SEMESTER III

16PHP302	**LASER AND ITS APPLICATIONS**	**L T P C** **4 - - 4**

Scope: Laser is a versatile tool with applications in almost all fields from medical to astronomy, communications, welding, cutting etc. This paper explains the characteristics of lasers, different types of lasers and their construction. Applications of lasers in different fields are also explained.

Objectives: To give exposure to students about the characteristics of different lasers, their fabrication techniques, applications etc.

Unit- I

Laser Characteristics: Spontaneous and stimulated emission, Einstein's quantum theory of radiation, theory of some optical processes, coherence and monochromacity, kinetics of optical absorption, line broadening mechanism, Basic principle of lasers, population inversion, laser pumping, two & three level laser systems, resonator, Q-factor, losses in cavity, threshold condition, quantum yield.

Unit – II

Laser Systems: Solid state lasers- the ruby laser, Nd:YAG laser, ND: Glass laser, semiconductor lasers – features of semiconductor lasers, intrinsic semiconductor lasers, Gas laser - neutral atom gas laser, He-Ne laser, molecular gas lasers, CO2 laser, Liquid lasers, dye lasers and chemical laser.

Unit-III

Advances in laser Physics : Production of giant pulse -Q-switching, giant pulse dynamics, laser amplifiers, mode locking and pulling, Non-linear optics, Harmonic generation, second harmonic generation, Phase matching, third harmonic generation, optical mixing, parametric generation and self-focusing of light.

Unit – IV

Multi-photon processes; multi-quantum photoelectric effect, Theory of two-photon process, three- photon process, second harmonic generation, parametric generation of light, Laser spectroscopy : Rayleigh and Raman scattering, Stimulated Raman effect, Hyper-Raman effect, Coherent anti-stokes Raman Scattering, Photo-acoustic Raman spectroscopy.

Unit – V

Laser Applications – ether drift and absolute rotation of the Earth, isotope separation, lasma, thermonuclear fusion, laser applications in chemistry, biology, astronomy, engineering and medicine. Communication by lasers: ranging, fiber Optics Communication, Optical fiber, numerical aperture, propagation of light in a medium with variable index, pulse dispersion.

Text Books:

Ajoy Ghatak & Thyagarajan 2nd edition,2013,Laser Fundementals and applications Laxmi Publications (P) Ltd

REFERENCE BOOKS:

1. Laud, B.B.:1st Edition 2011 Lasers and nonlinear optics, New Age Int.Pub.
2. Thyagarajan, K and Ghatak, A.K 2009: Lasers theory and applications

Plenum press,
3. Ghatak, A.K.and Thyagarajan, K :2010 Optical electronics Cambridge Univ. Press
4. Seigman, A.E.: Lasers (Oxford Univ. 2008)
5. Maitland, A. and Dunn, M.H. 2013 : Laser Physics N.H.Amsterdam.
6. Hecht, 4^{th} edition 2012 Laser Guide book McGraw Hill, NY.
7. Demtroder, W. : Laser Spectroscopy (Springe series in chemical physics vol.5,Springe verlag, Berlin, 2014).

Lecture Plan **UNIT - I**

Si.No	Lecture Duration (hr.)	Topics to be covered	Support Materials
1	1hr	Introduction	
2	1hr	LASER Characteristics	T1(1-3)
3	1hr	Spontaneous & stimulated emission.	T1(2-6)
4	1hr	Einstein’s Quantum Theory of Radiation	T1(7-14)
5	1hr	continuation	
6	1hr	Theory of Some Optical Process	T1(58-59)
7	1hr	Coherence & Monochromatic	T1(59)
8	1hr	Kinetic of Optical absorption & Line broadening Mechanism	T1(60-62) T1(64-70)
9	1hr	Basic Principle of Lasers, Population inversion & LASER Pumping	T1(73-74)
10	1hr	Two & Three level Laser Systems	T1(74-76)
11	1hr	Resonator	T1(78,79)
12	1hr	Q- Factor and losses cavity	T1(83-84)
13	1hr	Threshold condition,	T1(85-86)
14	1hr	Quantum Yield	T1 (86-89)
15	1hr	Revison	
Total no. of Hours planned for unit-I			9 hr.

LECTURE PLAN Unit –II

Si.No	Lecture Duration (hr.)	Topics to be covered	Support Materials
1	1hr	Laser systems : Solid state Lasers – Ruby Lasers	T1(91-93)
Si.No	**Lecture Duration (hr.)**	**Topics to be covered**	**Support Materials**
2	1hr	ND : YAG Laser	T1(199)
3	1hr	ND : Glass Laser	T1(205-206) T1(207-208)
4	1hr	Semi conductor Laser – Features	T1(209)
5	1hr	Intrinsic Semiconductor Laser’s	T1(211)
6	1hr	Gas Lasers – Neutral atom gas laser, He-Ne laser, Molecular gas lasers	T1(105-110) T1(116-117)
7	1hr	CO_2 Laser, Liquid Lasers, Dye Lasers and Chemical Lasers	T1(116-120) T1(139-141) T1(145-149)
8	1hr	Revision	
Total no. of hours planned for unit –IV		8hr	

1	1hr	Advances in laser physics: Production of giant pulse and switching ,giant pulse dynamics	T1(150) T1(155-57)
2	1hr	Laser amplifiers, Mode locking and pulling	T1(158-164)
3	1hr	Nonlinear optics-Harmonic generation	T1(178-180)
4	1hr	Second harmonic generation, phase matching	T1(180-183)
5	1hr	Third harmonic generation and optical mixing	T1(184-185)
6	1hr	Para metric generation	T1(186)
7	1hr	Self-focusing of light	T1(187)
8	1hr	Revision	
Total no. of Hours planned for unit-III			8 hr.

LECTURE PLAN UNIT -III

LECTURE PLAN UNIT IV

Si.No	Lecture Duration (hr.)	Topics to be covered	Support Materials
1	1hr	Multi-photon processes; multi-quantum photoelectric effect, Theory of two-photon process	T1(189-190) T1(190-191) T1(198)
2	1hr	Theory of three photon process, second harmonic generation, parametric generation of light	T1(199)
3	1hr	Laser spectroscopy : Rayleigh and Raman scattering, Stimulated Raman effect	T1(205-206) T1(207-208)
4	1hr	Hyper-Raman effect	T1(209)
5	1hr	Coherent anti-stokes Raman Scattering	T1(211)
6	1hr	Photo-acoustic Raman spectroscopy	T1(215-216)
7	1hr	Revision	
Total no. of hours planned for unit –IV		7	

LECTURE PLAN UNIT - V

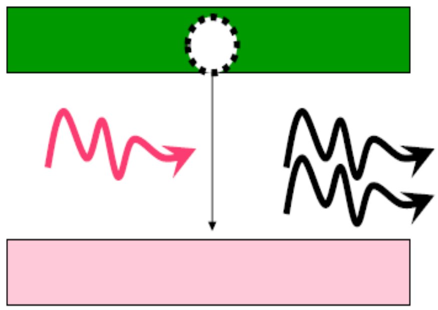
Si.No	Lecture Duration (hr.)	Topics to be covered	Support Materials
1	1hr	Laser Applications – ether drift and absolute rotation of the Earth	T1(236)
2	1hr	contination	
3	1hr	isotope separation, lasma,	T1(237-239)
4	1hr	thermonuclear fusion	T1(239-240)
5	1hr	laser applications in chemistry, biology,	T1(240-242)
6	1hr	astronomy	T1(243-243)
7	1hr	engineering and medicine	T1(243-245)
8	1hr	Communication by lasers: ranging,	T1(247-248)
9	1hr	fibre Optics Communication, Optical fibre,	T1(252-254)
10	1hr	numerical aperture	T1(255-256)
11	1hr	propagation of light in a medium with variable index	T1(255-256)
12	1hr	pulse dispersion	T1(256-258)
13	1hr	Revision	
14	1hr	old question Paper discussion	
15	1hr	Old question paper discussion	
16	1hr	Old question paper discussion	
		Total no. of hours planned for unit –v	**16**

LASER CHARACTERESTIC

SPONTANEOUS AND STIMULATED EMISSION

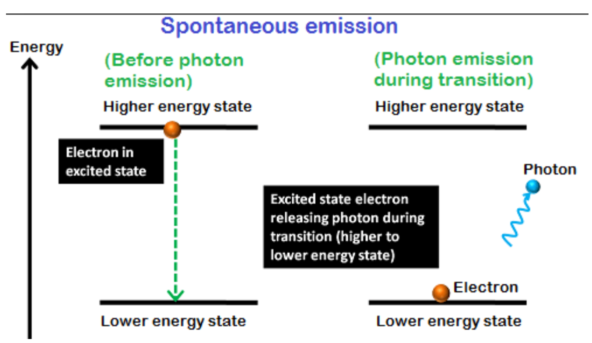
Stimulated emission

An incident photon causes an upper level atom to decay, emitting a “stimulated” photon whose properties are identical to those of the incident photon. The term “stimulated” underlines the fact that this kind of radiation only occurs if an incident photon is present. The amplification arises due to the similarities between the incident and emitted photons



Spontaneous absorption

Spontaneous emission is the process in which a quantum mechanical system (such as an atom, molecule or subatomic particle) transitions from an excited energy state to a lower energy state (e.g., its ground state) and emits a quantum in the form of a photon



EINSTEIN QUANTUM THEORY OF RADIATION

Sixteen years ago, when Planck created quantum theory by deriving his radiation formula, he took the following approach. He calculated the mean energy $\bar{E}$ of a resonator as a function of temperature according to his newly found quantum-theoretic basic principles, and determined from this the radiation density ρ as a function of frequency ν and temperature. He accomplished this by deriving based upon electromagnetic considerations a relation between radiation density and resonator energy $\bar{E}$:

$$\bar{E} = c^3 \rho / 8 \pi \nu^2 \qquad \text{--------------} \qquad (1)$$

His derivation was of unparalleled boldness, but found brilliant confirmation. Not only the radiation formula proper and the calculated value of the elementary quantum in it were confirmed, but also the quantum-theoretically calculated value of $\bar{E}$ was confirmed by later investigations on specific heat. In this manner, equation (1), originally found by electromagnetic reasoning, was also confirmed. However, it remained unsatisfactory that the electromagnetic-mechanical analysis is incompatible with quantum theory, and it is not surprising that Planck himself and all theoreticians who work on this topic incessantly tried to modify the theory such as to base it on non-contradictory foundations.

Since Bohr's theory of spectra has achieved its great successes, it seems no longer doubtful that the basic idea of quantum theory must be maintained. It so appears that the uniformity of the theory must be established such that the electro magneto-mechanical considerations, which led Planck to equation (1), are to be replaced by quantum theoretical contemplations on the interaction between matter and adiation.

1. PLANCK's Resonator in a Field of Radiation

The behavior of a monochromatic resonator in a field of radiation, according to the classical theory, can be easily understood if one recalls the manner of treatment that was first used in the theory of Brownian movement. Let E be the energy of the resonator at a given moment in time; we ask for the energy after time τ has elapsed. Hereby, τ is assumed to be large compared to the period of oscillation of the resonator, but still so small that the percentage change of E during τ can be treated as infinitely small. Two kinds of change can be distinguished. First the change

$$\Delta_1 E = - A E_\tau$$

effected by emission; and second, the change $\Delta_2 E$ caused by the work done by the electric field on the resonator. This second change increases with the radiation density and has a "chance"-dependent value and a "chance"-dependent sign. An electromagnetic, statistical consideration yields the mean-value relation

$$< \Delta_2 E > = - B \rho \tau$$

The constants A and B can be calculated in known manner. We call $\Delta_1 E$ the energy change due to emitted radiation, $\Delta_2 E$ the energy change due to incident radiation. Since the mean value of E, taken over many resonators, is supposed to be independent of time, there has to be

$$< E + \Delta_1 E + \Delta_2 E > = \bar{E}$$

or

$$\bar{E} = - (B / A) \rho$$

One obtains relation equation (1) calculates B and A for the monochromatic resonator in the known way with the help of electromagnetism and mechanics. We now want to undertake corresponding considerations, but on a quantum-theoretical basis and without specialized suppositions about the interaction between radiation and those structures which we want to call "molecules."

2. Quantum Theory and Radiation

We consider a gas of identical molecules that are in static equilibrium with thermal radiation. Let each molecule be able to assume only a discrete sequence Z_1, Z_2, etc., of states with energy values ε_1, ε_2, respectively. Then it follows in known manner and in analogy to statistical mechanics, or directly from Boltzmann's principle, or finally from thermodynamic considerations, that the probability W_n of state Z_n (or the relative number of molecules which were in state Z_n) is given by

$$W_n = p_n e^{-\varepsilon_n / k T} \qquad (2)$$

where k is the well-known Boltzmann constant. p_n is the statistical "weight" of state Z_n, i.e., a constant that is characteristic of the quantum state of the molecule but independent of the gas temperature T. Molecule can go from state Z_n to state Z_m by absorbing radiation of the distinct frequency $\nu = \nu_{nm}$; and likewise from state Z_m to state Z_n by emitting such radiation. The radiation energy involved is $\varepsilon_m - \varepsilon_n$. In general, this is possible for any combination of two indices m and n. With respect to any of these elementary processes there must be a statistical equilibrium in thermal equilibrium. Therefore, we can confine ourselves to a single elementary process belonging to a distinct pair of indices (n,m).At the thermal equilibrium, as many molecules per time unit will change from state Z_n to state Z_m under absorption of radiation, as molecules will go from state Z_m to state Z_n with emission of radiation. We shall state simple hypotheses about these transitions, where our guiding principle is the limiting case of classical theory, as it has been briefly outlined above.

We shall distinguish here also two types of transitions:

Emission of Radiation:

This will be a transition from state Z_m to state Z_n with emission of the radiation energy $\varepsilon_m - \varepsilon_n$. This transition will take place without external influence. One can hardly imagine it to be other than similar to radioactive reactions. The number of transitions per time unit will have to be put at $A_m^n N_m$,where A_m^n is a constant that is characteristic of the combination of the states Z_m and Z_n, and N_m is the number of molecules in state Z_m.

b) Incidence of Radiation. Incidence is determined by the radiation within which the molecule resides; let it be proportional to the radiation density ρ of the effective frequency. In case of the resonator it may cause a loss in energy as well as an increase in energy; that is, in our case, it may cause a transition $Z_n \rightarrow Z_m$ as well as a transition $Z_m \rightarrow Z_n$. The number of transitions $Z_n \rightarrow Z_m$ per unit time is then $B_n^m N_n \rho$,

and the number of transitions $Z_m \rightarrow Z_n$ is to be expressed as

$$B_m^n N_m \rho,$$

where B_n^m, B_m^n are constants related to the combination of states Z_n, Z_m.

