the lower state with help of photon is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission	stimulated emission
The photons produced by stimulated emission is called	Primary photon	secondary photon	spontaneous photon	none	secondary photon

The secondary photon is always with the stimulating photons	out of phase	coherent	in phase	none	in phase
By laser action all the emitted photons are with each other	out of phase	coherent	in phase	none	in phase
In the microwave region wavelength=	.5 cm	15 cm	20 cm	10 cm	10 cm
In microwave region, the stimulated emission rate is the spontaneous rate	equal to	higher than	smaller than	none	higher than
The spontaneous emission is more predominant in the region	optical	IR	UV	microwave	optical
Excited atoms undergo transition to the lower level byemission	spontaneous	stimulated	both a and b	none	both a and b
The population difference between the two levels in a steady stateon the decay time of the upper level	depends	independent	same	none	depends
The probability per unit time, where the atoms are excited to the upper level is called	normal pumping	abnormal pumping	pumping	none	pumping
The pumping power is always upon decay time	same	independence	depends	none	depends
The cavity which does not contain any active medium is calledresonator	active	passive	band pass	low pass	passive
The cavity which contain active medium is calledresonator	active	passive	band pass	low pass	active
The atoms having same central frequency and the same atomic line shape is known as	homogeneous	heterogeneous	non- homogeneous	none	homogeneous
In normal population the no. of atoms in the ground state is than the no. of atoms in the excited state.	less than	greater than	both a & b	none	greater than
In thermal equilibrium the no. of atoms in the ground state is greater than the no. of atoms in the excited state is called	normal population	population inversion	abnormal population	none of these	normal population
In optical region, hw/KT is approximately equal to	10	1000	1500	100	100
In microwave region, hw/KT is approximately equal to	$5 \times 10^{-2}$	5x10 <sup>-6</sup>	5x10 <sup>-3</sup>	none	none
In threshold condition a is calledgain coefficient	saturated	unsaturated	normal	none	unsaturated
The particular shape of the function g (w) on the phenomenon responsible for the line broadening	same	independence	depends	none	depends
Line broadening mechanism can be classified as	homogeneous & heterogeneous	homogeneous & non homogeneous	heterogeneous & non homogeneous	none	homogeneous & non homogeneous
Laser emits light in direction.	various	1	2	none	1
Laser radiations have degree of coherence.	low	high	medium	very low	high
Time incoherence is a characteristics of a beam of light	single	multiple	Both a and b	None of the above	single
Another name of temporal coherence is coherence	transverse	spatial	longitudinal	none of these	longitudinal
is a best example of an optically pumped rare earth laser system	calcium ion	erbium ion	uranium ion	neodymium ion	neodymium ion
The fluorescent quantum efficiency was found to be near	zero	less than unity	unity	greater than unity	unity
The point at which the strength of the beam has dropped to 1/e times its value at the centre is called	inner edge	half edge	full edge	outer edge	outer edge
Rayleigh range begins to spread linearly with distance because of effect	interference	dispersion	diffraction	refraction	diffraction
Who determine the equation $2d \sin \theta = m\lambda$	Heisenberg	Bragg	Planck	None	Bragg

### **BASIC ELEMENTS OF SPECTROSCOPY**

Spectroscopy pertains to the dispersion of an object's light into its component colors (i.e. energies). By performing this dissection and analysis of an object's light, astronomers can infer the physical properties of that object (such as temperature, mass, luminosity and composition).

#### **REPRESENTATION OF SPECTRUM**

#### The Electromagnetic Spectrum

Physicists classify light waves by their energies (wavelengths). Labeled in increasing energy, we might draw the entire *electromagnetic* spectrum as shown in the figure below:



The Electromagnetic Spectrum. Shows how small the visible region of the spectrum is, compared to the entire range of wavelengths. the atoms absorb or emit electromagnetic radiation only in certain bundles termed quanta. The photoelectric effect, German-born American physicist Albert Einstein used the term photon to describe these electromagnetic quanta. Planck determined that energy of light was proportional to its frequency (i.e., as the frequency of light increases, so does the energy of the light). Planck's constant,  $h = 6.626 \times 10^{-34}$  joule-second in the meter-kilogram-second system ( $4.136 \times 10^{-15}$  eV-sec), relates the energy of a photon to the frequency of the electromagnetic wave and allows a precise calculation of the energy of electromagnetic radiation in all portions of the electromagnetic spectrum.

### BASIC ELEMENTS OF PRACTICAL SPECTROSCOPY

#### Wavelength

The length of one wave is called wavelength. The wavelength of radiation is given in units such as inches or centimeters, but for very small wavelengths, they are often given in angstroms (abbreviated Å). There are 10,000,000,000 angstroms in 3.3 ft (1 m).

# Frequency

An alternative way of describing a wave is by its frequency, or the number of peaks which pass in one second. Frequencies are normally given in cycles per second, or hertz (abbreviation Hz), after Hertz. Other common units are kilohertz (kHz, or thousands of cycles per second), megahertz (MHz, millions of cycles per second), and gigahertz (GHz, billions of cycles per second).

The frequency and wavelength, when multiplied together, give the speed of the wave. For electromagnetic waves in empty <u>space</u>, that speed is the speed of light, which is approximately 186,000 miles per second (300,000 km per sec).

In addition to the wave-like properties of electromagnetic radiation, it also can behave as a particle. The energy of a particle of light, or photon, can be calculated from its frequency by multiplying by Planck's constant. Thus, higher frequencies (and lower wavelengths) have higher energy. A common unit used to describe the energy of a photon is the electron volt (eV). Multiples of this unit, such as keV (1000 electron volts) and MeV (1,000,000 eV), are also used.

### SIGNAL TO NOISE RATIO

The ability of the spectrometer to make accurate measurements depends on the quality of the signal obtained from the detector and the subsequent electrical circuits. The signal-tonoise ratio (SNR) provides a measure of the signal quality. The SNR compares the average power available in the signal to the average power contained in the noise, which includes any signal from sources other than the target signal source. In a spectrometer, the desired signal consists of the optical power at a given wavelength directed by the diffraction grating (and by the DMD, in a DLP-based system) to the detector. The noise signal arises from a number of sources, both electrical and optical. The SNR is calculated according to:

$$SNR = {2 \atop sig} / {2 \atop n} = (R _{opt})^2 / {2 \atop n1} + {2 \atop n2} + {2 \atop n3} + \dots + {2 \atop nN}$$

where is the average optical power in the desired signal, and refers to the variance of the i<sup>th</sup> source of noise current, in  $A^2$ , which describes the average power in a random signal based on Fourier Transform theory. To better understand the SNR equation, consider the two conditions in Figure SNR.1 below. The signal current (numerator of SNR) and the noise current (denominator of SNR) are about equal – i.e., the SNR 1. One can see that in this condition, the spectrometer cannot separate the signal containing information about the sample from the noise signal, and thus the measurement provides no useful data.

# **RESOLVING POWER**

Resolving power, R, is a measure of the ability of a spectrometer to separate two close wavelengths and is defined by

$$R = \frac{\lambda}{\Delta \lambda}$$

where is the average of the two wavelengths and  $\triangle$  is the difference between the two wavelengths. The higher *R* the better the resolving power. The resolving power is the inverse of chromatic resolution.

### INTENSITY OF SPECTRAL TRANSITIONS

The intensity of a spectral line at a given frequency is related to the net rate of absorption (or emission) at that frequency.

Thus no lines are observed at frequencies that do not correspond to a transition between two energy states – since no absorption can occur at these frequencies, the intensity of a spectral line at this frequency is zero, i.e. no line is observed.

Three different contributors to the transitions between states were identified by Einstein:Stimulated absorption occurs when a transition from a lower energy state to a higher energy one is caused by oscillation of the electromagnetic field at the transition frequency (i.e. when there is a component of the incident radiation at the transition frequency, and absorption of a photon of equal energy to the transition takes place causing excitation to the higher energy state).