As a condition for the statistical equilibrium between the reactions $Z_n \rightarrow Z_m$ and $Z_m \rightarrow Z_n$ one finds, therefore, the equation

$$A_m^n N_m + B_m^n N_m \rho = B_n^m N_n \rho \qquad (3)$$

Equation (2), on the other hand, yields

$$N_n / N_m = (p_n / p_m)\, e^{(\varepsilon_m - \varepsilon_n)/kT} \qquad (4)$$

From (3) and (4) follows

$$A_m^n p_m = \rho\, (B_n^m p_n\, e^{(\varepsilon_m - \varepsilon_n)/kT} - B_m^n p_m) \qquad (5)$$

ρ is the radiation density of that frequency which is emitted with the transition $Z_m \rightarrow Z_n$ and is absorbed with $Z_n \rightarrow Z_m$. Our equation shows the relation between T and ρ at this frequency.

If we postulate that ρ must approach infinity with ever increasing T, then we necessarily have

$$B_n^m p_n = B_m^n p_m \qquad (6)$$

Introducing the abbreviation

$$A_m^n / B_m^n p_m = \alpha_{mn}, \qquad (7)$$

one finds

$$\rho = \alpha_{mn} / (e^{(\varepsilon_m - \varepsilon_n)} / k T - 1) \qquad (5a)$$

Einstein has derived Planck's blackbody law

This is Planck's relation between ρ and T with the constants left indeterminate. The constants A_m^n and B_m^n could be calculated directly if we possessed a modified version of electrodynamics and mechanics that is in compliance with the quantum hypothesis.

Einstein derives Bohr's second postulate

The fact that ρ must be a universal function of T and ν implies that α_{mn} and $\varepsilon_m - \varepsilon_n$ cannot depend upon the specific constitution of the molecule, but only upon the effective frequency ν. From Wien's law follows furthermore that α_{mn} must be proportional to the third power, and $\varepsilon_m - \varepsilon_n$ to the first power of ν . Consequently, one has

$$\varepsilon_m - \varepsilon_n = h\nu \qquad (8)$$

where hν is a constant.

While the three hypotheses concerning emission and incidence of radiation lead to Planck's radiation formula, I am of course very willing to admit that this does not elevate them to confirmed results. But the simplicity of the hypotheses, the generality with which the analysis can be carried out so effortlessly, and the natural connection to Planck's linear oscillator (as a limiting case of classical electrodynamics and mechanics) seem to make it highly probable that these are basic traits of a future theoretical representation. The postulated statistical law of emission is nothing but Rutherford's law of radioactive decay, and the law expressed by (8), in conjunction with (5a), is identical with the second basic hypothesis in Bohr's theory of spectra this too speaks in favor of the theory presented here.

Remark on the Photochemical Law of Equivalence

The photochemical law of equivalence falls in line with our train of thoughts in the following manner. Let there be a gas of such low temperature that the thermal radiation of frequency ν, which leads from state Z_m to state Z_n, does not practically occur.

According to (2) and (5a), the state Z_m will be quite rare compared to state Z_n, and we shall assume that almost all gas molecules are in state Z_n. Aside from the previously considered process $Z_m \rightarrow Z_n$, let the molecule in state Z_m also have the capability of another elementary "chemical" process, e.g., monomolecular dissociation. Let us furthermore assume that the reaction rate of this dissociation is large compared to the rate of occurrence of the reaction $Z_m \rightarrow Z_n$.

Under absorption of the radiation energy

$$\varepsilon_m - \varepsilon_n = h\nu,$$

Molecules will continually go from state Z_n to state Z_m. Only a very small fraction of these molecules will return to state Z_n by emission or absorption. Most, by far, will suffer chemical dissociation, corresponding to the postulated higher reaction rate of this process. This means that per dissociating molecule, we will practically find that the radiation energy hν has been absorbed, just as the law of equivalence demands. The essence of this interpretation is that molecular dissociation is achieved by the absorption of light via the quantum state Z_m, but not directly without this intermediate state. In consequence, one need not distinguish between a chemically effective and a chemically ineffective absorption of radiation. The absorption of light and the chemical process appear as independent.

COHERENCE AND MONOCHROMATICITY

Coherence

Two wave sources are perfectly coherent if they have a constant phase difference and the same frequency, and the same waveform. Coherence is an ideal property of waves that enables stationary (i.e. temporally and spatially constant) interference. It contains several distinct concepts, which are limiting cases that never quite occur in reality but allow an understanding of the physics of waves, and has become a very important concept in quantum physics. More generally, coherence describes all properties of the correlation between physical quantities of a single wave, or between several waves or wave packets. Interference is nothing more than the addition, in the mathematical sense, of wave functions. A single wave can interfere with itself, but this is still an addition of two waves (see Young's double slits experiment). Constructive or destructive interferences are limit cases, and two waves always interfere, even if the result of the addition is complicated or not remarkable.

When interfering, two waves can add together to create a wave of greater amplitude than either one (constructive interference) or subtract from each other to create a wave of lesser amplitude than either one (destructive interference), depending on their relative phase. Two waves are said to be coherent if they have a constant relative phase. The amount of coherence can readily be measured by the interference visibility, which looks at the size of the interference fringes relative to the input waves (as the phase offset is varied); a precise mathematical definition of the degree of coherence is given by means of correlation functions.

Spatial coherence describes the correlation (or predictable relationship) between waves at different points in space, either lateral or longitudinal.[1] Temporal coherence describes the correlation between waves observed at different moments in time. Both are observed in the Michelson–Morley experiment and Young's interference experiment. Once the fringes are obtained in the Michelson interferometer, when one of the mirrors is moved away gradually, the time for the beam to travel increases and the fringes become dull and finally are lost, showing temporal coherence. Similarly, if in a double-slit experiment, the space between the two slits is increased, the coherence dies gradually and finally the fringes disappear, showing spatial coherence. In both cases, the fringe amplitude slowly disappears, as the path difference increases past the coherence length.

Monochromaticity

Monochromacity which produce a monochromatic light. Sodium vapour lamp emits yellow color light is called monochromaticity. Na Vapour lamp produce yellow light of two different wavelengths 5890 Ǻ and 5896Ǻ.

LINE BROADENING

Broadening in laser physics is a physical phenomenon that affects the spectroscopic line shape of the laser emission profile. The laser emission is due to the (excitation and subsequent) relaxation of a quantum system (atom, molecule, ion, etc.) between an excited state (higher in energy) and a lower one. These states can be thought as the Eigen states of the energy operator. The difference in energy between these states is proportional to the frequency/wavelength of the photon emitted. Since this energy difference has a fluctuation, then the frequency/wavelength of the "macroscopic emission" (the beam) will have a certain width (i.e. it will be "broadened" with respect to the "ideal" perfectly monochromatic emission).

Depending on the nature of the fluctuation, there can be two types of broadening. If the fluctuation in the frequency/wavelength is due to a phenomenon that is the same for each quantum emitter, there is homogeneous broadening, while if each quantum emitter has a different type of fluctuation, the broadening is inhomogeneous.Examples of situations where the fluctuation is the same for each system (homogeneous broadening) are natural or lifetime broadening, and collisional or pressure broadening. In these cases each system is affected "on average" in the same way (e.g. by the collisions due to the pressure).

The most frequent situation in solid state systems where the fluctuation is different for each system (inhomogeneous broadening) is when because of the presence of dopants, the local electric field is different for each emitter, and so the Stark effect changes the energy levels in an inhomogeneous way. The homogeneous broadened emission line will have a Lorentzian profile (i.e. will be best fitted by a Lorentzian function), while the in homogeneously broadened emission will have a Gaussian profile. One or more phenomena may be present at the same time, but if one has a wider fluctuation, it will be the one responsible for the character of the broadening.

These effects are not limited to laser systems, or even to optical spectroscopy. They are relevant in magnetic resonance as well, where the frequency range is in the radiofrequency region for NMR, and one can also refer to these effects in EPR where the line shape is observed at fixed (microwave) frequency and in a magnetic field range.

BASIC PRINCIPLES OF LASER

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.

$$E2 - E1 = h\upsilon_0$$

Where E2 is the upper energy level

E1 is the lower energy level

h is Plank's constant

υ_0 is frequency of the radiated EM wave.

Stimulated Emission

The atoms of the active medium are initially in E_2. If external EM waves with frequency υ_0 that is near the transition frequency between E_2 and E_1 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 E_1, 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 E_2. This process is called **Stimulated Absorption**.

Non-Radiative Decay

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

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.

Pumping 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 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

$U(x) = nh\upsilon_0$. The increase in the signal is given by

$$du(x)/dx= K[N_2(x)-N_1(x)]U(x)$$

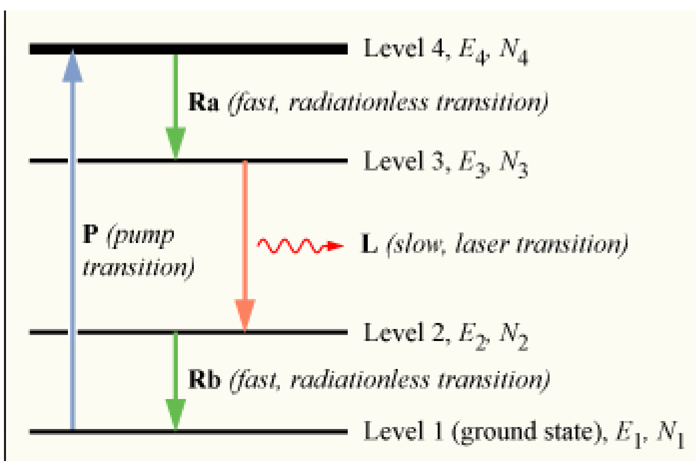
K is a proportionality constant. The solution is

$$U(x)=\exp[-K(N_1-N_2]x$$

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.

POPULATION INVERSION

A population inversion occurs while a system (such as a group of atoms or molecules) exists in a state in which more members of the system are in higher, excited states than in lower, unexcited energy states. It is called an "inversion" because in many familiar and commonly encountered physical systems, this is not possible. The concept is of fundamental importance in laser science because the production of a population inversion is a necessary step in the workings of a standard laser.



LASER PUMPING

Laser pumping is the act of energy transfer from an external source into the gain medium of a laser. The energy is absorbed in the medium, producing excited states in its atoms. When the number of particles in one excited state exceeds the number of particles in the ground state or a less-excited state, population inversion is achieved. In this condition, the mechanism of stimulated emission can take place and the medium can act as a laser or an optical amplifier. The pump power must be higher than the lasing threshold of the laser. The pump energy is usually provided in the form of light or electric current, but more exotic sources have been used, such as chemical or nuclear reactions.

TWO AND THREE LEVEL LASER SYSTEM

In a three-level system, the laser transition ends on the ground state. The unpumped gain medium exhibits strong absorption on the laser transition. A population inversion and consequently net laser gain result only when more than half of the ions (or atoms) are pumped into the upper laser level; the threshold pump power is thus fairly high.

The population inversion can be achieved only by pumping into a higher-lying level, followed by a rapid radiative or non-radiative transfer into the upper laser level, because in this way one avoids stimulated emission caused by the pump wave. (For transitions between only two levels, simultaneous pump absorption and signal amplification can not occur).An example of a three-level laser medium is ruby (Cr^{3+}:Al_2O_3), as used by Maiman for the first laser.

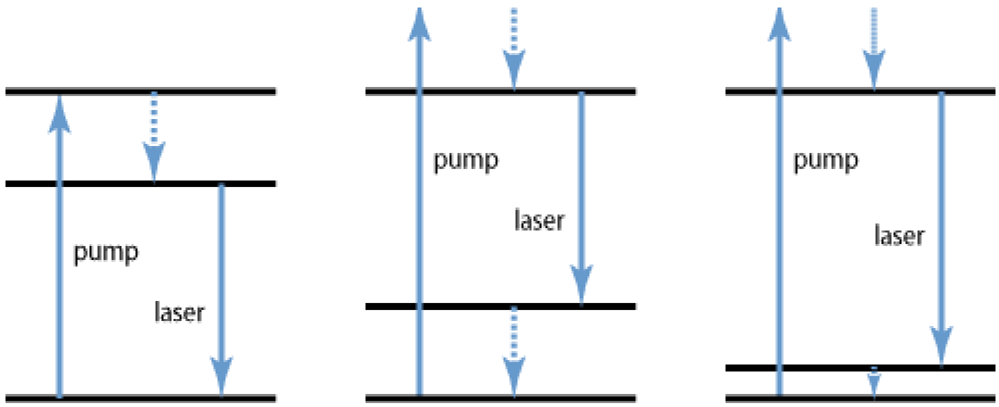


Figure 1: Energy level diagrams of different laser systems. The horizontal lines indicate energy levels; the higher a line, they higher the corresponding energy. Left: a three-level system, where the laser transitions ends on the ground state. Middle: a four-level system, where the laser transition ends on a level above the ground state, which is quickly depopulated e.g. via phonons. Right: a quasi-three-level system, where the lower laser level has some population in thermal equilibrium.

Energy level diagrams of different laser system. The horizontal lines indicate energy levels.

The higher energy level was exited state. The second level was Meta stable state the life time of atoms was very high in this state.

RESONATOR

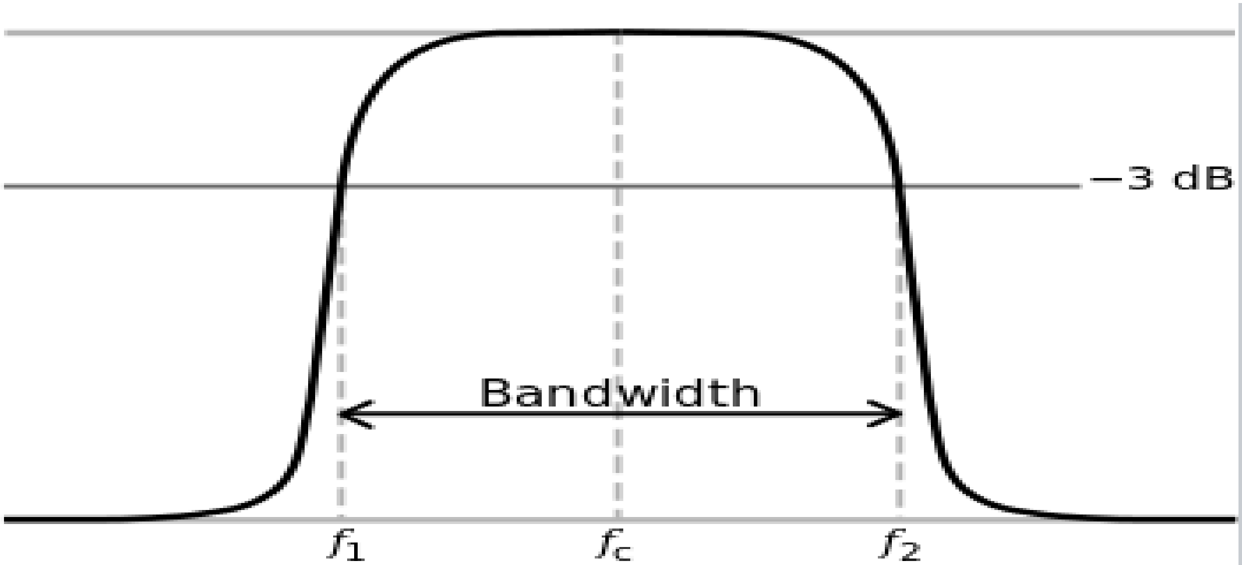
An optical cavity, resonating cavity or optical resonator is an arrangement of mirrors that forms a standing wave cavity resonator for light waves. Optical cavities are a major component of lasers, surrounding the gain medium and providing feedback of the laser light.

Q FACTOR

The quality factor or *Q* factor is a dimensionless parameter that describes how underdamped an oscillator or resonator is, and characterizes a resonator's bandwidth relative to its center frequency.Higher *Q* indicates a lower rate of energy loss relative to the stored energy of the resonator; the oscillations die out more slowly. A pendulum suspended from a high-quality bearing, oscillating in air, has a high *Q*, while a pendulum immersed in oil has a low one. Resonators with high quality factors have low damping, so that they ring or vibrate longer.

Q factor is a parameter that describes the resonance behavior of an underdamped harmonic oscillator (resonator). Sinusoidally driven resonators having higher *Q* factors resonatewith greater amplitudes (at the resonant frequency) but have a smaller range of frequencies around that frequency for which they resonate; the range of frequencies for which the oscillator resonates is called the bandwidth. Thus, a high-*Q* tuned circuit in a radio receiver would be more difficult to tune, but would have more selectivity; it would do a better job of filtering out signals from other stations that lie nearby on the spectrum. High-*Q* oscillators oscillate with a smaller range of frequencies and are more stable.

The quality factor of oscillators varies substantially from system to system, depending on their construction. Systems for which damping is important (such as dampers keeping a door from slamming shut) have *Q* near ½. Clocks, lasers, and other resonating systems that need either strong resonance or high frequency stability have high quality factors. Tuning forks have quality factors around 1000. The quality factor of atomic clocks, superconducting RF cavities used in accelerators, and some high-*Q* lasers can reach as high as 10and higher.



The bandwidth $\Delta f = f_2 - f_1$ of a damped oscillator is shown on a graph of energy versus frequency. The Q factor of the damped oscillator, or filter, is $\frac{f_c}{\Delta f}$. The higher the Q, the narrower and 'sharper' the peak is.

THRESHOLD CONDITION

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. Above threshold, the slope of power vs. excitation is orders of magnitude greater. The line width of the laser's emission also becomes orders of magnitude smaller above the threshold than it is below. Above the threshold, the laser is said to be lasing.

QUANTUM YIELD

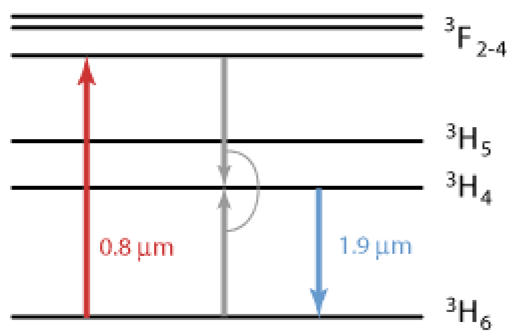
The quantum efficiency (or *quantum yield*) is often of interest for processes which convert light in some way. It is defined as the percentage of the input photons which contribute to the desired effect.

For Examples:

In a laser gain medium, the pump process may require the transfer of laser-active ions from one electronic level (into which the ions are pumped) to the upper level of the laser transition. This pump quantum efficiency is the fraction of the absorbed pump photons which contributes to the population of the upper laser level. This efficiency is close to unity (100%) for many laser gain media, but can be substantially smaller for others. It may depend on factors like the excitation density and parasitic absorption processes.

Similarly, the quantum efficiency of fluorescence can be defined. It can be reduced by non-radiative processes such as multi-phonon transitions and energy transfer processes. If such effects do not occur, it can be essentially 100%.

In a photodiode (or some other photo detector), the quantum efficiency can be defined as the fraction of incident (or alternatively, of absorbed) photons which contribute to the external photocurrent. In the visible and near-infrared region, quantum efficiencies above 90% are possible, although values between 40% and 80% are more common.



In the figure clearly shows that 9-µm emission in a thulium-doped fiber laser with > 100% quantum efficiency. the quantum efficiency of a laser or laser amplifier can be larger than unity. This is due to certain energy transfer processes between laser-active ions, which lead to a kind of cross-relaxation: starting with one ion in some excited state, a part of its energy is transferred to some other ion, which was originally in the electronic ground state, and both ions are finally in the upper laser level. This can, of course, only happen when the photon energy of the laser transition is lower than half that of the pump light. An example, illustrated in the above Figure, is that of thulium-doped 1.9-μm fiber lasers, where ions are pumped into the level $^3F_{2-4}$, and a cross-relaxation process (gray arrows) populates the upper laser level $^3H_4$. This could in principle lead to a quantum efficiency of up to 200%. Values well above 100% can be reached in practice.

UNIT 2

LASR SYSTEM

SOLID STATE LASER

A solid-state laser is a laser that uses a gain medium that is a solid, rather than a liquid such as in dye lasers or a gas as in gas lasers. Semiconductor-based lasers are also in the solid state, but are generally considered as a separate class from solid-state lasers. Generally, the active medium of a solid-state laser consists of a glass or crystalline "host" material, to which is added a "dopant" such as neodymium, chromium, erbium, thulium or ytterbium. Many of the common dopants are rare-earth elements, because the excited states of such ions are not strongly coupled with the thermal vibrations of their crystal lattices (phonons), and their operational thresholds can be reached at relatively low intensities of laser pumping.

There are many hundreds of solid-state media in which laser action has been achieved, but relatively few types are in widespread use. Of these, probably the most common is neodymium-doped yttrium aluminum garnet (Nd:YAG). Neodymium-doped glass (Nd:glass) and ytterbium-doped glasses or ceramics are used at very high power levels (tera watts) and high energies (mega joules), for multiple-beam inertial confinement fusion.The first material used for lasers was synthetic ruby crystals. Ruby lasers are still used for a few applications, but they are not common because of their low power efficiencies. At room temperature, ruby lasers emit only short pulses of light, but at cryogenic temperatures they can be made to emit a continuous train of pulses.

Some solid-state lasers can also be tunable using several intracavity techniques, which employ etalons, prisms, and gratings, or a combination of these. Sapphires widely used for its broad tuning range, 660 to 1080 nanometers. Alexandrite lasers are tunable from 700 to 820 nm and yield higher-energy pulses than titanium-sapphire lasers because of the gain medium's longer energy storage time and higher damage threshold.

Solid-state lasers are being developed as optional weapons for the F-35 Lightning II, and are reaching near-operational status, as well as the introduction of Northrop Grumman's FIRESTRIKE laser weapon system in high energy solid state laser. The exact range is classified, but they said it fired "miles not yards".

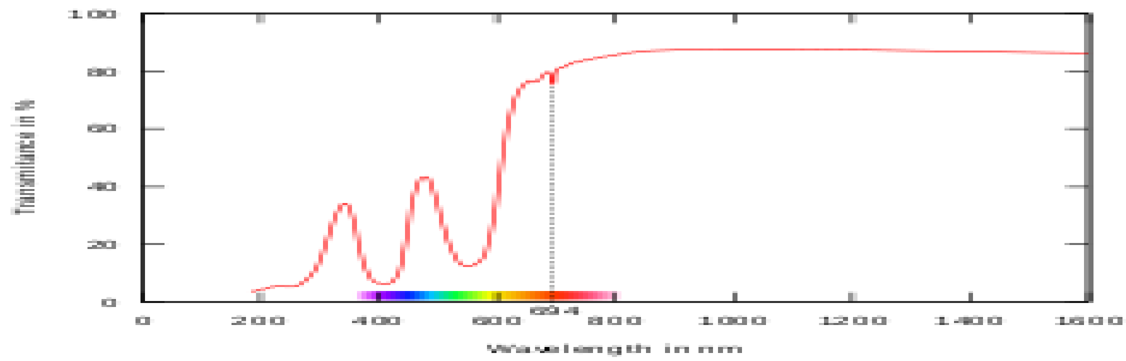
Uranium-doped calcium fluoride was the second type of solid state laser invented, in the 1960s. Peter Sorokin and Mirek Stevenson at IBM's laboratories in Yorktown Heights achieved lasing at 2.5 µm shortly after Maiman's ruby laser preparing to test a truck-mounted laser system using a 58 kW fiber laser .The scalability of the laser opens up use on everything from drones to massive ships at different levels of power. The new laser puts 40 percent of available energy into its beam, which is considered very high for solid-state lasers. Since more and more military vehicles and trucks are using advanced hybrid engine and propulsion systems that produce electricity for applications like lasers the applications are likely to proliferate in trucks, drones, ships, helicopters and planes.

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 1960. Ruby lasers produce pulses of coherent visible light at a wavelength of 694.3 nm, which is a deep red color. Typical ruby laser pulse lengths are on the order of a millisecond.

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 color, with a very narrow linewidth 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.



Transmittance of ruby in optical and near-IR spectra. Note the two broad blue and green absorption bands and the narrow absorption band at 694 nm, which is the wavelength of the ruby laser.

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 synthetic 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.

One of the first applications for the ruby laser was in range finding. By 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, because ruby's high-powered beam closely matches diamond's broad absorption band (the GR1 band) in the red. 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.

Nd :YAG LASER

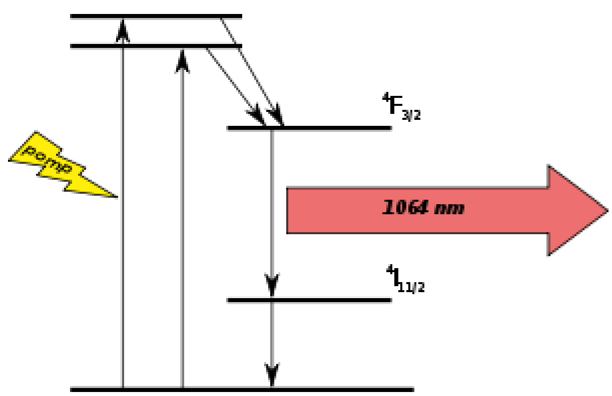
Nd:YAG (neodymium-doped yttrium aluminium garnet; Nd:$Y_3Al_5O_{12}$) is a crystal that is used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium, Nd(III), typically replaces a small fraction (1%) of the yttrium ions in the host crystal structure of the yttrium aluminium garnet (YAG), since the two ions are of similar size. It is the neodymium ion which provides the lasing activity in the crystal, in the same fashion as red chromium ion in ruby lasers.

Nd:YAG lasers are optically pumped using a flashtube or laser diodes. These are one of the most common types of laser, and are used for many different applications. Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 946, 1120, 1320, and 1440 nm. Nd:YAG lasers operate in both pulsed and continuous mode. Pulsed Nd:YAG lasers are typically operated in the so-called Q-switching mode.

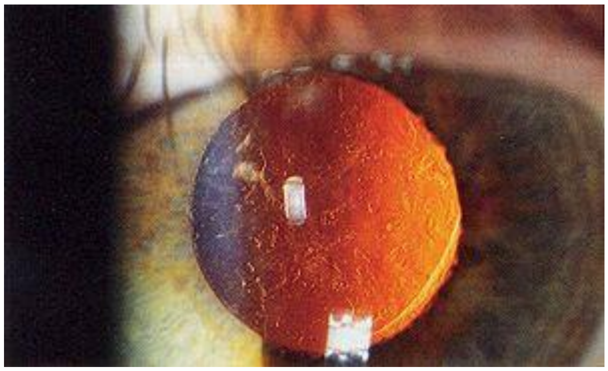
An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved. The high-intensity pulses may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355, 266 and 213 nm.

Nd:YAG absorbs mostly in the bands between 730–760 nm and 790–820 nm. At low current densities krypton flash lamps have higher output in those bands than do the more common xenon lamps, which produce more light at around 900 nm. The former are therefore more efficient for pumping Nd:YAG lasers.

The amount of the neodymium dopant in the material varies according to its use. For continuous wave output, the doping is significantly lower than for pulsed lasers. The lightly doped CW rods can be optically distinguished by being less colored, almost white, while higher-doped rods are pink-purplish. other common host materials for neodymium are: YLF (yttrium lithium fluoride, 1047 and 1053 nm), YVO_4 (yttrium orthovanadate, 1064 nm), and glass. A particular host material is chosen in order to obtain a desired combination of optical, mechanical, and thermal properties. Nd:YAG lasers and variants are pumped either by flashtubes, continuous gas discharge lamps, or near-infrared laser diodes (DPSS lasers). Prestabilized laser (PSL) types of Nd:YAG lasers have proved to be particularly useful in providing the main beams for gravitational wave interferometers such as LIGO, VIRGO, GEO600 and TAMA.