The more intense the incident radiation, the greater the rate at which transitions are induced to the higher state and thus the stronger the absorbance of the sample.

### MICROWAVE SPECTROSCOPY

The study of the interaction of matter and electromagnetic radiation in the microwave region of the spectrum.

The interaction of microwaves with matter can be detected by observing the attenuatio n or phase shift of a microwave fieldas it passes through matter. These are determined by the imaginary or real parts of the microwave susceptibility (the index ofrefraction). The absorptio n of microwaves may also trigger a much more easily observed event like the emission of an opticalphoton in an optical doubleresonance experiment or the deflection of a radioactive ato m in an atomic beam.

At room temperature, the relative population difference between the states involved in a microwave transition is a few percentor less. The population difference can be close to 100 % at liquid helium temperatures, and microwave spectroscopicexperiments are often perform ed at low temperatures to enhance population differences and to eliminate certain linebroadening mechanisms. The population differences between the states involved in a microw ave transition can also beenhanced by artificial means. When the molecules or atoms with inv erted populations are placed in an appropriatemicrowave cavity, the cavity will oscillate spon taneously as a maser (microwave amplification by stimulated emission ofradiation).

The magnetic dipole and electric quadrupole interactions between the nuclei and elect rons in atoms and molecules can leadto energy splittings in the microwave region of the spect rum. Thus, microwave spectroscopy has been used extensively forprecision determinations of spins and moments of nuclei.

The rotational frequencies of molecules often fall within the microwave range, and mi crowave spectroscopy has contributed agreat deal of information about the moments of inerti a, the spin rotation coupling mechanisms, and other physical properties frotating molecules.

The magnetic resonance frequencies of electrons in fields of a few thousand gauss (a few tent hs of a tesla) lie in themicrowave region. Thus, microwave spectroscopy is used in the study of electron-spin resonance or paramagnetic resonance.

The cyclotron resonance frequencies of electrons in solids at magnetic fields of a few thousand gauss (a few tenths of atesla) lie within the microwave region of the spectrum.

Microwave spectroscopy has been used to map out the dependence of the effective ma ss on the electron momentum.

# **CLASSIFICATION OF MOLECULES**

If analysis of a molecule yielded a list of all present symmetry elements, then a list is the basis to form classes of molecules with common symmetry. Such a class is called a symmetry point group. Any molecule is unambiguously a member of one single point group. Though the point groups relevant in chemistry are numerous, we are able to work straightforward within this field as these groups are characterized by sets of increasingly complicated symmetry operations.

#### List of point groups

- 1. The groups  $C_1$ ,  $C_i$  and  $C_s$ . If a molecule (or any object) possesses no symmetry element other than the identity, it belongs to  $C_i$ . Only a rotation about 360° produces an identical image of the molecule. As this operation establishes the initial orientation, any body, asymmetric as it may be, meets this criterion. If a molecules possesses the identity and the inversion as the only elements, it belongs to the group  $C_i$ . If it possesses a plane of symmetry as the only element apart from the identity, it is classified as belonging to the group  $C_s$ .
- 2. The groups  $C_n$ . If a molecule possesses the identity element and an *n*-fold axis of symmetry, it belongs to the group  $C_n$ . (Note that  $C_n$  is now playing a triple role: it is a label for one of the symmetry elements present and denotes the corresponding operation as well as the name of the group.)
- 3. The groups  $C_{nv}$ . Objects in these groups possess a  $C_n$  axis and *n* vertical reflection planes v.
- 4. The groups  $C_{nh}$ . Objects possessing a  $C_n$ -axis and a perpendicular horizontal mirror plane belong to the group  $C_{nh}$ . Note that this is an example for a group where automatically other symmetry operations can be applied. In this case the inversion i is found too as  $C_2$  and h are present.
- 5. The groups  $D_n$  with molecules possessing an n-fold principal axis and *n* two-fold axis perpendicular to  $C_n$ .
- 6. The groups  $D_{nh}$ . Molecules belong to this group if they belong to  $D_n$  and possess a horizontal mirror plane. All homonuclear diatomics belong to group  $D_n$  and all heteronuclear molecules to  $C_v$ .
- 7. The groups  $D_{nd}$ . The classification of  $D_n$  is also based on  $D_n$  but requires the additional presence of vertical mirror planes bisecting the angles between all the neighbouring axis  $C_2$ .
- 8. The groups  $S_n$ . Molecules with an rotatory reflection axis  $S_n$  belong to this group. There are only a few molecules with n < 4. Group  $S_2$  is identical with  $C_i$ .
- 9. The cubic groups *T* and *O*. A number of very important molecules possess more than one principal axis of symmetry. For example,  $CH_4$  possesses four  $C_3$  axes, one along each bond. The groups to which these belong are called the tetrahedral groups *T*,  $T_d$  and  $T_h$  and the octahedral groups  $O_h$  and *O*. The regular tetrahedron is a representative of  $T_d$ ; the regular octahedron of  $O_h$ . If the molecule possesses the rotational symmetry of the tetrahedron or the octahedron but none of its planes of reflection, it belongs to the simpler groups T and O, respectively. The group  $T_h$  is slightly peculiar because it is based on *T* but also includes a centre of inversion.

10. The full rotation group  $R_3$  is the group of operations shown by a spherical object. An atom belongs to  $R_3$ , but no molecule does. Exploring the consequences of  $R_3$  symmetry is a very important way of applying the group-theoretical arguments to atoms.

### INTERACTION OF RADIATION WITH ROTATING MOLECULES

In absorption spectroscopy the ratio of the transmitted light intensity to the incident light intensity at a given frequency is called transmittance, T of the sample:

$$T = \frac{I}{I_0}$$

According to the Lambert-Beer law, the transmitted light intensity varies with the sample length l as

$$I = I_0 e^{-\sigma N l}$$

where  $\sigma$  is an absorption cross section and N is the number of molecules per volume (concentration). Adequate units are:  $cm^2$  for  $\sigma$ ,  $cm^{-3}$  for N, and cm for l.

Another form of eq.  $(\underline{16})$  which is widely used in laboratory practice is

$$I = I_0 10^{-\epsilon c l},$$

where  $\mathbf{E}$  is the extinction coefficient and  $\mathbf{C}$  is a molar concentration :

$$c = \frac{n}{V} = \frac{\text{number of molecules}}{N_A V} = N/N_A,$$

where  $\begin{array}{c} N_A & N_A \approx 6.022 \, 10^{-23} mol^{-1} \\ \text{is the Avogadro number,} & . The appropriate units are } \\ [molL^{-1}] & [Lmol^{-1}cm^{-1}] \\ \text{mole/liter}( ) \text{ for } c \text{ and } & \text{for } \epsilon. \end{array}$ 

Each of the coefficient  $\sigma$  and  $\epsilon$  can be determined from experimental data

$$\ln(\frac{I}{I_0}) = -\epsilon c l \ln(10) = -\sigma N l,$$

where the I,  $\sigma$  and  $\varepsilon$  are function of the light frequency  $\nu$ .

In case if the exponent factor  $\alpha = \sigma Nl$  in eq.(<u>16</u>) is small compare to unity the exponential function can be expanded over  $\alpha$ . Keeping in this expansion only first two terms one comes to the important for practice particular case called low optical density of the sample:

Mr.Mohan Rangam Kadiresan Dept of Physics  $I = I_0(1 - \sigma N l).$ 

Integrating the expression in above equation is over the light frequency within the absorption peak, one obtains the integrated cross section

$$<\sigma>=\int\sigma d\nu = B_{mn}\frac{h\nu_0}{c}$$
,

where  $B_{mn}$  is the Einstein absorption coefficient and  $\nu_0$  is the center of the molecular absorption line.

Thus the Einstein coefficient  $B_{mn}$  can be directly determined from experiment.