Neodymium ions in various types of ionic crystals, and also in glasses, act as a laser gain medium, typically emitting 1064 nm light from a particular atomic transition in the neodymium ion, after being "pumped" into excitation from an external source Medicine Slit lamp photo of posterior capsular opacification visible a few months after implantation of intraocular lens in eye, seen on retro illumination



Intraocular lens in eye.

Nd:YAG lasers are used in ophthalmology to correct posterior capsular opacification, a condition that may occur after cataractsurgery, and for peripheral iridotomy in patients with acute angle-closure glaucoma, where it has superseded surgical iridectomy.

Frequency-doubled Nd:YAG lasers (wavelength 532 nm) are used for pan-retinal photocoagulation in patients with diabetic retinopathy. In certain cases these lasers are also used to treat eye floaters.

Nd:YAG lasers emitting light at 1064 nm have been the most widely used laser for laser-induced thermotherapy, in which benign or malignant lesions in various organs are ablated by the beam.

In oncology, Nd:YAG lasers can be used to remove skin cancers. They are also used to reduce benign thyroid nodules, and to destroy primary and secondary malignant liver lesions.

To treat benign prostatic hyperplasia (BPH),

Nd:YAG lasers can be used for laser prostate surgery—a form of transurethral resection of the prostate.

These lasers are also used extensively in the field of cosmetic medicine for laser hair removal and the treatment of minor vascular defects such as spider veins on the face and legs.

Recently used for Dissecting cellulitis of the scalp, a rare skin disease. Using hysteroscopy the Nd:YAG laser has been used for removal of uterine septa within the inside of the uterus.
In podiatry, the Nd:YAG laser is being used to treat onychomycosis, which is fungus infection of the toenail. The merits of laser treatment of these infections are not yet clear, and research is being done to establish effectiveness.

Dentistry

Nd:YAG dental lasers are used for soft tissue surgeries in the oral cavity, such as gingivectomy, periodontal sulcular debridement, LANAP, frenectomy, biopsy, and coagulation of graft donor sites.

Manufacturing

Nd:YAG lasers are used in manufacturing for engraving, etching, or marking a variety of metals and plastics, or for metal surface enhancement processes like laser peening.[16] They are extensively used in manufacturing for cutting and welding steel, semiconductors and various alloys. For automotive applications (cutting and welding steel) the power levels are typically 1–5 kW. Super alloy drilling (for gas turbine parts) typically uses pulsed Nd:YAG lasers (millisecond pulses, not Q-switched). Nd:YAG lasers are also employed to make subsurface markings in transparent materials such as glass or acrylic glass. Lasers of up to 2 kW are used for selective laser melting of metals in additive layered manufacturing. In aerospace applications, they can be used to drill cooling holes for enhanced air flow/heat exhaust efficiency.[*citation needed*]
Nd:YAG lasers are also used in the non-conventional rapid prototyping process laser engineered net shaping (LENS).
Laser peening typically uses high energy (10 to 40 Joule), 10 to 30 nanosecond pulse, flashed laser systems to generate gigawatts of power on the surface of a part by focusing the laser beam down to a few millimeters in diameter. Laser peening is unlike the other manufacturing processes in that it neither heats or adds material; it is a mechanical process of cold working the metallic component to impart compressive residual stresses. Laser peening is widely used in gas fired turbine engines in both aerospace and power generation for component damage tolerance improvement and fatigue life and strength increase.

Fluid dynamics

Nd:YAG lasers can be used for flow visualization techniques in fluid dynamics (for example particle image velocimetry or laser-induced fluorescence).

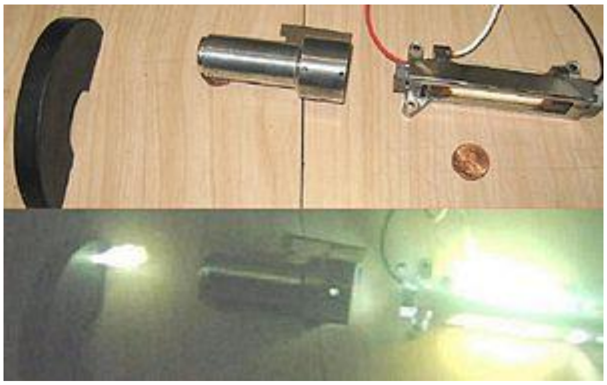
Biophysics Nd:YAG lasers are frequently used to build optical tweezers for biological applications. This is because Nd:YAG lasers mostly emit at a wavelength of 1064 nm. Biological samples have a low absorption coefficient at this wavelength, as biological samples are usually mostly made up of water. As such, using an Nd:YAG laser minimizes the damage to the biological sample being studied.

Automotive

The lasers use several 800 picosecond long pulses to ignite the fuel, producing faster and more uniform ignition. The researchers say that such igniters could yield better performance and fuel economy, with fewer harmful emissions.

Defence

Nd:YAG laser used for range finder firing.



The laser fires through a collimator, for focusing the beam, which blasts a hole through a rubber block, releasing a burst of plasma.The Nd:YAG laser is the most common laser used in laser designators and laser range finders. Cavity ring-down spectroscopy (CRDS) and Laser-induced breakdown spectroscopy (LIBS)

A range of Nd:YAG lasers are used in analysis of elements in the periodic table. Though the application by conventional methods such as XRF or ICP, it has proven to be less time consuming and a cheaper option to test element concentrations. A high-power Nd:YAG laser is focused onto the sample surface to produce plasma. Light from the plasma is captured by spectrometers and the characteristic spectra of each element can be identified, allowing concentrations of elements in the sample to be measured.

Laser pumping

Nd:YAG lasers, mainly via their second and third harmonics, are widely used to excite dye lasers either in the liquid or solid state. They are also used as pump sources for vibronically broadened solid-state lasers such as Cr^{4+}:YAG or via the second harmonic for pumping Ti:sapphire lasers.

GLASS LASER

Laser glass is the heart of the NIF laser system; it's the material that amplifies the laser light to the very high energies required for experiments.NIF's laser glass is a phosphate glass that contains a chemical additive with neodymium atoms (Nd:glass). Neodymium-doped laser glass is the preferred gain medium for use in high-peak-power lasers for fusion energy research.

The NIF laser system uses about 3,070 42-kilogram plates of laser glass. Each glass plate measures 3.4 by 46 by 81 centimeters (about three feet long and about half as wide). If stacked end-to-end, the plates would form a continuous ribbon of glass 1.5 miles long. The glass slabs are set on edge at a specific angle, known as Brewster's angle, so that the laser beams have very low reflective losses while propagating through the glass. laser glass at a rate 20 times faster, five times cheaper, and with two to three times better optical quality than with previous processes.

Flash lamps

The amplifier slabs are surrounded by vertical arrays of flashlamps. Measuring nearly 180 centimeters (6 feet) of arc length, NIF's 7,680 flashlamps are the largest commercial units ever made. Each is driven with about 50,000 joules of electrical energy. The flashlamps excite the neodymium in the glass slabs to provide optical gain at the infrared frequency of 1,053-nanometer wavelength, also referred to as "one omega," or 1ω, light. Some of the energy stored in the neodymium is released when the laser pulses from the injection laser system pass through the amplifier slabs

SEMICONDUCTING LASER

Semiconductor lasers or laser diodes play an important part in our everyday lives by providing cheap and compact-size lasers. They consist of complex multi-layer structures requiring nanometer scale accuracy and an elaborate design. Their theoretical description is important not only from a fundamental point of view, but also in order to generate new and improved designs. It is common to all systems that the laser is an inverted carrier density system. The carrier inversion results in an electromagnetic polarization which drives an electric field In most cases, the electric field is confined in a resonator, the properties of which are also important factors for laser performance.

In semiconductor laser theory, the optical gain is produced in a semiconductor material. The choice of material depends on the desired wavelength and properties such as modulation speed. It may be a bulk semiconductor, but more often a quantum hetero structure. Pumping may be electrically or optically (disk laser). All these structures can be described in a common framework and in differing levels of complexity and accuracy. Light is generated in a semiconductor laser by radiative recombination of electrons and holes. In order to generate more light by stimulated emission than is lost by absorption, the system has to be inverted, see the article on lasers. A laser is, thus, always a high carrier density system that entails many-body interactions. These cannot be taken into account exactly because of the high number of particles involved.

Various approximations can be made:

Hartree Fock approximation: To describe an interacting carrier system at any density, the semiconductor Bloch equations (SBEs) may be employed. These may be solved in the Hartree–Fock approximation. In this case, carrier–carrier interaction leads to renormalisation terms for band structure and electric field. The collision terms, using a relaxation time or T_2-time for the polarization.

Correlation effects: Taking the collision terms into account explicitly requires a large numerical effort, but can be done with state-of-the-art computers.[5] Technically speaking, the collision terms in the semiconductor Bloch equations are included in second-Born approximation.[3] This microscopic model has the advantage of having predictive character, i.e., it yields the correct linewidth for any temperature or excitation density. In the other models, the relaxation time has to be extracted from experiment, but depends on the actual parameters meaning the experiment has to be redone for any temperature and excitation intensity.

INTRINSIC SEMI CONDUCTING LASER

A semiconductor is a material whose conductivity lies between those of conductor and insulator. Semiconductors are of two types:

a) Intrinsic semiconductors or pure semiconductors

b) Extrinsic semiconductors or doped semiconductors

Extrinsic semiconductors are further classified into two types depending upon the type of majority carriers:

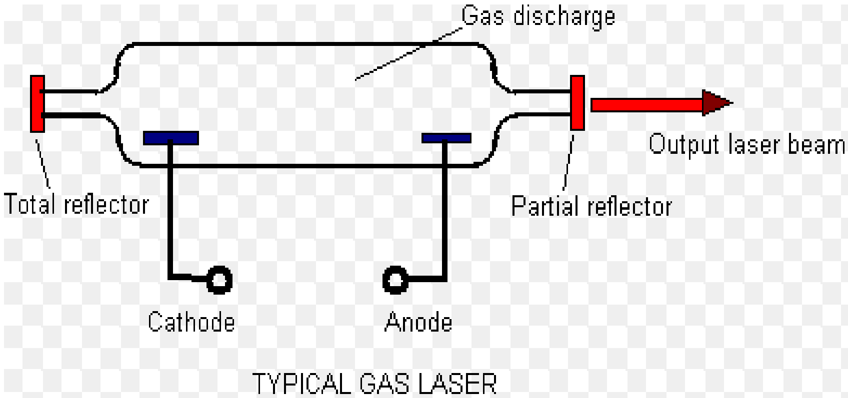
i) n-type semiconductors where electrons are majority carriers.

ii) p- type semiconductors where holes are majority carriers.

When a p-type semiconductor and a n- type semiconductor is joined by special techniques, there will be flow of electrons from n side to p side and flow of holes from p side to n side. After some time, an electric field will be created which will oppose this flow and flow stops. Thus, there will be formation of depletion region. This region is called so because it is depleted from charge carriers.

GAS LASER

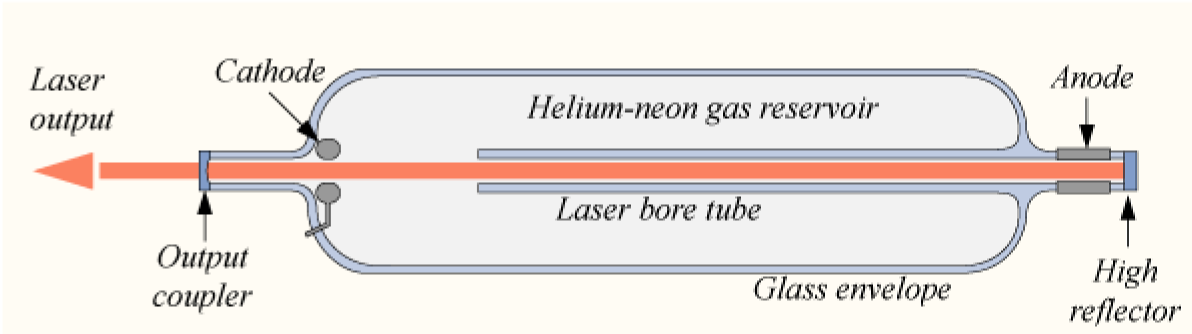
A gas laser is a laser in which an electric current is discharged through a gas to produce coherent light. The gas laser was the first continuous-light laser and the first laser to operate on the principle of converting electrical energy to a laser light output. Gas Lasers are lasers that use an electric current discharged through a gas medium to produce a beam. Common Gas Lasers include helium neon, argon, or carbon dioxide. The type of gas used can determine or influence the laser'swavelength, efficiency.



He -Ne LASER

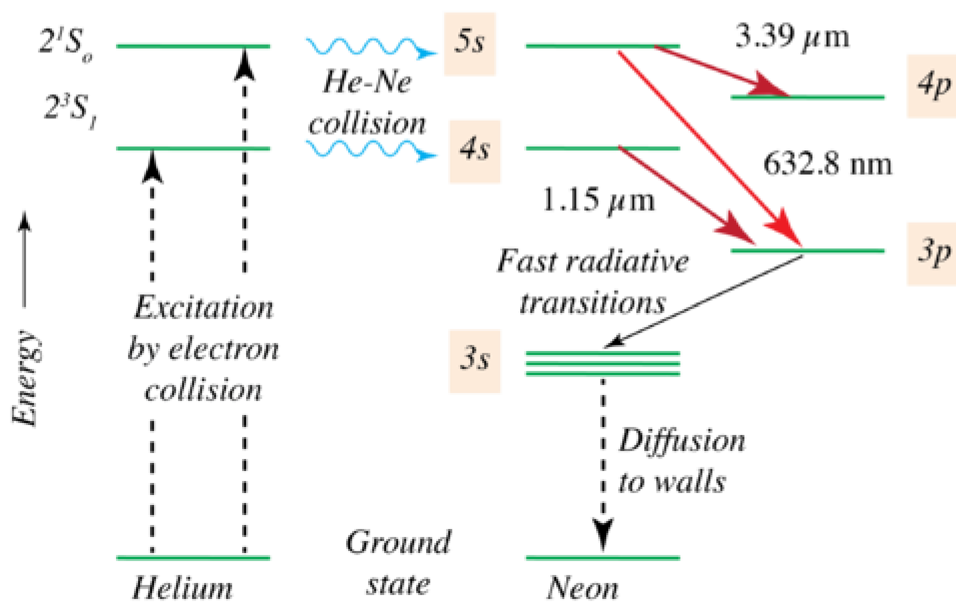
A helium–neon laser or HeNe laser, is a type of gas laser whose gain medium consists of a mixture of 85% helium and 15% neon inside of a small bore capillary tube, usually excited by a DC electrical discharge. The best-known and most widely used HeNe laser operates at a wavelength of 632.8 nm, in the red part of the visible spectrum.

The gain medium of the laser, as suggested by its name, is a mixture of helium and neon gases, in approximately a 10:1 ratio, contained at low pressure in a glass envelope. The gas mixture is mostly helium, so that helium atoms can be excited. The excited helium atoms collide with neon atoms, exciting some of them to the state that radiates 632.8 nm. Without helium, the neon atoms would be excited mostly to lower excited states responsible for non-laser lines. A neon laser with no helium can be constructed but it is much more difficult without this means of energy coupling. Therefore, a HeNe laser that has lost enough of its helium (e.g., due to diffusion through the seals or glass) will lose its laser functionality because the pumping efficiency will be too low.[5] The energy or pump source of the laser is provided by a high voltage electrical discharge passed through the gas between electrodes (anode and cathode) within the tube. A DC current of 3 to 20 mA is typically required for CW operation. The optical cavity of the laser usually consists of two concave mirrors or one plane and one concave mirror, one having very high (typically 99.9%) reflectance and the output coupler mirror allowing approximately 1% transmission.



Schematic diagram of a helium–neon laser

Commercial HeNe lasers are relatively small devices, among gas lasers, having cavity lengths usually ranging from 15 cm to 50 cm (but sometimes up to about 1 metre to achieve the highest powers), and optical output power levels ranging from 0.5 to 50 mW. The red HeNe laser wavelength of 633 nm has an actual vacuum wavelength of 632.991 nm, or about 632.816 nm in air. The wavelengths of the stimulated emission modes lie within about 0.001 nm above or below this value, and the wavelengths of those modes shift within this range due to thermal expansion and contraction of the cavity. Frequency-stabilized versions enable the wavelength of a single mode to be specified to within 1 part in 10^8 by the technique of comparing the powers of two longitudinal modes in opposite polarizations. Absolute stabilization of the laser's frequency (or wavelength) as fine as 2.5 parts in 10^{11}can be obtained through use of an iodine absorption cell.



Energy levels in a He-Ne Laser

The mechanism producing population inversion and light amplification in a HeNe laser plasma] originates with inelastic collision of energetic electrons with ground state helium atoms in the gas mixture. As shown in the accompanying energy level diagram, these collisions excite helium atoms from the ground state to higher energy excited states, among them the 2^3S_1 and 2^1S_0 (LS or Russell-Saunder coupling, front number 2 tells that an excited electron is n = 2 state) in long-lived metastable states. Because of a fortuitous near coincidence between the energy levels of the two He metastable states, and the $5s_2$ and $4s_2$(Paschen notation [9]) levels of neon, collisions between these helium metastable atoms and ground state neon atoms results in a selective and efficient transfer of excitation energy from the helium to neon. This excitation energy transfer process is given by the reaction equations:

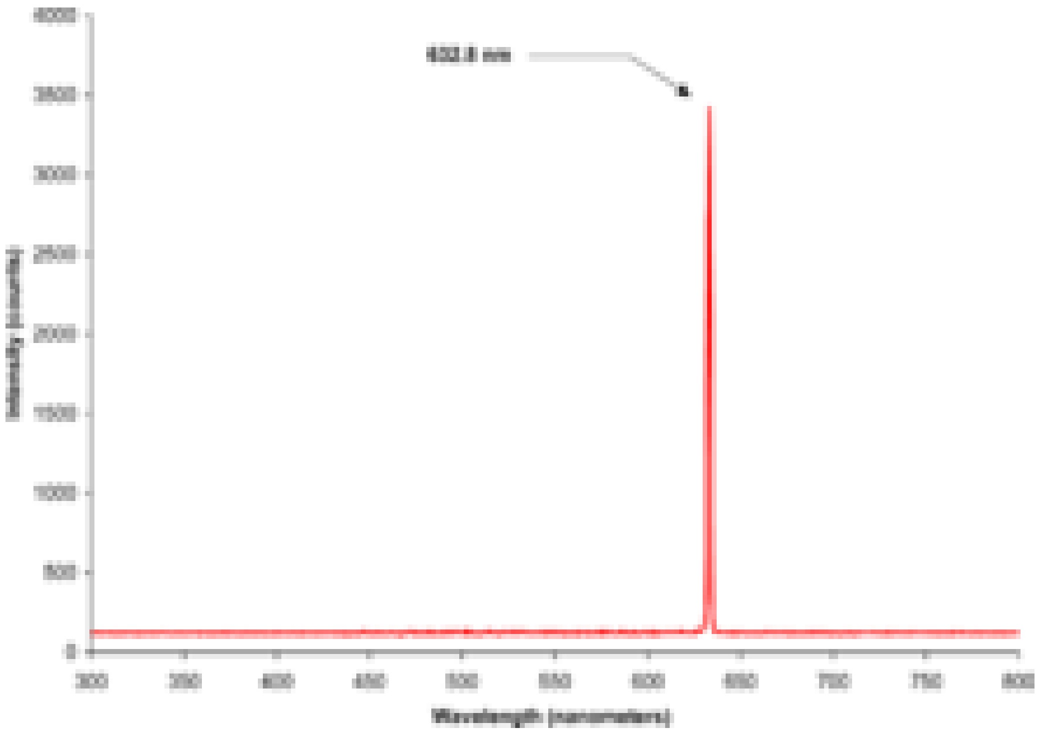
$$He^*(2^3S_1) + Ne^1S_0 \rightarrow He(^1S_0) + Ne^*4s_2 + \Delta E$$

and

$$He^*(2^1S) + Ne^1S_0 + \Delta E \rightarrow He(^1S_0) + Ne^*5s_2$$

where (*) represents an excited state, and ΔE is the small energy difference between the energy states of the two atoms, of the order of 0.05 eV or 387 cm^{-1}, which is supplied by kinetic energy. Excitation energy transfer increases the population of the neon $4s_2$ and $5s_2$levels manyfold. When the population of these two upper levels exceeds that of the corresponding lower level neon state, $3p_4$ to which they are optically connected, population inversion is present. The medium becomes capable of amplifying light in a narrow band at 1.15 μm (corresponding to the $4s_2$ to $3p_4$ transition) and in a narrow band at 632.8 nm (corresponding to the $5s_2$ to $3p_4$ transition at 632.8 nm). The $3p_4$ level is efficiently emptied by fast radiative decay to the 1s state, eventually reaching the ground state.

The remaining step in utilizing optical amplification to create an optical oscillator is to place highly reflecting mirrors at each end of the amplifying medium so that a wave in a particular spatial mode will reflect back upon itself, gaining more power in each pass than is lost due to transmission through the mirrors and diffraction. When these conditions are met for one or more longitudinal modes then radiation in those modes will rapidly build up until gain saturation occurs, resulting in a stable continuous laser beam output through the front (typically 99% reflecting) mirror.



Spectrum of a helium neon laser illustrating its very high spectral purity (limited by the measuring apparatus). The 0.002 nm bandwidth of the stimulated emission medium is well over 10,000 times narrower than the spectral width of a light-emitting diode (whose spectrum is shown here for comparison), with the bandwidth of a single longitudinal mode being much narrower still.

The gain bandwidth of the He-Ne laser is dominated by Doppler broadening rather than pressure broadening due to the low gas pressure, and is thus quite narrow: only about 1.5 GHz full width for the 633 nm transition. With cavities having typical lengths of 15 cm to 50 cm, this allows about 2 to 8 longitudinal modes to oscillate simultaneously (however single longitudinal mode units are available for special applications). The visible output of the red He-Ne laser, long coherence length, and its excellent spatial quality, makes this laser a useful source for holography and as a wavelength reference for spectroscopy. A stabilized He-Ne laser is also one of the benchmark systems for the definition of the meter. Prior to the invention of cheap, abundant diode lasers, red He-Ne lasers were widely used in barcode scanners at supermarket checkout counters. Laser gyroscopes have employed He-Ne lasers operating at 0.633 μm in a ring laser configuration.

He-Ne lasers are generally present in educational and research optical laboratories.

Red He-Ne lasers have many industrial and scientific uses. They are widely used in laboratory demonstrations in the field of optics because of their relatively low cost and ease of operation compared to other visible lasers producing beams of similar quality in terms of spatial coherence (a single-mode Gaussian beam) and long coherence length . A consumer application of the red He-Ne laser is the Laser Disc player. The laser is used in the device to read the optical disk.

MOLECULAR GAS LASER

In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.

In CO2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

C02 Molecular Gas Laser

It was the first molecular gas laser developed by Indian born American scientist Prof.C.K.N.Pillai.

It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser

ENERGY LEVELS OF CO_2 MOLECULES

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

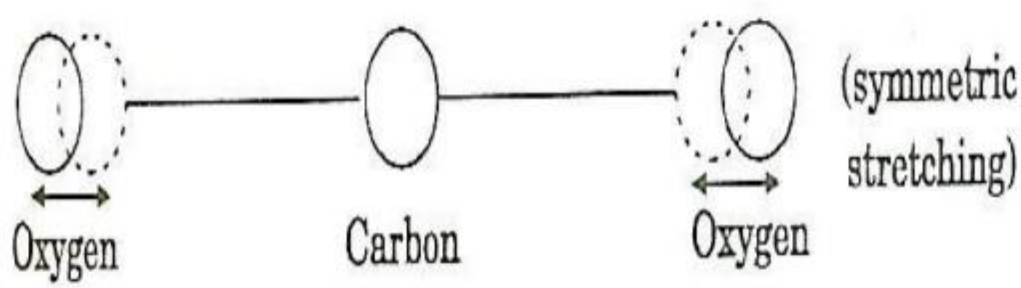
a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

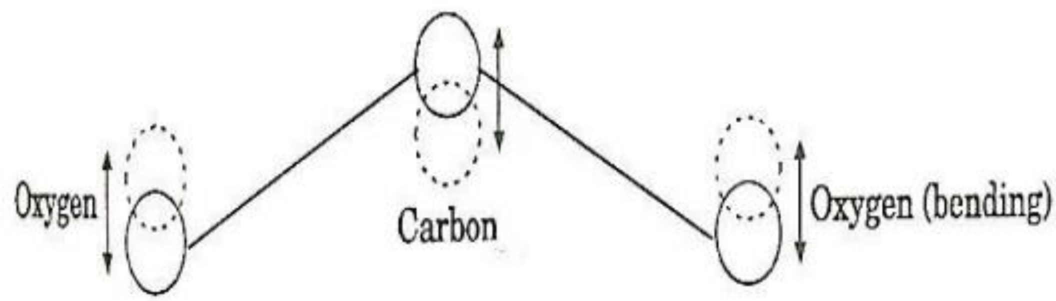
SYMMETRY STRETCHING MODE

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

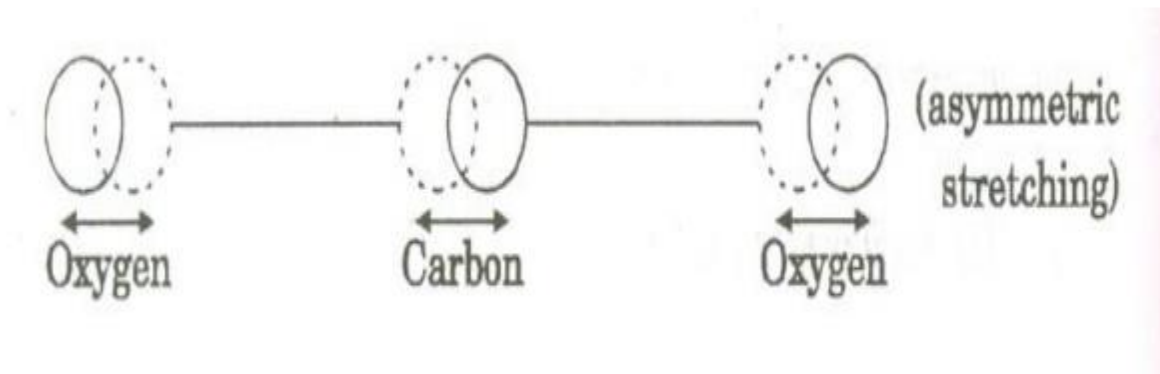


b. Bending mode:

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.



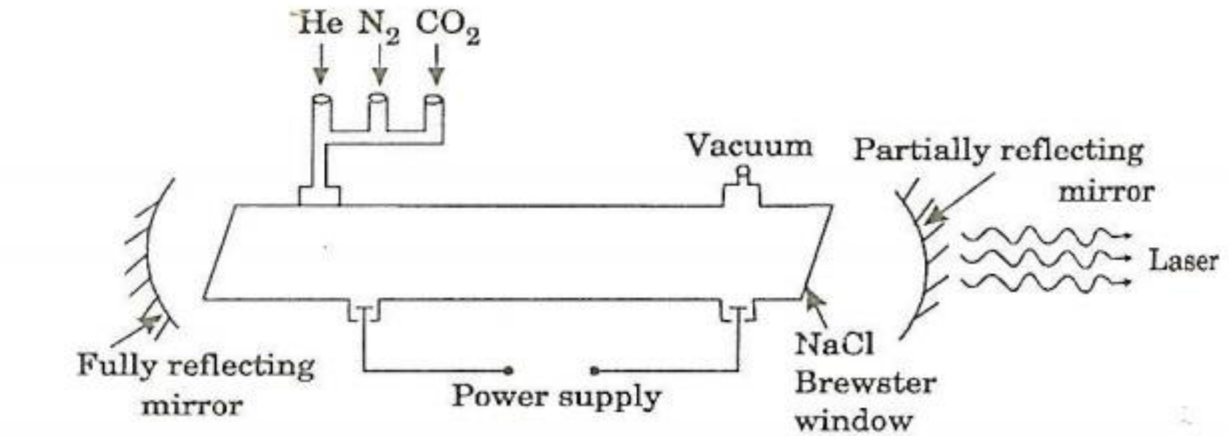
c. Asymmetric stretching mode:



In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

Principle:

The active medium is a gas mixture of CO_2, N_2 and He. The laser transition takes place between the vibrational states of CO_2molecules.