#### **ROTATIONAL SPECTRUM OF RIGID DIATOMIC MOLECULE EXAMPLE OF CO**

The rotation of a diatomic molecule can be described by the rigid rotor model. To imagine this model think of a spinning dumbbell. The dumbbell has two masses set at a fixed distance from one another and spins around its center of mass (COM). This model can be further simplified using the concept of reduced mass which allows the problem to be treated as a single body system.

#### Introduction

Similar to most quantum mechanical systems our model can be completely described by its wave function. Therefore, when we attempt to solve for the energy we are lead to the Schrödinger Equation. In the context of the rigid rotor where there is a natural center (rotation around the COM) the wave functions are best described in spherical coordinates. In addition to having pure rotational spectra diatomic molecules have rotational spectra associated with their vibrational spectra. The order of magnitude differs greatly between the two with the rotational transitions having energy proportional to 1-10 cm<sup>-1</sup> (microwave radiation) and the vibrational transitions having energy proportional to 100-3,000 cm<sup>-1</sup> (infrared radiation). Rotational spectroscopy is therefore referred to as microwave spectroscopy.

#### **Rigid Rotor Model**

A diatomic molecule consists of two masses bound together.



Figure 1.11.1: Rigid Rotor Model of a Diatomic Molecule

### **Reduced Mass**

The system can be simplified using the concept of reduced mass which allows it to be treated as one rotating body. The system can be entirely described by the fixed distance between the two masses instead of their individual radii of rotation. Relationships between the radii of rotation and bond length are derived from the COM given by:

M1R1=M2R2,(1.1)(1.1)M1R1=M2R2,

where l is the sum of the two radii of rotation:

l=R1+R2.(1.2)(1.2)l=R1+R2.

Through simple algebra both radii can be found in terms of their masses and bond length:

R1=M2M1+M2l(1.3)(1.3)R1=M2M1+M2l

and

$$R2=M1M1+M2I.(1.4)(1.4)R2=M1M1+M2I.$$

The kinetic energy of the system, TT, is sum of the kinetic energy for each mass:

T=M1v21+M2v222,(1.5)(1.5)T=M1v12+M2v222,

where

v1=2 R1 rot(1.6)(1.6)v1=2 R1 rot

and

v2=2 R2 rot.(1.7)(1.7)v2=2 R2 rot.

Using the angular velocity,

```
=2 \operatorname{rot}(1.8)(1.8) = 2 \operatorname{rot}
```

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The kinetic energy can now be written as:

$$\Gamma = M1R21 + M2R222$$
 .(1.9)(1.9) $T = M1R12 + M2R222$ 

With the moment of inertia,

I=M1R21+M2R22,(1.10)(1.10)I=M1R12+M2R22,

the kinetic energy can be further simplified:

T=I 22.(1.11)(1.11)T=I 22.

The moment of inertia can be rewritten by plugging in for R1R1 and R2R2:

#### I=M1M2M1+M2l2,(1.12)(1.12)I=M1M2M1+M2l2,

where

#### M1M2M1+M2(1.13)(1.13)M1M2M1+M2

is the reduced mass,  $\mu\mu$ . The moment of inertia and the system are now solely defined by a single mass,  $\mu\mu$ , and a single length, ll:

I=μl2.(1.14)(1.14)I=μl2.

#### INFORMATION DERIVED FROM ROTATIONAL SPECTRUM

Molecular rotations require little energy to excite them. Pure rotation spectra occur in the microwave region of the spectrum ( $\sim 1 - 200 \text{ cm}^{-1}$ ). It is important to note that a molecule cannot rotate about some arbitrary axis - the principle of conservation of angular momentum dictates that only a few rotations are possible. In general, rotation must be about the centre of mass of a molecule, and the axis must allow for conservation of angular momentum. A pure rotation spectrum can only arise when the molecule possesses a permanent electric dipole moment. Like with vibrational spectroscopy, the physical effect that couples to photons is a changing dipole moment. Since molecular bond lengths remain constant in pure rotation, the magnitude of a molecule's dipole cannot change. However, since electric dipole is a vector quantity (it has both size and direction) rotation can cause a permanent dipole to change direction, and hence we observe its spectra. Since homonuclear molecules such as dinitrogen (N<sub>2</sub>) have no dipole moment they have no rotation spectrum. Highly symmetric polyatomic molecules, such as carbon dioxide, also have no net dipole moment - the dipoles along the C-O bonds are always equal and opposite and cancel each other out. It is important to recognise also that if a molecule has a permanent dipole, but this dipole lies along the main rotation axis, then the molecule will not have a rotational spectrum - such as for a water molecule.

In pure rotational spectroscopy for a simple diatomic molecule, the energy levels - as displayed below - are given by  $E_J = BJ(J+1)$ , where J is the *rotational quantum number*, B is the rotational constant for the particular molecule given by  $B = h^2 / 8^{-2}I$  with the unit of Joules, where I is the moment of inertia, given by  $I = \mu r^2$  where r is the bond length of this particular diatomic molecule and  $\mu$  is the reduced mass, given by

 $\mu = m_1 m_2 / m_1 + m_2.$ 

Mr.Mohan Rangam Kadiresan Dept of Physics Most energy level transitions in spectroscopy come with selection rules. These rules restrict certain transitions from occuring - though often they can be broken. In pure rotational spectroscopy, the selection rule is  $J = \pm 1$ .



### Spectra

A rotational spectrum would have the following appearence. Each line corresponds to a transition between energy levels, as shown. Notice that there are no lines for, for example, J = 0 to J = 2 etc. This is because the pure rotation spectrum obeys the selection rule  $J = \pm 1$ . The energy gap between each level increases by 2B as the energy levels we consider increase by J = 1. This leads to the line spacing of 2B in the spectrum. Each transition has an energy value of 2B more than the previous transition.



### **Molecular Dipole**

The presence of a permanent molecular dipole is a requirement for a molecule being visible in rotational spectroscopy. However, it might not be immediately obvious where the dipole comes from, and what it is.

Essentially, the molecular dipole is the presence of the imbalance of charge in a molecule. The lack of an even distribution of charge leads to a potential difference between regions of the molecule. This leads to an effective, static, electric field on the molecule. It is this electric field that may couple to photons. The imbalance of charge in the molecule arises from a combination of Pauling electronegativity and molecular symmetry. For example, in  $BF_3$  (shown below), each Fluorine atom is more electronegative than the central Boron atom (3.98 and 2.04 respectively). This leads to an effective dipole moment that is positive at the central B and negative at each F. However, since the molecule is planar, and each B-F bond is of equal length, the dipoles overall cancel out. This is why boron trifluoride has no net dipole and hence no absorption in pure rotation spectroscopy. However, it does have a transient dipole in its asymmetric vibrational modes - which appear in its vibrational spectrum. You can explore molecular dipoles.



A simple example of a molecule with a permanent molecular dipole is water, shown below. In this example, the vector sum of the bond dipole moments does not equal 0, as in  $BF_3$ .



Water has a permanent molecular dipole, and so could appear in pure rotation spectroscopy. However, since this dipole vector contains the main rotation axis of the molecule, the molecular dipole remains static as the molecule rotates. As such, water does not have a pure rotation spectrum.