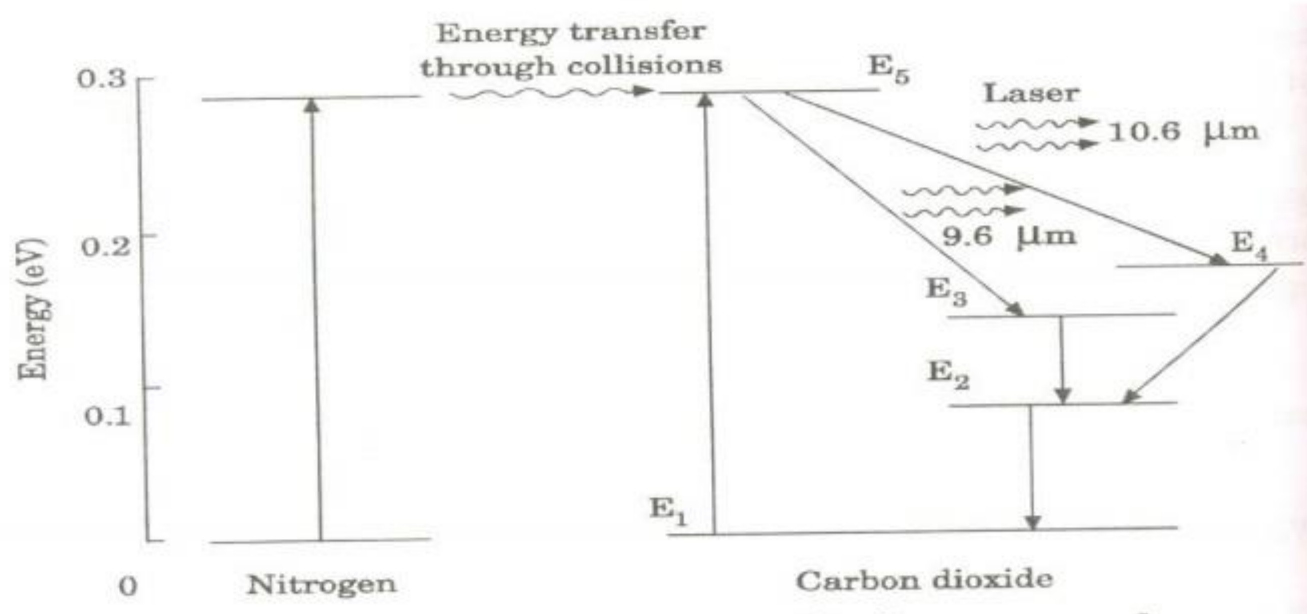
Construction:

It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2 (active medium), helium and nitrogen with suitable partial pressures.

The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.
Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working:

Figure shows energy levels of nitrogen and carbon dioxide molecules.



When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$$N_2 + e^* = N_2^* + e$$

N_2 = Nitrogen molecule in ground state e* = electron with kinetic energy
N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

Now N_2 molecules in the excited state collide with Co_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.
This process is represented by the equation $N_2^* + Co_2 = Co_2^* + N_2$

N2* = Nitrogen molecule in excited state. CO_2 = Carbon dioxide atoms in ground state CO_2^* = Carbon dioxide atoms in excited state N_2 = Nitrogen molecule in ground state.

Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases.

As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1.Transition E5 to E4 :

This will produce a laser beam of wavelength 10.6μm

2.Transition E5 to E3

This transition will produce a laser beam of wavelength 9.6μm. Normally 10.6μm transition is more intense than 9.6μm transition. The power output from this laser is 10kW.

Characteristics:

1. Type: It is a molecular gas laser.

2. Active medium: A mixture of CO2 , N2 and helium or water vapour is used as active medium

3. Pumping method: Electrical discharge method is used for Pumping action

4. Optical resonator: Two concave mirrors form a resonant cavity

5. Power output: The power output from this laser is about 10kW.

6. Nature of output: The nature of output may be continuous wave or pulsed wave.

7. Wavelength of output: The wavelength of output is 0.6μm and 10.6μm.

Advantages:

1. The construction of CO_2 laser is simple

2. The output of this laser is continuous.

3. It has high efficiency

4. It has very high output power.

5. The output power can be increased by extending the length of the gas tube.

Disadvantages:

1. The contamination of oxygen by carbon monoxide will have some effect on laser action

2. The operating temperature plays an important role in determining the output power of laser.

3. The corrosion may occur at the reflecting plates.

4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

Applications:

1. High power CO_2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6μm makes CO_2 laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.

5. It is mostly used in neuro surgery and general surgery.

6. It is used to perform microsurgery and bloodless operation

LIQUID LASER

A liquid-crystal laser is a laser that uses a liquid crystal as the resonator cavity, allowing selection of emission wavelength and polarization from the active laser medium. The lasing medium is usually a dye doped into the liquid crystal. Liquid-crystal lasers are comparable in size to diode lasers, but provide the continuous wide spectrum of dye lasers while maintaining a large coherence area. The tuning range is typically several tens of nanometers. Self-organization at micrometer scales reduces manufacturing complexity compared to using layered photonic meta materials. It can be achieved by doping the liquid crystal with a chiral molecule. For light circularly polarized with the same handedness, this regular modulation of the refractive index yields selective reflection of the wavelength given by the helical pitch, allowing the liquid-crystal laser to serve as its own resonator cavity. Photonic crystals are amenable to band theory methods, with the periodic dielectric structure playing the role of the periodic electric potential and a photonic band gap (reflection notch) corresponding to forbidden frequencies. The lower photon group velocity and higher density of states near the photonic band gap suppresses spontaneous emission and enhances stimulated emission, providing favorable conditions for lasing. If the electronic band edge falls in the photonic band gap, electron-hole recombination is strictly suppressed. This allows for devices with high lasing efficiency, low lasing threshold, and stable frequency, where the liquid-crystal laser acts its own waveguide. "Colossal" nonlinear change in refractive index is achievable in doped nematic-phase liquid crystals, that is the refractive index can change with illumination intensity at a rate of about $10^3 cm^2/W$ of illumination intensity. Most systems use a semiconductor pumping laser to achieve population inversion, though flash lamp and electrical pumping systems are possible.[15]
Tuning of the output wavelength is achieved by smoothly varying the helical pitch: as the winding changes, so does the length scale of the crystal. This in turn shifts the band edge and changes the optical path length in the lasing cavity. Applying a static electric field perpendicular to the dipole moment of the local nematic phase rotates the rod-like subunits in the hexagonal plane and reorders the chiral phase, winding or unwinding the helical pitch.[16] Similarly, optical

tuning of the output wavelength is available using laser light far from the pick-up frequency of the gain medium, with degree of rotation governed by intensity and the angle between the polarization of the incident light and the dipole moment. Reorientation is stable and reversible. The chiral pitch of a cholesteric phase tends to unwind with increasing temperature, with a disorder-order transition to the higher symmetry nematic phase at the high end. By applying a temperature gradient perpendicular to the direction of emission varying the location of stimulation, frequency may be selected across a continuous spectrum. Similarly, a quasi-continuous doping gradient yields multiple laser lines from different locations on the same sample. Spatial tuning may also be accomplished using a wedge cell. The boundary conditions of the narrower cell squeeze the helical pitch by requiring a particular orientation at the edge, with discrete jumps where the outer cells rotate to the next stable orientation; frequency variation between jumps is continuous.

If a defect is introduced into the liquid crystal to disturb the periodicity, a single allowed mode may be created inside of the photonic bandgap, reducing power leeching by spontaneous emission at adjacent frequencies.

Applications

Biomedical sensing: small size, low cost, and low power consumption offer a variety of advantages in biomedical sensing applications. Potentially, liquid-crystal lasers could form the basis for "lab on a chip" devices that provide immediate readings without sending a sample away to a separate lab.

Medical: low emission power limits such medical procedures as cutting during surgeries, but liquid-crystal lasers show potential to be used in microscopy techniques and techniques such as photodynamic therapy.

Display screens: liquid-crystal-laser-based displays offer most of the advantages of standard liquid-crystal displays, but the low spectral spread gives more precise control over color. Individual elements are small enough to act as single pixels while retaining high brightness and color definition. A system in which each pixel is a single spatially tuned device could avoid the sometimes long relaxation times of dynamic tuning, and could emit any color using spatial addressing and the same monochromatic pumping source.

Environmental sensing: using a material with a helical pitch highly sensitive to temperature, electric field, magnetic field, or mechanical strain, color shift of the output laser provides a simple, direct measurement of environmental conditions.

DYE LASER

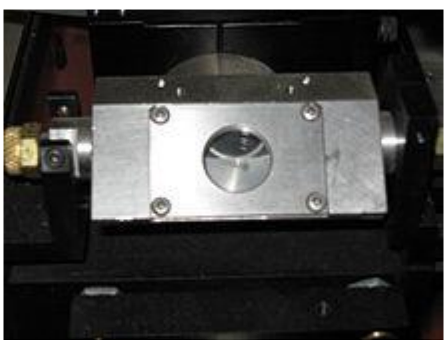
A dye laser is a laser which uses an organic dye as the lasing medium, usually as a liquid solution. Compared to gasesand most solid state lasing media, a dye can usually be used for a much wider range of wavelengths, often spanning 50 to 100 nanometers or more. The wide bandwidth makes them particularly suitable for tunable lasers and pulsed lasers. The dye rhodamine 6G, for example, can be tuned from 635 nm (orangish-red) to 560 nm (greenish-yellow), and produce pulses as short as 16 femtoseconds.[1] Moreover, the dye can be replaced by another type in order to generate an even broader range of wavelengths with the same laser, from the near-infrared to the near-ultraviolet, although this usually requires replacing other optical components in the laser as well, such as dielectric mirrors or pump lasers.

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.

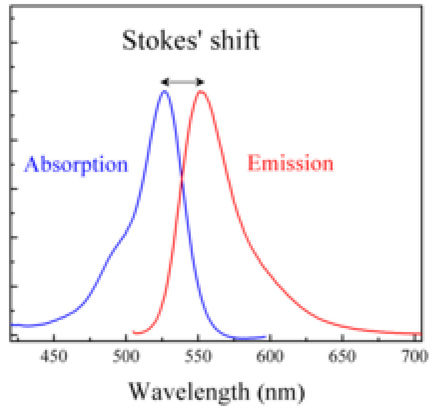
A dye laser uses a gain medium consisting of an organic dye, which is a carbon-based, soluble stain that is often fluorescent, such as the dye in a high lighter pen. The dye is mixed with a compatible solvent, allowing the molecules to diffuse evenly throughout the liquid. The dye solution may be circulated 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 flashtube 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 99.9% 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 flashtube 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 often a thin tube approximately equal in length to the flashtube, with both windows and an inlet or outlet for the liquid on each end. The dye cell is usually side-pumped, with one or more flashtubes 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 flashtube produces. Axial pumped lasers have a hollow, annular-shaped flashtube 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 flashtube, for even better transfer efficiency, but have a lower gain due to diffraction losses. Flash pumped lasers can be used only for pulsed output applications.

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 laser, 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.



A cuvette used in a dye laser. A thin sheet of liquid is passed between the windows at high speeds. The windows are set at Brewster's angle (air-to-glass interface) for the pump laser, and at Brewster's angle (liquid-to-glass interface) for the emitted beam.



Stokes shift in Rhodamine 6G during broadband absorption or emission. In laser operation, the Stokes shift is the difference between the pump wavelength and the output.

The dyes used in these lasers contain rather large, organic molecules which fluoresce. Most dyes have a very short time between the absorption and emission of light, referred to as the fluorescence lifetime, which is often on the order of a few nanoseconds. (In comparison, most solid-state lasers have a fluorescence lifetime ranging from hundreds of microseconds to a few milliseconds.) Under standard laser-pumping conditions, the molecules emit their energy before a population inversion can properly build up, so dyes require rather specialized means of pumping. Liquid dyes have an extremely high lasing threshold. In addition, the large molecules are subject to complex excited state transitions during which the spin can be "**flipped**", quickly changing from the useful, fast-emitting "**singlet**" state to the slower "triplet" state.

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 partially opaque. 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. Due to their high absorption, the pumping energy may often be concentrated into a rather small volume of liquid.

Now days 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 more-complicated alignment.

Liquid dyes have very high gain as laser media. The beam needs to make only 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 reflections from the dye-cell walls or flashlamp reflector cause parasitic oscillations, dramatically reducing 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.[11]

A benefit of organic dyes is their high fluorescence efficiency. The greatest losses in many lasers and other fluorescence devices is not from the transfer efficiency (absorbed versus reflected/transmitted energy) or quantum yield (emitted number of photons per absorbed number), but from the losses when high-energy photons are absorbed and reemitted as photons of longer wavelengths. Because the energy of a photon is determined by its wavelength, the emitted photons will be of lower energy; a phenomenon called the Stokes shift. The absorption centers of many dyes are very close to the emission centers. Sometimes the two are close enough that the absorption profile slightly overlaps the emission profile. As a result, most dyes exhibit very small Stokes shifts and consequently allow for lower energy losses than many other laser types due to this phenomenon. The wide absorption profiles make them particularly suited to broadband pumping, such as from a flashtube. It also allows a wide range of pump lasers to be used for any certain dye and, conversely, many different dyes can be used with a single pump laser

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 vapor 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 tunablities 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, femtosecond 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.

Tunable lasers are used in swept-frequency metrology to enable measurement of absolute distances with very high accuracy. A two axis interferometer is set up and by sweeping the frequency, the frequency of the light returning from the fixed arm is slightly different from the frequency returning from the distance measuring arm. This produces a beat frequency which can be detected and used to determine the absolute difference between the lengths of the two arms.

CHEMICAL LASER

A chemical laser is a laser that obtains its energy from a chemical reaction. Chemical lasers can reach continuous wave output with power reaching to megawatt levels. They are used in industry for cutting and drilling.