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### **Possible Questions**

- (1) Give an account on the production of X-rays by using Coolidge tube method.
- (2) Derive Bragg's law for X-ray diffraction in crystals and how it is verified?
- (3) The longest wavelength of the incident radiation than can eject electrons from platinum is 1972Å. Calculate the work function of platinum in electron volts
- (4) Describe Millikan's method of verifying Einstein's equation. How the value of Planck's constant determined from photoelectric effect?
- (5) Explain the working of Bragg X-ray spectrometer with neat diagram
- (6) Explain briefly the Raman spectroscopy
- (7) Describe the vector atom model of the atom and explain the different quantum numbers associated with it
- (8) What is photoelectric cell? Explain any one type of photoelectric cell.
- (9) The photoelectric threshold for a metal is 3000Å. Find the kinetic energy of an electron ejected from it by radiation of wavelength 1200Å

Questions	opt1	opt2	opt3	opt4	Answer
UNIT-IV					
In which type of lasers, atomic transitions have been used	ruby	He-Ne	dye	CO <sub>2</sub>	He-Ne
In He –Ne laser action, which atoms assists in the pumping process	Ne	Не	Both a & b	none	Не
In medicine, the lasers are used for and cauterizing	cutting	welding	drilling	none	cutting
The carbon dioxide laser is operated in mode	no flow	fast flow	slow axial flow	All the above	all the above
Lasers are found to be very effective in cutting types of material.	different	same	invariant	identical	different
The hologram contains in the form of the pattern	Interference	diffraction	scattering	refraction	Interference
The reference beam of the balancing of the plate would be proportional to	E <sub>0ê</sub> <sup>3</sup>	$ E_{0\hat{e}}^2$	E <sub>0</sub>	$E_0^{2}$	$ E_{0\hat{e}}^2$
The virtual image produced by a hologram appears in complete	1	2	3	6	3
dimensional form.	4	2	5	0	5
With the help of laser the astronomers have been able to extend range of observation.	CO <sub>2</sub> laser	ruby laser	dye laser	He-Ne laser	ruby laser
Who determine the equation $2d \sin \theta = m\lambda$	Heisenberg	Bragg	Planck	None	Bragg
Who discovered ruby laser?	Theodore Maiman	Brillouin	Raman	None	Theodore Maiman
contains in the form of the interference pattern	maser	laser	hologram	none	hologram
The first working laser was made by Theodore Maiman in	1950	1955	1960	1965	1960
The first laser diode was demonstrated by	Robert N. Hall	Donald Herriot	Ali Javan	William R. Bennett	Robert N. Hall
The first laser diode was demonstrated by Robert N. Hall in	1959	1960	1961	1962	1962
lasers are powered by a chemical reaction involving an excited dimer.	He-Ne	Excimer	Ruby	Dye	Excimer
The efficiency of a $CO_2$ laser is over	5%	10%	15%	20%	10%
Elastic and inelastic scatterings are referred as	Hyper and Hyper Raman Rayleigh	Raman and stokes	Rayleigh and stokes	Rayleigh and anti stokes	Hyper and Hyper Raman Rayleigh
The ruby laser was first demonstrated in the year of	1967	1987	1950	1960	1960
Nd:YAG is an level laser system.	two	four	three	none	four
Nd:YAG lasers are mostliy used in applications.	military	range finding	target destination	All the above	all the above
In Nd Glass lasers, type of glasses are used. What is the lifetime of ns state of Ne <sup>2</sup>	oxide glasses	halide glasses	chalcogenide glasses	All the above	all the above
	100115	50115	150115	200115	100115
What kind of mirrors are used in co2 lasers?	Si coated with Al	Ni coated with Al	Fe coated with Al	none	Si coated with Al
What is the voltage used in co2 laser?	10-30kV	20-30kV	10-20kV	around 50kV	10-30kV
What is the Current used in co2 laser?		30mA	50mA	/0mA	100mA
What kind of pumping is used in semiconductor laser?	electrical	optical pumping	thermal	none	electrical
Is the ruby laser is CW or pulsed?	CW	pulsed	both	none	pulsed
Solid state masers have noise level than hat of ammonium laser.	higher	stable	lower	unstable	lower
Solid state maser uses as an active element.	chromium	nickel	aluminium	copper	chromium

The image of a 3 dimensional object is recorded on a dimensional photography plate.	1	2	3	both a & b	2
Holography means	complete decoding	partial recording	complete recording	partial decoding	complete recording
Holography works under the principle of	interference	diffraction	dispersion	refraction	interference
Light waves with degree of coherence is required in holography.	medium	low	high	none of these	high
The fine structure of interference fringes required photographic emulsion with a special resolution	high	low	medium	none of these	high
A major drawback of conventional holographic process is requirement	incoherent	coherent	incoherent	coherent	coherent
of in the image construction.	illumination	illumination	emission	emission	illumination
Volume hologram is a grating.	1-D	2-D	3-D	none of these	3-D
Rainbow hologram can be viewed with a source.	white light	red light	green light	both a and b	white light
Volume hologram, the colour light will be at a particular angle by hologram.	reflected	refracted	diffracted	scattered	refracted
Three level maser system has its chief disadvantage that	it can operate only in bursts	it can operate only in low temperature	it can operate only in low pressure	none of these	it can operate only in bursts
is a pulsed laser.	1 level	2 level	3 level	4 level	2 level
The conduction for gases remains absorptive is	n1> n2	n1 <n2< td=""><td>n1=n2</td><td>both a and b</td><td>n1&gt;n2</td></n2<>	n1=n2	both a and b	n1>n2
A continuous maser operation is possible in a	1 level	2 level	3 level	none of these	3 level
The absorption transition will continue as long as the gas remains	absorptive	refractive	reflective	dispersive	absorptive
In three level maser is used.	separation in space	frequency separation	amplitude separation	none of these	frequency separation
The basic element of the early maser was	gaseous ammonia	liquid ammonia	gaseous nitrogen	liquid nitrogen	gaseous ammonia
The ammonia molecule in structure.	linear	tetrahedral	hexagonal	octahedral	tetrahedral
The energy of a symmetric state in ammonia molecule is	$1/\sqrt{2} (\psi 1 + \psi 2)$	$\frac{1}{2}(\psi 1 + \psi 2)$	$\frac{1}{2}(\psi 1 - \psi 2)$	$1/\sqrt{2} (\psi 1 - \psi 2)$	$1/\sqrt{2} (\psi 1 + \psi 2)$
The antisymmetric state has energy than the symmetric state.	higher	lower	stable	none of the above	higher
The wavelength of radiation in ammonia maser is	1cm	1.25 cm	1.30 cm	1.5 cm	1.25 cm
An example for two level maser system is	fibre maser	He-Ne maser	ammonia maser	CO <sub>2</sub> maser	ammonia maser
Ammonia maser is maser system.	2 level	3 level	4 level	none of these	2 level
For efficient maser action it is imperative that a cavity losses are as as possible.	high	small	medium	none of these	small
The losses depend upon the of the cavity.	intensity	energy stored	energy lost	Q-factor	Q-factor
Ammonia masers have power output.	very low	very high	medium	none of these	very low
Ammonium masers have power output around watt.	$10^{-3}$	10+3	10 <sup>-9</sup>	10 <sup>+9</sup>	10 <sup>-9</sup>
The splitting of state increases with field.	increasing	decreasing	stable	none of these	increasing
The coherence of maser radiation produces a line width	broad	narrow	medium	none of these	narrow
What is the lifetime of electron hole pair in a semiconductor laser?	1-5ns	1-10ns	1-3ns	none	1-10ns
What is the active material in dye lasers?	methanol	glycerol	both a and b	none	both a and b
What is the concentration of dye molecules?	1 part in 1000	1 part in 100	1 part in 10000	none	1 part in 10000

The lifetime of lower vibrational level of S1 is about	lns	3ns	4ns	7ns	lns
The lifetime of higher vibrational level of S1 is about	10(-10)s	10(-12)s	10(-19)s	10(-15)s	10(-12)s

### I.R SPECTROSCOPY: PRACTICAL ASPECTS

We have seen infrared lamps keep food hot and often associate infrared radiation with heat. While the generation of heat is a probable event following the absorption of infrared radiation. Infrared is a form of radiation that can travel through a vacuum while heat is associated with the motion and kinetic energy of molecules. The concept of heat in a vacuum has no meaning because of the lack of molecules and molecular motion. Infrared spectroscopy is the study of how molecules absorb infrared radiation and ultimately convert it to heat. An infrared spectrum of a chemical substance, is very much like a photograph of a molecule. However, unlike a normal photograph which would reveal the position of nuclei, the infrared spectrum will only reveal a partial structure. It is the purpose of this narrative to provide you with the tools necessary to interpret infrared spectra, successfully. In some respects, this process is similar to reading an X-ray of the chest. While most of us could easily identify the gross structural features of the chest such as the ribs, most of us would need some guidance in identifying those features of the X-ray associated with disease.