Common examples of chemical lasers are the chemical oxygen iodine laser (COIL), all gas-phase iodine laser (AGIL), and the hydrogen fluoride (HF) and deuterium fluoride (DF) lasers, all operating in the mid-infrared region. There is also a DF–CO_2 laser (deuterium fluoride–carbon dioxide), which, like COIL, is a "transfer laser." The HF and DF lasers are unusual, in that there is several molecular energy transitions with sufficient energy to cross the threshold required for lasing. Since the molecules do not collide frequently enough to re-distribute the energy, several of these laser modes operate either simultaneously, or in extremely rapid succession, so that an HF or DF laser appears to operate simultaneously on several wavelengths unless a wavelength selection device is incorporated into the resonator.

UNIT 3

ADVANCE IN LASER PHYSICS

Q switching

Q-switching, sometimes known as giant pulse formation or Q-spoiling, is a technique by which a laser can be made to produce a pulsed output beam. The technique allows the production of light pulses with extremely high (giga watt) peak power, much higher than would be produced by the same laser if it were operating in a continuous wave (constant output) mode. Compared to mode locking, another technique for pulse generation with lasers, Q-switching leads to much lower pulse repetition rates, much higher pulse energies, and much longer pulse durations. The two techniques are sometimes applied together.

Q-switching was first switched Kerr cell shutters in a ruby laser, Q-switching is achieved by putting some type of variable attenuator inside the laser's optical resonator. When the attenuator is functioning, light which leaves the gain medium does not return, and lasing cannot begin. This attenuation inside the cavity corresponds to a decrease in the Q factor or quality factor of the optical resonator. A high Q factor corresponds to low resonator losses per round trip, and vice versa. The variable attenuator is commonly called a "Q-switch", when used for this purpose.

Initially the laser medium is pumped while the Q-switch is set to prevent feedback of light into the gain medium (producing an optical resonator with low Q). This produces a population inversion, but laser operation cannot yet occur since there is no feedback from the resonator. Since the rate of stimulated emission is dependent on the amount of light entering the medium, the amount of energy stored in the gain medium increases as the medium is pumped. Due to losses from spontaneous emission and other processes, after a certain time the stored energy will reach some maximum level; the medium is said to be gain saturated. At this point, the Q-switch device is quickly changed from low to high Q, allowing feedback and the process of optical amplification by stimulated emission to begin. Because of the large amount of energy already stored in the gain medium, the intensity of light in the laser resonator builds up very quickly; this also causes the energy stored in the medium to be depleted almost as quickly. The net result is a short pulse of light output from the laser, known as a giant pulse, which may have a very high peak intensity.

Applications

Q-switched lasers are often used in applications which demand high laser intensities in nanosecond pulses, such as metal cutting or pulsed holography. Nonlinear optics often takes advantage of the high peak powers of these lasers, offering applications such as 3D optical data storage and 3D micro fabrication.

Q-switched lasers can also be used for measurement purposes, such as for distance measurements (range finding) by measuring the time it takes for the pulse to get to some target and the reflected light to get back to the sender. It can be also used in chemical dynamic study, e.g. temperature jump relaxation study.

Q-switched lasers are also used to remove tattoos by shattering ink pigments into particles that are cleared by the body's lymphatic system. Full removal can take between six and twenty treatments depending on the amount and colour of ink, spaced at least a month apart, using different wavelengths for different coloured inks. Nd:YAG lasers are currently the most favoured lasers due to their high peak powers, high repetition rates and relatively low costs. introduced based on clinical research which appears to show better clearance with 'difficult' colours such as green and light blue.

Q-switch laser is also used by beauticians around the world to treat skin-related issues like acne, pigmentation, dark spots, and fixes for ant-aging. Q switch is a more effective alternative than most other techniques.

LASER AMPLIFIER

An optical amplifier is a device which receives some input signal and generates an output signal with higher optical power. Typically, inputs and outputs are laser beams, either propagating as Gaussian beams in free space or in a fiber. The amplification occurs in a so-called gain medium, which has to be "pumped" (i.e., provided with energy) from an external source. Most optical amplifiers are either optically or electrically pumped.

Multimode and Single-mode Amplifiers

Some types of optical amplifiers are intrinsically multimode devices. For example, an amplifier based on bulk laser crystal can amplify multimode beams and can also handle beams with different angular positions and directions in certain ranges, which makes it possible to construct a multipass amplifier.

Other optical amplifiers are single-mode devices. For example, many fiber amplifiers and semiconductor optical amplifiers are based on a single-mode fiber or waveguide. In such cases, only a single mode can be amplified, and that has to be mode-matched to the amplifier.

When a single-mode laser amplifier provides a high gain within some bandwidth, it inevitably generates a substantial level of amplified spontaneous emission (ASE). In a multimode amplifier, this effect is correspondingly stronger. Even if ASE is negligible (for lower gain), a multimode amplifier typically exhibits more power losses by spontaneous emission (and thus has a lower gain efficiency) because a larger amount of laser-active material has to be kept in the excited state.

Important Parameters of an Optical Amplifier

Important parameters of an optical amplifier include:

The maximum gain, specified as an amplification factor or in decibels (dB)

The saturation power, which is related to the gain efficiency

the saturated output power (for a given pump power)

the power efficiency and pump power requirements

the saturation energy

the time of energy storage (→ upper-state lifetime)

the gain bandwidth (and possibly smoothness of gain spectrum)

the noise figure and possibly more detailed noise specifications

the sensitivity to back-reflections

the number of modes it can amplify

Applications

Typical applications of optical amplifiers are:

An amplifier can boost the (average) power of a laser output to higher levels (→ master oscillator power amplifier = MOPA).

It can generate extremely high peak powers, particularly in ultrashort pulses, if the stored energy is extracted within a short time.

It can amplify weak signals before photo detection, and thus reduce the detection noise, unless the added amplifier noise is large.

In long fiber-optic links for optical fiber communications, the optical power level has to be raised between long sections of fiber before the information is lost in the noise.

MODE LOCKING AND PULLING

Mode-locking is a technique in optics by which a laser can be made to produce pulses of light of extremely short duration, on the order of picoseconds (10^{-12} s) or femtoseconds (10^{-15} s).The basis of the technique is to induce a fixed-phase relationship between the longitudinal modes of the laser's resonant cavity. The laser is then said to be 'phase-locked' or 'mode-locked'. Interference between these modes causes the laser light to be produced as a train of pulses. Depending on the properties of the laser, these pulses may be of extremely brief duration, as short as a few femtoseconds.

In a simple laser, each of these modes oscillates independently, with no fixed relationship between each other, in essence like a set of independent lasers all emitting light at slightly different frequencies. The individual phase of the light waves in each mode is not fixed, and may vary randomly due to such things as thermal changes in materials of the laser. In lasers with only a few oscillating modes, interference between the modes can cause beating effects in the laser output, leading to fluctuations in intensity; in lasers with many thousands of modes, these interference effects tend to average to a near-constant output intensity.

If instead of oscillating independently, each mode operates with a fixed phase between it and the other modes the laser output behaves quite differently. Instead of random or constant output intensity, the modes of the laser will periodically all constructively interfere with one another, producing an intense burst or pulse of light. Such a laser is said to be 'mode-locked' or 'phase-locked'.

These pulses occur separated in time by

$$\boldsymbol{\tau = 2L/c},$$

where τ is the time taken for the light to make exactly one round trip of the laser cavity.

This time corresponds to a frequency exactly equal to the mode spacing of the laser,

$$\boldsymbol{\Delta\nu = 1/\tau}.$$

The duration of each pulse of light is determined by the number of modes which are oscillating in phase (in a real laser, it is not necessarily true that all of the laser's modes will be phase-locked). If there are N modes locked with a frequency separation $\Delta\nu$, the overall mode-locked bandwidth is $N\Delta\nu$, and the wider this bandwidth, the shorter the pulse durationfrom the laser. In practice, the actual pulse duration is determined by the shape of each pulse, which is in turn determined by the exact amplitude and phase relationship of each longitudinal mode. For example, for a laser producing pulses with a Gaussian temporal shape, the minimum possible pulse duration Δt is given by

$$\Delta t = \frac{0.441}{N\Delta\nu}.$$

The value 0.441 is known as the 'time-bandwidth product' of the pulse, and varies depending on the pulse shape. For ultra-short pulse lasers, a hyperbolic-secant-squared ($sech^2$) pulse shape is often assumed, giving a time-bandwidth product of 0.315.

Using this equation, the minimum pulse duration can be calculated consistent with the measured laser spectral width. For the He-Ne laser with a 1.5-GHz spectral width, the shortest Gaussian pulse consistent with this spectral width would be around 300 picoseconds; for the 128-THz bandwidth Ti sapphire laser, this spectral width would be only 3.4 femtoseconds. These values represent the shortest possible Gaussian pulses consistent with the laser's line width; in a real mode-locked laser, the actual pulse duration depends on many other factors, such as the actual pulse shape, and the overall dispersion of the cavity.

Subsequent modulation could in principle shorten the pulse width of such a laser further; however, the measured spectral width would then be correspondingly increased.

Applications

Nuclear fusion. (inertial confinement fusion).

Nonlinear optics, such as second-harmonic generation, parametric down-conversion, optical parametric oscillators, and generation of Terahertz radiation

Optical Data Storage uses lasers, and the emerging technology of 3D optical data storage generally relies on nonlinear photochemistry. For this reason, many examples use mode-locked lasers, since they can offer a very high repetition rate of ultrashort pulses.

Femtosecond laser nanomachining – The short pulses can be used to nanomachine in many types of materials.

An example of pico- and femtosecond micromachining is drilling the silicon jet surface of ink jet printers

Two-photon microscopy

Corneal Surgery. Femtosecond lasers can create bubbles in the cornea, if multiple bubbles are created in a planar fashion parallel to the corneal surface then the tissue separates at this plane and a flap like the one in LASIK is formed (Intralase: Intralasik or SBK (Sub Bowman Keratomileusis) if the flap thickness is equal or less than 100 micrometres). If done in multiple layers a piece of corneal tissue between these layers can be removed (Visumax: FLEX Femtosecond Lenticle Extraction).

A laser technique has been developed that renders the surface of metals deep black. A femtosecond laser pulse deforms the surface of the metal forming nanostructures. The immensely increased surface area can absorb virtually all the light that falls on it thus rendering it deep black. This is one type of black gold[3]

Photonic Sampling, using the high accuracy of lasers over electronic clocks to decrease the sampling error in electronic ADCs.

NONLINEAR OPTICS

Nonlinear optics (NLO) is the branch of optics that describes the behavior of light in *nonlinear media*, that is, media in which the dielectric polarization P responds nonlinearly to the electric field E of the light. The nonlinearity is typically observed only at very high light intensities (values of the electric field comparable to interatomic electric fields, typically 10^8V/m) such as those provided by lasers. Above the Schwinger limit, the vacuum itself is expected to become nonlinear. In nonlinear optics, the superposition principle no longer holds.

Nonlinear optics remained unexplored until the discovery in 1961 of second-harmonic generation by Peter Franken *et al.* at University of Michigan, shortly after the construction of the first laser by Theodore Harold Maiman.[1] However, some nonlinear effects were discovered before the development of the laser.[2] The theoretical basis for many nonlinear processes were first described in Bloembergen's monograph "Nonlinear Optics".

Example uses for non linear optics

Frequency doubling

One of the most commonly used frequency-mixing processes is frequency doubling, or second-harmonic generation. With this technique, the 1064 nm output from Nd:YAG lasersor the 800 nm output from Ti:sapphire lasers can be converted to visible light, with wavelengths of 532 nm (green) or 400 nm (violet) respectively.

Practically, frequency doubling is carried out by placing a nonlinear medium in a laser beam. While there are many types of nonlinear media, the most common media are crystals. Commonly used crystals are BBO (β-barium borate), KDP (potassium dihydrogen phosphate), KTP (potassium titanyl phosphate), and lithium niobate. These crystals have the necessary properties of being strongly birefringent (necessary to obtain phase matching, see below), having a specific crystal symmetry, being transparent for both the impinging laser light and the frequency-doubled wavelength, and having high damage thresholds, which makes them resistant against the high-intensity laser light.

Optical phase conjugation

It is possible, using nonlinear optical processes, to exactly reverse the propagation direction and phase variation of a beam of light. The reversed beam is called a conjugate beam, and thus the technique is known as optical phase conjugation (also called time reversal, wavefront reversal and retro reflection).

One can interpret this nonlinear optical interaction as being analogous to a real-time holographic process.[18] In this case, the interacting beams simultaneously interact in a nonlinear optical material to form a dynamic hologram (two of the three input beams), or real-time diffraction pattern, in the material. The third incident beam diffracts at this dynamic hologram, and, in the process, reads out the phase-conjugate wave. In effect, all three incident beams interact (essentially) simultaneously to form several real-time holograms, resulting in a set of diffracted output waves that phase up as the "time-reversed" beam. In the language of nonlinear optics, the interacting beams result in a nonlinear polarization within the material, which coherently radiates to form the phase-conjugate wave.

SECOND HARMONIC GENERATION

Second harmonic generation (also called frequency doubling or abbreviated SHG) is a nonlinear optical process, in which photons with the same frequency interacting with a nonlinear material are effectively "combined" to generate new photons with twice the energy, and therefore twice the frequency and half the wavelength of the initial photons. Second harmonic generation, as an even-order nonlinear optical effect, is only allowed in media without inversion symmetry. It is a special case of sum frequency generation and is the inverse of half-harmonic generation.

Second harmonic generation was first demonstrated by Peter Franken, A. E. Hill, Peters, The demonstration was made possible by the invention of the laser, which created the required high intensity coherent light. They focused a ruby laser with a wavelength of 694 nm into a quartz sample. They sent the output light through a spectrometer, recording the spectrum on photographic paper, which indicated the production of light at 347 nm. The formulation of SHG was initially described by N. Bloembergen and P. S. Pershan at Harvard in 1962. In their extensive evaluation of Maxwell's equations at the planar interface between a linear and nonlinear medium, several rules for the interaction of light in non-linear mediums were elucidated.

Generating the second harmonic, often called frequency doubling, is also a process in radio communication; it was developed early in the 20th century, and has been used with frequencies in the megahertz range. It is a special case of frequency multiplication.