In order to interpret infrared spectra, having some idea or model of the physical process involved when a molecule interacts with infrared radiation would be useful. You may recall in introductory chemistry, the discussion of how atoms interact with electromagnetic radiation led to the development of quantum theory and the introduction of quantum numbers. The interaction of infrared radiation with molecules requires a similar treatment. While the use of quantum theory is necessary to explain this interaction, most of us live in a world that appears continuous to us and we do not have much experience discussing phenomena that occur is discrete steps. The discussion that follows will attempt to develop a model of how molecules interact with infrared radiation that is based as much as possible on classical physics. When necessary, we will insert the modifications required by quantum mechanics. This model, while perhaps oversimplified, will contain the physical picture that is useful to understand the phenomena and will be correct from a quantum mechanical standpoint.

Two isolated atoms, a hydrogen and a bromine atom moving toward each other from a great distance. The two atoms must attract each other and accelerate toward each other, thereby increasing their kinetic energy. The change in kinetic energy is illustrated by the dotted line in the figure. At some point they will "collide" as indicated by the part of the potential energy curve that rises steeply at small inter atomic distances and then the atoms will begin to move away from each other. Unless some energy from this system is lost, say by emission of a photon of light or collision by a third body to remove some energy, these are two ships passing in the night. The kinetic energy resulting from the coulombic attraction of the two atoms will exactly equal the drop in potential energy and the two atoms will fly apart. Potential Energy Diagram for HBr



**Figure 1.** The potential (solid line) and kinetic energy (dotted line) of HBr as a function of the separation of the two nuclei.

The kinetic energy at every point illustrated by the dotted line is equal to the potential energy plus the small amount of kinetic energy associated with initial motion of the two nuclei when separated at large distances.

The collision of a third body which will remove some energy and result in the trapping of the molecule in the well. Though very excited, this molecule will now survive until other collisions with less energetic molecules leads to molecule at the bottom of the well and the generation of heat (kinetic energy) that would be experienced in the exothermic reaction of hydrogen and bromine atoms to form hydrogen bromide. Let us now consider a hydrogen bromide molecule that has lost a little kinetic energy by collision and has been trapped in the potential energy well of Figure 1. We might ask, "How would a molecule that does not have enough kinetic energy to escape the well behave in this well? A molecule with some kinetic energy below this threshold value (total energy slightly less than 0 in Fig. 1) will be able to move within this well. The internuclear separation will vary within the limits governed by the available kinetic energy. Since this motion involves a stretching or compression of the internuclear distance it is usually described as a vibration. Additional collisions with other molecules will eventually lead to the dissipation of the energy associated with formation of the hydrogen bromide bond. At this point If we remove all the excess kinetic energy . Before

Physicists found many years ago some interesting properties of such a system which they referred to as a harmonic oscillator. Such a system repeatedly interconverts potential and kinetic energy, depending on whether the spring is exerting a force on the balls or the momentum of the balls is causing the spring to be stretched or compressed. The potential energy of this system (PE) is given by the parabola,

$$PE = k(x-xo)^{21}$$

where x-xo is the displacement of the balls from their equilibrium condition when the system is at rest and k is a measure of the stiffness of the spring. While this simple equation does not apply to molecules, please notice how similar the potential energy surface of the parabola (Figure 3) is to the bottom of the surface of Figure 1. The constant k is used to describe chemical bonds and is referred to as the force constant. As you might imagine, it is a measure of the stiffness of the chemical bond.

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Several other relationships were observed that do carry over in describing molecular systems. For example, they found that when a ball was suspended on a spring from a horizontal wall, the frequency of vibration or oscillation, The term A is a constant of the proportionality. By varying the mass of the ball and the stiffness of the spring, they were able to uncover the following simple relationship between frequency, mass and force constant:

$$v = A \sqrt{\frac{k}{m}}$$

Suspending a ball and spring from a horizontal surface is a special case of the more general situation when you have two more comparable masses attached to each other. Under these circumstances, when two similar masses are attached to a spring, the relationship between frequency of vibration, mass and force constant is given by:

$$v = A \sqrt{\frac{k}{\mu}}_{3}$$

where m1 & m2 represents the product of the masses divided by their sum  $(m_1m_2/(m_1+m_2))$ . This latter term is found in other physical relationships and has been given the name, the reduced mass. It can easily be seen that the above equation is a special case of the more general relationship given by equation 3. If we consider m1to be much larger than m2, the sum of m1+ m2 m1 and substituting this approximation into (m1m2/(m1+m2)) m2.

Substituting m2 into equation 3 where m2 is the smaller of the two masses gives us exactly the same relationship as we had above when the ball was suspended from a horizontal wall. The horizontal wall is much more massive than the ball so that the vibration of a smaller ball has very little effect on the wall. Despite their simplicity, equations 2 and 3 play an important role in explaining the behavior of molecular systems. However, before we discuss the important role these equations play in our understanding of infrared spectroscopy, we need to review some of the properties of electromagnetic radiation, particularly radiation in the infrared range.

### THEORY OF I.R ROTATION VIBRATION

Infra red (IR) spectroscopy deals with the interaction between a molecule and radiation from the IR region of the EM spectrum (IR region =  $4000 - 400 \text{ cm}^{-1}$ ). The cm<sup>-1</sup> unit is the wave number scale and is given by 1 / (wavelength in cm).

IR radiation causes the excitation of the vibrations of covalent bonds within that molecule. These vibrations include the stretching and bending modes.

An IR spectrum show the energy absorptions as one 'scans' the IR region of the EM spectrum.

As an example, the IR spectrum of butanal is shown below.

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IR spectrum into two approximate regions:

- 4000-1000 cm<sup>-1</sup> known as the functional group region, and
- $< 1000 \text{ cm}^{-1}$  known as the fingerprint region



- Most of the information that is used to interpret an IR spectrum is obtained from the functional group region.
- In practice, it is the polar covalent bonds than are IR "active" and whose excitation can be observed in an IR spectrum.
- In organic molecules these polar covalent bonds represent the functional groups.
- Hence, the most useful information obtained from an IR spectrum is what functional groups are present within the molecule (NMR spectroscopy typically gives the hydrocarbon fragments).
- Remember that some functional groups can be "viewed" as combinations of different bond types. For example, an ester, CO<sub>2</sub>R contains both C=O and C-O bonds, and both are typically seen in an IR spectrum of an ester.
- In the fingerprint region, the spectra tend to be more complex and much harder to assign.

#### SPECTRA OF GASEOUS DIATOMIC MOLECULES

The gross selection rule for the observation of vibrational Raman transitions is that the polarisability of the molecule should change as the molecule vibrates. Both homonuclear and heteronuclear diatomics fulfill this requirement, so both molecules are vibrationally Raman active.

If we approximate the potential energy curve of a vibrating bond as a parabola (i.e. assume that the vibration is harmonic) then the specific selection rule for vibrational Raman transitions is  $= \pm 1$ .

Transitions for which  $\Delta v = -1$  lie to high frequency of the incident radiation, and are called the Stokes lines.

Transitions for which  $\Delta v = +1$  lie to low frequency of the incident radiation, and are called the anti-Stokes lines. These are usually more intense than the Stokes lines, as the

Stokes lines require the molecules to initially be in excited vibrational states, which is a relatively rare occurrence.

In gas-phase spectra, the lines of the vibrational spectrum have a branch structure similar to that of the lines in an infra-red vibrational spectrum. They again arise from rotational transitions simultaneous with the vibrational transitions.

In this case, the selection rules are  $\Delta J = 0, \pm 2$  (as in pure rotational Raman spectroscopy), and the three branches are termed the O branch ( $\Delta J = -2$ ), the Q branch ( $\Delta J = 0$ ), and the S branch ( $\Delta J = +2$ ).

Note that in Raman spectroscopy, the Q branch is always observed.



This diagram is a schematic representation of the rotational structure within a vibrational line in a high resolution Raman spectrum.Note that in this diagram, unlike that for the infra-red rotation-vibration spectrum, the frequency (and thus the wavenumber) increases from right to left.

### **APPLICATIONS OF I.R SPECTROSCOPY**

Infrared spectroscopy is widely used in industry as well as in research. It is a simple and reliable technique for measurement, quality control and dynamic measurement. It is also employed in forensic analysis in civil and criminal analysis.

Some of the major applications of IR spectroscopy are as follows:

#### Identification of functional group and structure elucidation

Entire IR region is divided into group frequency region and fingerprint region. Range of group frequency is 4000-1500 cm<sup>-1</sup> while that of finger print region is 1500-400 cm<sup>-1</sup>.

In group frequency region, the peaks corresponding to different functional groups can be observed. According to corresponding peaks, functional group can be determined.

Each atom of the molecule is connected by bond and each bond requires different IR region so characteristic peaks are observed. This region of IR spectrum is called as finger print region of the molecule. It can be determined by characteristic peaks.

### **BASIC PRINCIPLES OF F.T.I.R SPECTROSCOPY**

The development of Fourier Transform InfraRed spectroscopy (FTIR) in the early 1970s provided a quantum leap in infrared analytical capabilities for monitoring trace pollutants in ambient air. This technique offered a number of advantages over conventional infrared systems, including sensitivity, speed and improved data processing.

The basic components of an FTIR are shown schematically in Figure 1. The infrared source emits a broad band of different wavelength of infrared radiation. The IR source used in the Temet GASMET FTIR CR-series is a SiC ceramic at a temperature of 1550 K. The IR radiation goes through an interferometer that modulates the infrared radiation. The interferometer performs an optical inverse Fourier transform on the entering IR radiation. The modulated IR beam passes through the gas sample where it is absorbed to various extents at different wavelengths by the various molecules present. Finally the intensity of the IR beam is detected by a detector, which is a liquid-nitrogen cooled MCT (Mercury-Cadmium-Telluride) detector in the case of the Temet GASMET FTIR CR-series. The detected signal is digitised and Fourier transformed by the computer to get the IR spectrum of the sample gas.



Figure 1: Basic components of FTIR

The unique part of an FTIR spectrometer is the interferometer. A Michelson type plane mirror interferometer is displayed in Figure 2. Infrared radiation from the source is collected and collimated (made parallel) before it strikes the beamsplitter. The beamsplitter ideally transmits one half of the radiation, and reflects the other half. Both transmitted and reflected beams strike mirrors, which reflect the two beams back to the beamsplitter. Thus, one half of the infrared radiation that finally goes to the sample gas has first been reflected from the beamsplitter to the *moving* mirror, and then back to the beamsplitter. The other half of the infrared radiation going to the sample has first gone through the beamsplitter and then reflected from the *fixed* mirror back to the beamsplitter. When these two optical paths are reunited, interference occurs at the beamsplitter because of the optical path difference caused by the scanning of the moving mirror.



Radiation to the sample gas and detector

### Figure 2: Michelson interferometer

The optical path length difference between the two optical paths of a Michelson interferometer is two times the displacement of the moving mirror. The interference signal measured by the detector as a function of the optical path length difference is called the interferogram. A typical interferogram produced by the interferometer is shown in Figure 3. The graph shows the intensity of the infrared radiation as a function of the displacement of the moving mirror. At the peak position, the optical path length is exactly the same for the radiation that comes from the moving mirror as it is for the radiation that comes from the fixed mirror.





The spectrum can be computed from the interferogram by performing a Fourier transform. The Fourier transform is performed by the same computer that ultimately performs the quantitative analysis of the spectrum.

The degree of absorption of infrared radiation at each wavelength is quantitatively related to the number of absorbing molecules in the sample gas. Since there is a linear relationship between the absorbance and the number of absorbing molecules, multicomponent quantitative analysis of gas mixtures is feasible.

To perform multicomponent analysis we start with the sample spectrum. In addition, we need reference spectra of all the gas components that may exist in the sample, if these components are to be analysed. A reference spectrum is a spectrum of one single gas component of specific concentration. In multicomponent analysis we try to combine these reference spectra with appropriate multipliers in order to get a spectrum that is as close as possible to the sample spectrum. If we succeed in forming a spectrum similar to the sample spectrum, we get the concentration of each gas component in the sample gas using the multipliers of the reference spectra, provided that we know the concentrations of the reference gases.

For example, suppose we have a sample spectrum and reference spectra like those shown in Figure 4. In this case, we know that the sample gas consists of gases Reference 1 and Reference 2. We have the reference spectra available and we know that these reference

spectra represent concentrations of 10 ppm and 8 ppm respectively. To find out the concentration of each component in the sample gas, we try to form the measured sample spectrum using a linear combination of the reference spectra. we get a spectrum that is similar to the sample spectrum. Accordingly, the sample gas contains reference gas 1 at five times the amount in the reference spectrum 1, and reference gas 2 at two times the amount in the reference spectrum 2. The analysis indicates that the sample indeed consists of these two reference gases. The concentration of the reference gas 1 in the sample is found to be 50 ppm, and the concentration of the reference gas 2 in the sample is 16 ppm.



Figure 4: An example of spectra for multicomponent analysis

This multicomponent ability of FTIR means that theoretically, any spectrum obtained with the FTIR can be reprocessed at a future date to determine the concentration of any newly calibrated gases. Therefore it is worth saving the spectra obtained from FTIR since they potentially contain so much information about the sample gas.

# **RAMAN SPECTROSCOPY:**

#### Introduction

Raman spectroscopy is one of the vibrational spectroscopic techniques used to provide information on molecular vibrations and crystal structures. This technique uses a laser light source to irradiate a sample, and generates an infinitesimal amount of Raman scattered light, which is detected as a Raman spectrum using a CCD camera. The characteristic fingerprinting pattern in a Raman spectrum makes it possible to identify substances including polymorphs and evaluate local crystallinity, orientation and stress.

Raman spectroscopy has some unique advantages such as:

- o Non-contact and non-destructive analysis
- High spatial resolution up to sub-micron scale
- o In-depth analysis of transparent samples using a confocal optical system
- No sample preparation needed.
- o Both organic and inorganic substances can be measured
- Samples in various states such as gas, liquid, solution, solid, crystal, emulsion can be measured
- Samples in a chamber can be measured through a glass window
- Typically, only 10 msec to 1 sec exposure to get a Raman spectrum

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• Imaging analysis is possible by scanning the motorized stage or laser beam Because of these advantages, Raman spectroscopy plays an important role in both R&D and QA/QC in a variety of industries and academic fields such as semiconductors, polymers, pharmaceuticals, batteries, life sciences and more.







Figure 2. Diagram of the Rayleigh and Raman Scattering Processes (a) An electron is excited from the ground level and falls to the original ground level. (b) An electron is excited from the ground level and falls to a vibrational level.

(c) An electron is excited from a vibrational level and falls to the ground level.

# CLASSICAL AND QUANTUM THEORY OF RAMAN EFFECT -

Classical mechanics of molecular vibrations

Let's investigate an N-atomic molecule. Affix a coordinate system to the molecule: (a) shift the origin to the center of mass (COM), and (b) direct the molecular axes along the principal axes of rotation (a, b, and c). Kinetic energy Define the Cartesian displacement coordinates as follows, where subscript 0 refers to the chosen reference (equilibrium) configuration:  $-\alpha \alpha = \alpha$ ,  $0 \operatorname{zcc} - \alpha \alpha = \alpha$ ,  $0 \operatorname{y} \operatorname{bb} - \alpha \alpha = \alpha, 0 \operatorname{x} a \operatorname{a}$  The form of the kinetic energy is

**B.Sc Physics** 

### **ROTATION VIBRATION RAMAN SPECTRA OF DIATOMIC MOLECULES**

The observation of vibrational Raman transitions is that the polarisability of the molecule should change as the molecule vibrates..

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In gas-phase spectra, the lines of the vibrational spectrum have a branch structure similar to that of the lines in an infra-red vibrational spectrum. They again arise from rotational transitions simultaneous with the vibrational transitions.

In this case, the selection rules are  $\Delta J = 0, \pm 2$  (as in pure rotational Raman spectroscopy), and the three branches are termed the O branch ( $\Delta J = -2$ ), the Q branch ( $\Delta J = 0$ ), and the S branch ( $\Delta J = +2$ ).

Note that in Raman spectroscopy, the Q branch is always observed.



This diagram is a schematic representation of the rotational structure within a vibrational line in a high resolution Raman spectrum

#### **ROTATION VIBRATION RAMAN SPECTRA OF POLYATOMIC MOLECULES**

Let N > 2 be the number of nuclei in a polyatomic molecule with 3N degrees of freedom. With 3 for the center-of-mass and 3 for rotation (or 2 for a linear molecule with two rotational degrees), there are 3N-6 (or 3N-5) vibrational degrees of freedom, e.g., three for N = 3 and six for N = 4, etc. We consider the vibrational frequencies as given. Once the Mr.Mohan Rangam Kadiresan Karpagam Acadamy of Higher Education Dept of Physics Page **10** of **15**  equilibrium configuration is known, this is a problem in classical Lagrangian mechanics. Of course high vibrational levels are subject to anharmonic corrections, as discussed in Lec. 17. See Ch. 8 of Seinfeld for a discussion of Lagrangian and more elegant methods, with explicit solutions for N = 3 and 4.

Vibrations of XY2 Molecules, e.g., H<sub>2</sub>O and C<sub>2</sub>H

### **APPLICATIONS**

Raman spectroscopy is being successfully applied to the analysis of a wide range of materials and systems. Raman microscope, combined Raman / scanning probe microscope systems, and combined SEM-Raman system.

# LASER RAMAN SPECTROSCOPY

Raman spectroscopy is a useful technique for the identification of a wide range of substances - solids, liquids, and gases. It is a straightforward, non-destructive technique requiring no sample preparation. Raman spectroscopy involves illuminating a sample with monochromatic light and using a spectrometer to examine light scattered by the sample.

At the molecular level photons can interact with matter by absorption or scattering processes. Scattering may occur either elastically, or inelastically. The elastic process is termed Rayleigh scattering, whilst the inelastic process is termed Raman scattering. The electric field component of the scattering photon perturbs the electron cloud of the molecule and may be regarded as exciting the system to a 'virtual' state. Raman scattering occurs when the system exchanges energy with the photon, and the system subsequently decays to vibrational energy levels above or below that of the initial state. The frequency shift corresponding to the energy difference between the incident and scattered photon is termed the Raman shift. Depending on whether the system has lost or gained vibrational energy, the Raman shift occurs either as an up- or down-shift of the scattered photon frequency relative to that of the incident photon. The down-shifted and up-shifted components are called respectively the Stokes and anti-Stokes lines. A plot of detected number of photons versus Raman shift from the incident laser energy gives a Raman spectrum. Different materials have different vibrational modes, and therefore characteristic Raman spectra. This makes Raman spectroscopy a useful technique for material identification. There is one important distinction to make between the Raman spectra of gases and liquids, and those taken from solids - in particular, crystals. For gases and liquids it is meaningful to speak of the vibrational energy levels of the individual molecules which make up the material. Crystals do not behave as if composed of molecules with specific vibrational energy levels, instead the crystal lattice undergoes vibration. These macroscopic vibrational modes are called *phonons*.





In modern Raman spectrometers (Fig. 2.1), lasers are used as a photon source due to their highly monochromatic nature, and high beam fluxes. This is necessary as the Raman effect is weak, typically the Stokes lines are  $\sim 10^5$  times weaker than the Rayleigh scattered component. In the visible spectral range, Raman spectrometers use notch filters to cut out the signal from a very narrow range centred on the frequency corresponding to the laser radiation. Most Raman spectrometers for material characterisation use a microscope to focus the laser beam to a small spot (<1-100 m diameter). Light from the sample passes back through the microscope optics into the spectrometer. Raman shifted radiation is detected with a charge-coupled device (CCD) detector, and a computer is used for data acquisition and curve fitting. These factors have helped Raman spectroscopy to become a very sensitive and accurate technique.



Figure 2.2 Raman spectrum of natural diamond (type IIa), showing the main Raman active mode at ~1332 cm<sup>-1</sup> (Taken using 514.5 nm laser excitation wavelength). The Raman signal intensity is in arbitrary units (a.u.).

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### SURFACE ENHANCED

Surface-Enhanced Raman Scattering (SERS)

Raman signals are inherently weak, especially when using visible light excitation and so a low number of scattered photons are available for detection. One method to amplify weak Raman signals is to employ surface-enhanced Raman scattering (SERS). SERS uses nanoscale roughened metal surfaces typically made of gold (Au) or silver (Ag). Laser excitation of these roughened metal nanostructures resonantly drives the surface charges creating a highly localized (plasmonic) light field. When a molecule is absorbed or lies close to the enhanced field at the surface, a large enhancement in the Raman signal can be observed. Raman signals several orders of magnitude greater than normal Raman scattering are common, thereby making it possible to detect low concentrations (10<sup>-11</sup>) without the need for fluorescent labeling. The Raman signal can be amplified further when the roughened metal surface is used in combination with laser light that is matched to the absorption maxima of the molecule. This effect is known as surface-enhanced resonance Raman scattering, (SERRS).



SERS substrate

Figure 1: Conceptual illustration of SERS.

SERS is finding increasing use in a variety of applications ranging from:

- Basic analytical chemistry testing
- Drug discovery
- Forensic field testing
- Detecting of trace amounts of chemical and biological threat agents
- Point-of-care (POC) medical diagnostic devices



### **RAMAN SCATTERING.**

A form of molecular spectroscopy based on the Raman effect, described above. A laser beam is used to irradiate a spot on the sample under investigation. The scattered radiation produced by the Raman effect contains information about the energies of molecular vibrations and rotations, and these depend on the particular atoms or ions that comprise the molecule, the chemical bonds connect them, the symmetry of their molecule structure, and the physico-chemical environment where they reside.



Energy levels and transitions related to the Raman effect: Laser- produced, monochromatic light of ultra- violet, visible, or infrared frequency can be used as the excitation source. In conventional Raman spectroscopy, visible lasers are used (e.g., Ar+, Kr+, Nd:YAG, He-Ne, diode) to stimulate the molecules to high-energy " virtual" states of excitation. A Raman photon is emitted if a molecule then undergoes a transition to a higher vibrational energy state than its original state (Stokes-Raman), or to a lower energy vibrational state (Anti-Stokes Raman). Normally, Stokes Raman radiation has the higher intensity. Sometimes, the laser stimulates fluorescent radiations, but these are not part of the Raman scattering.

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### **Possible Questions**

- (1) Describe different types of X-ray spectra. How are they explained?
- (2) Write a short notes on
  - (i) Periodic classification of elements
  - (ii) Electronic configuration of some light elements with symbolic representation
- (3) What is Zeeman effect? Describe the experimental arrangement for studying the Zeeman effect
- (4)Write a detailed note on the Pauli's Exclusion Principle.

(5) What is the effect of magnetic field on spin electron motion and explain normal Zeeman Effect.

- (6) Derive the expression for Zeeman effect.
- (7) Explain Inferred Spectroscopy practical aspects.
- (8) Explain the basic principle of FTIR Spectroscopy.
- (9) Explain Quantum theory of Raman Effect.
- (10) What is Surface Enhanced Raman Spectroscopy.

Questions	opt1	opt2	opt3	opt4	Answer
UNIT-V					
Second harmonic generation was first demonstrated by	P. A. Franken	C. W. Peters	G. Weinreich	All the above	All the above
SHG has been extended to applications	biological	scientific	medical	industrial	biological
The phenomenon of the concentration of the field of a light wave in a nonlinear medium whose refractive index depends on the	density	energy	intensity	field intensity	field intensity
The inverse phenomenon the nonlinear broadening of a light beam is called	focussing	parametic generation	self-focussing	defocussing	defocussing
Light energy can be transmitted over long distances by means of	fibers	wave guide	radar	none	wave guide
Technique involves switching the cavity Q factor is known as Q- switching.	From a high to a low value	From a low to a high value	From high value	From low value	From a low to a high value
Laser is used in the Radio telescope.	He-Ne	$CO_2$	ruby	XY laser	ruby
A Q-switched laser is used for excitation of source.	Ruby	He-Ne	CO2	dve	Ruby
spectra have been observed in water molecule.	Hyper Raman spectra	Raman spectra	Rayleigh spectra	none	Hyper Raman spectra
In holography a light wave is a carrier of information and it is recorded in terms of	wave parameters	electrons	photons	none of these	wave parameters
In holography light is recorded.	refracted	reflected	diffracted	dispersive	reflected
In recording of the hologram spacing between the fringes is as	0.001mm	0.01mm	0.1 mm	1mm	0.001mm
In reconstruction of the image the real image formed is known as	pseudoscopic image	reflected wave	real image	virtual image	pseudoscopic image
Which rays are not used for recording?	acoustic radiation	X-ray	electron beam	uv ray	uv ray
The virtual image produced by a hologram appears in complete form.	1 dimensional	2 dimensional	3 dimensional	none of these	3 dimensional
electrons in paramagnetic substance make solid state masers possible.	paired	unpaired	valance	excited	valance
The magnetic moment is associated with the spin of the atom.	molecular	orbital	nuclear	electronic	nuclear
Maser is an acronym for	Microwave amplification by stimulated emission of radiation	Microwave amplification by spontaneous emission of radiation	Microwave absorption by stimulated emission of radiation	None of the above	Microwave amplification by stimulated emission of radiation
A hologram is made by illuminating the volume by a laser which freezes the motion of particle.	short pulse	long pulse	medium pulse	either a or c	short pulse
The waves in which the radiated energy produced by stimulated emission may be increased by	by increasing the radiation density	by increasing the population in the upper level	both a and b	none of these	both a and b
A Q-switched laser is used for excitation of source.	Ruby	He-Ne	CO2	dye	Ruby
spectra have been observed in water molecule.	Hyper Raman spectra	Raman spectra	Rayleigh spectra	none	Hyper Raman spectra
CCl3 and methane molecules have been observed spectra.	Raman	Rayleigh	a and b	hyper Raman	hyper Raman
An erbium-doped waveguide amplifier (EDWA) is an optical amplifier that uses a to boost an optical signal.	wave guide	optical fiber	attenuator	none	wave guide
A device that amplifies a laser beam by stimulated emission is called a	ruby laser	dye laser	laser amplifier	chemical laser	laser amplifier
Optical absorption and emission occur through the interaction of optical radiation with	photons	electrons	ions	phonons	electrons
A coherent optical amplifier is a device that increases the of an optical field while maintaining its phase.	amplitude	intensity	energy	wavelength	amplitude
an incoherent optical amplifier increases the intensity of an optical wave without preserving its phase.	amplitude	intensity	energy	wavelength	intensity
Q-switching, sometimes known as	giant pulse formation	Q-spoiling	both a and b	none	both a and b
Q-switching was first proposed in	1987	1876	1958	1976	1958

Q-switching was first demonstrated by using electrically switched shutters in	1 11	1 1 1 11	1 11		1 11
a ruby laser	kerr cell	leclanche cell	solar cell	none	kerr cell
The optical response of a material is expressed in terms of the	induced polarization	diffraction	interference	none	induced polarization
Nonlinear optics (NLO) is the branch of optics that describes the behavior of in	a a sum d	light			linkt
non-linear media.	sound	ngnt	current	none	ngnt
The another name of second harmonic generation is	phase matching	optical mixing	frequency doubling	self focussing	frequency doubling
In a non-linear material, the material polarization will have a component at twice the	fraguency	intensity	anaroy	none	fraguency
optical	nequency	intensity	energy	none	nequency
In many cases, the nonlinear mixing products can be efficiently accumulated over a	nhase matching	ontical mixing	self-focussing	none	nhase matching
greater length of crystal only if is achieved.	phase matering	optical mixing	sen-toeussing	none	phase matering
In non-linear optics, the electric polarization is proportional to the	frequency	wavelength	electric field strength	electric potential	electric field strength
A delayed nonlinear response is associated with	Raman scattering	Brillouin scattering.	rayleigh scattering	both a and b	both a and b
Self-focusing is a non-linear optical process induced by the change in of	refractive index	intensity	amplitude	none	refractive index
materials exposed to intense electromagnetic radiation		intensity	ampinuue	none	Terraterive materi
The most widely used dye is	Azines	Acridines	Colmarins	Xanthene	Xanthene
The inter system crossing will the no. of molecules available in the upper state for	Raduca	Increase	Both a & b	None	Paduca
laser action	Keduce	liletease		INDIE	Keuuce
The laser operates between two fully allowed transitions with no metastable state	$CO_2$	He- Ne	dye	Excimer	dye
The operating frequencies of laser are determined by energy levels in atoms					
<i>k</i> molecules	Free- electron	HC1	He –Ne	Dye	Free- electron
The frequencies of laser is tunable by variation of electric energy	Free- electron	HC1	He –Ne	Dve	Free- electron
The self numping laser is	Excimer	He-Ne	Colour	Chemical	Chemical
In which type of lasers, atomic transitions have been used	ruby	He Ne	dve	CO	He Ne
In the Ne loose extient, which store excite in the number measure	No		Dath a fe h	002	
in He –Ne laser action, which atoms assists in the pumping process	Ne From a high to a low	He Enome a loss to a high	Both a & b	none	He From a low to a high
Technique involves switching the cavity Q factor is known as Q- switching.	value	value	From high value	From low value	value
The pumping power is always upon decay time	same	independence	depends	none	depends
The cavity which does not contain any active medium is calledresonator	active	passive	band pass	low pass	passive
The cavity which contain active medium is calledresonator	active	passive	band pass	low pass	active
The atoms having same central frequency and the same atomic line shape is known as	homogeneous	heterogeneous	non- homogeneous	none	homogeneous
In normal population the no. of atoms in the ground state is than the no. of atoms	loss than	greater then	hath a fr h	nono	graatar than
in the excited state.		greater than		none	greater than
In thermal equilibrium the no. of atoms in the ground state is greater than the no. of atoms	normal nonulation	nonulation inversion	abnormal population	none of these	normal nonulation
in the excited state is called	normai population	population inversion	abilorinal population	none of these	normai population
What principle is responsible for light spreading as it passes through a narrow slit?	refraction	polarization	diffraction	interference	diffraction
What principle is responsible for alternating light and dark bands when light passes	refrection	nolorization	diffraction	interformed	interformed
through two or more narrow slits?	Terraction	polarization	unnaction	linterference	Interference
What principle is responsible for the fact that certain sunglasses can reduce glare from	rafraction	polorization	diffraction	total internal	nolarization
reflected surfaces?	Terraction	polarization	unnaction	reflection	polarization
The principle which allows a rainbow to form is	refraction	polarization	dispersion	total internal reflection	dispersion
Light has a wavelength of 600 nm in a vacuum. It passes into glass, which has an index	(00	500	400	200	100
of refraction of 1.50. What is the wavelength of the light in the glass?	ouu nm	500 nm	400 nm	500 nm	400 nm
All active bands are hyper Raman active.	infra red	micro wave	ultra violet	none	infra red