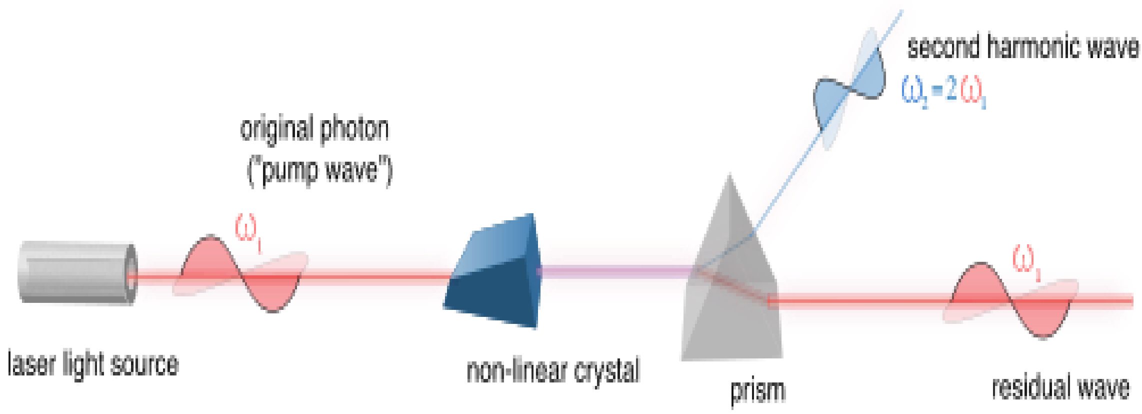


Diagram of the second harmonic generation process.

Derivation of SHG

The simplest case for analysis of second harmonic generation is a plane wave of amplitude *E(ω)* traveling in a nonlinear medium in the direction of its *k* vector. A polarization is generated at the second harmonic frequency

$$P(2\omega) = \epsilon_0 \chi^{(2)} E^2(\omega) = 2\epsilon_0 d_{\text{eff}}(2\omega;\omega,\omega) E^2(\omega),$$

where d_{eff} is the effective nonlinear optical coefficient which is dependent on specific components of $\chi^{(2)}$ that are involved in this particular interaction. The wave equation at 2ω (assuming negligible loss and asserting the slowly varying envelope approximation) is

$$\frac{\partial E(2\omega)}{\partial z} = -\frac{i\omega}{n_{2\omega} c} d_{\text{eff}} E^2(\omega) e^{i\Delta k z}$$

where $\Delta k = k(2\omega) - 2k(\omega)$.

At low conversion efficiency (*E(2ω)* << *E(ω)*) the amplitude $E(\omega)$ remains essentially constant over the interaction length, l. Then, with the boundary condition $E(2\omega, z=0) = 0$ we obtain

$$E(2\omega, z=l) = -\frac{i\omega d_{\text{eff}}}{n_{2\omega} c} E^2(\omega) \int_0^l e^{i\Delta k z} dz = -\frac{i\omega d_{\text{eff}}}{n_{2\omega} c} E^2(\omega) l \frac{\sin(\Delta k l/2)}{\Delta k l/2} e^{i\Delta k l/2}$$

In terms of the optical intensity, $I = n/2\sqrt{\epsilon_0/\mu_0}|E|^2$, this is,

$$I(2\omega, l) = \frac{2\omega^2 d_{\text{eff}}^2 l^2}{n_{2\omega} n_\omega^2 c^3 \epsilon_0} \left(\frac{\sin(\Delta k l/2)}{\Delta k l/2}\right)^2 I^2(\omega)$$

This intensity is maximized for the phase matched condition *Δk* = 0. If the process is not phase matched, the driving polarization at 2ω goes in and out of phase with generated wave *E*(2ω) and conversion oscillates as sin(*Δkl*/2). The coherence length is defined as $l_c = \frac{\pi}{\Delta k}$. It does not pay to use a nonlinear crystal much longer than the coherence length.

PHASE MATCHING

Quasi-phase-matching is a technique in nonlinear optics which allows a positive net flow of energy from the pump frequency to the signal and idler frequencies by creating a periodic structure in the nonlinear medium. Momentum is conserved, as is necessary for phase-matching, through an additional momentum contribution corresponding to the wavem vector of the periodic structure. Consequently, in principle any three-wave mixing process that satisfies energy conservation can be phase-matched. For example, all the optical frequencies involved can be collinear, can have the same polarization, and travel through the medium in arbitrary directions. This allows one to use the largest nonlinear coefficient of the material in the nonlinear interaction. Quasi-phase-matching ensures that there is positive energy flow from the pump frequency to signal and idler frequencies even though all the frequencies involved are not phase locked with each other. Energy will always flow from pump to signal as long as the phase between the two optical waves is less than 180 degrees. Beyond 180 degrees, energy flows back from the signal to the pump frequencies. The coherence length is the length of the medium in which the phase of pump and the sum of idler and signal frequencies are 180 degrees from each other. At each coherence length the crystal axes are flipped which allows the energy to continue to positively flow from the pump to the signal and idler frequencies.

The most commonly used technique for creating quasi-phase-matched crystals has been periodic poling. More recently, continuous phase control over the local nonlinearity was achieved using nonlinear meta surfaces with homogeneous linear optical properties but spatially varying effective nonlinear polarizability.

OPTICAL MIXING

An optical mix is when you create paint colors not by mixing them on the palette (or physically), but through knowledge of color theory and how the eye perceives colors that abut or overlay each other. Glazing is the most common optical mix technique used in painting.

PARAMETRIC GENERATION AND SELF-FOCUSING OF LIGHT

A parametric process is an optical process in which light interacts with matter in such a way as to leave the quantum state of the material unchanged. As a direct consequence of this there can be no net transfer of energy, momentum, or angular momentum between the optical field and the physical system. In contrast a non-parametric process is a process in which any part of the quantum state of the system changes.

Self-focusing is a non-linear optical process induced by the change in refractive index of materials exposed to intense electromagnetic radiation.[1][2] A medium whose refractive index increases with the electric field intensity acts as a focusing lens for an electromagnetic wave characterised by an initial transverse intensity gradient, as in a laser beam.[3] The peak intensity of the self-focused region keeps increasing as the wave travels through the medium, until defocusing effects or medium damage interrupt this process. Self-focusing of light was discovered by Gurgen Askaryan.

Self-focusing is often observed when radiation generated by femtosecond lasers propagates through many solids, liquids and gases. Depending on the type of material and on the intensity of the radiation, several mechanisms produce variations in the refractive index which result in self-focusing: the main cases are Kerr-induced self-focusing and plasma self-focusing.

UNIT 4

MULTI PHOTON PROCESS

Multi quantum photo electric effect

The photoelectric effect is the emission of electrons or other free carriers when light is shone onto a material. Electrons emitted in this manner can be called *photo electrons*. The phenomenon is commonly studied in electronic physics, as well as in fields of chemistry, such as quantum chemistry or electrochemistry.

According to classical electromagnetic theory, this effect can be attributed to the transfer of energy from the light to an electron. From this perspective, an alteration in the intensity of light would induce changes in the kinetic energy of the electrons emitted from the metal. Furthermore, according to this theory, a sufficiently dim light would be expected to show a time lag between the initial shining of its light and the subsequent emission of an electron. However, the experimental results did not correlate with either of the two predictions made by classical theory.

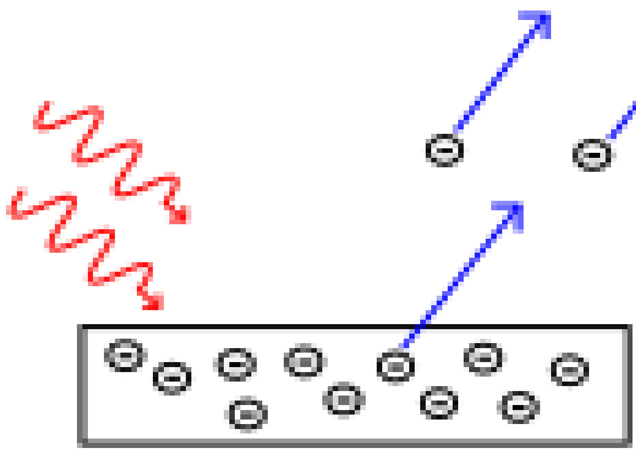
Instead, electrons are dislodged only by the impingement of photons when those photons reach or exceed a threshold frequency(energy). Below that threshold, no electrons are emitted from the material regardless of the light intensity or the length of time of exposure to the light (rarely, an electron will escape by absorbing two or more quanta. However, this is extremely rare because by the time it absorbs enough quanta to escape, the electron will probably have emitted the rest of the quanta.). To make sense of the fact that light can eject electrons even if its intensity is low, Albert Einstein proposed that a beam of light is not a wave propagating through space, but rather a collection of discrete wave packets (photons), each with energy $h\nu$. This shed light on Max Planck's previous discovery of the Planck relation ($E = h\nu$) linking energy (E) and frequency (ν) as arising from quantization of energy. The factor h is known as the Planck constant.[1][2]

In 1887, Heinrich Hertz[2][3] discovered that electrodes illuminated with ultraviolet light create electric sparks more easily. In 1900, while studying black-body radiation, the German physicist Max Planck suggested that the energy carried by electromagnetic waves could only be released in "packets" of energy. In 1905, Albert Einstein published a paper advancing the hypothesis that light energy is carried in discrete quantized packets to explain experimental data from the photoelectric effect. This model contributed to the development of quantum mechanics. In 1914, Robert Millikan's experiment supported Einstein's model of the photoelectric effect. Einstein was awarded the Nobel Prize in 1921 for "his discovery of the law of the photoelectric effect", and Millikan was awarded the Nobel Prize in 1923 for "his work on the elementary charge of electricity and on the photoelectric effect".

The photoelectric effect requires photons with energies approaching zero (in the case of negative electron affinity) to over 1 MeV for core electrons in elements with a high atomic number. Emission of conduction electrons from typical metals usually requires a few electron-volts, corresponding to short-wavelength visible or ultraviolet light. Study of the photoelectric effect led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave–particle duality.[1] Other phenomena where light affects the movement of electric charges include the photoconductive effect (also known as photoconductivity or photo resistivity), the photovoltaic effect, and the photo electrochemical effect.

Photoemission can occur from any material, but it is most easily observable from metals or other conductors because the process produces a charge imbalance, and if this charge imbalance is not neutralized by current flow (enabled by conductivity), the potential barrier to emission increases until the emission current ceases. It is also usual to have the emitting surface in a vacuum, since gases impede the flow of photoelectrons and make them difficult to observe. Additionally, the energy barrier to photoemission is usually increased by thin oxide layers on metal surfaces if the metal has been exposed to oxygen, so most practical experiments and devices based on the photoelectric effect use clean metal surfaces in a vacuum.

When the photoelectron is emitted into a solid rather than into a vacuum, the term internal photoemission is often used, and emission into a vacuum distinguished as external photoemission.



Theory of two-photon process

Two-photon absorption (TPA) is the simultaneous absorption of two photons of identical or different frequencies in order to excite a moleculefrom one state (usually the ground state) to a higher energy electronic state. The energy difference between the involved lower and upper states of the molecule is equal to the sum of the photon energies of the two photons. Two-photon absorption is a third-order process several orders of magnitude weaker than linear absorption at low light intensities. It differs from linear absorption in that the atomic transition rate due to TPA depends on the square of the light intensity, thus it is a nonlinear optical process, and can dominate over linear absorption at high intensities.

The opposite process of TPA is two-photon emission (TPE), which is a single electron transition accompanied by the emission of a photon pair. The energy of each individual photon of the pair is not determined, while the pair as a whole conserves the transition energy. The spectrum of TPE is therefore very broad and continuous.[16] TPE is important for applications in astrophysics, contributing to the continuum radiation from planetary nebulae (theoretically predicted for them in [17] and observed in [18]). TPE in condensed matter and specifically in semiconductors was only recently observed,[19] with emission rates nearly 5 orders of magnitude weaker than one-photon spontaneous emission, with potential applications in quantum information.

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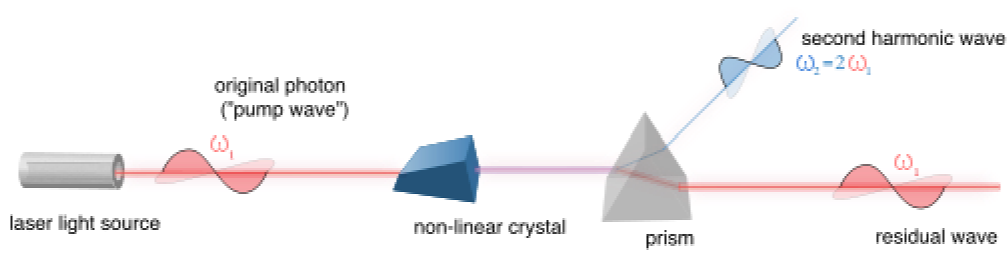


Parametric generation of light

A parametric process is an optical process in which light interacts with matter in such a way as to leave the quantum state of the material unchanged. As a direct consequence of this there can be no net transfer of energy, momentum, or angular momentum between the optical field and the physical system. In contrast a non-parametric process is a process in which any part of the quantum state of the system changes. Since a parametric process prohibits a net change in the energy state of the system, parametric processes are considered to be 'instantaneous' processes. This can be seen as follows: if an atom absorbs a photon with energy E, the atom's energy will increase by $\Delta E = E$. Since we are assuming this is a parametric process, the quantum state cannot change and thus this energy state must be a virtual state. By the Heisenberg Uncertainty Principle we know that $\Delta E \Delta t \sim \hbar/2$, thus the lifetime of a parametric process is roughly $\Delta t \sim \hbar/2\Delta E$, which is appreciably small for any non-zero ΔE.

In linear optics a parametric process will act as a lossless dielectric with the following effects:

- Refraction
- Diffraction
- Elastic scattering
- Rayleigh scattering
- Mie scattering
- Alternatively, non-parametric processes often involve loss (or gain) and give rise to:
- ➢ Absorption
- ➢ Inelastic scattering
- ➢ Raman scattering
- ➢ Brillouin scattering
- ➢ Various optical emission processes
    - Photoluminescence
    - Fluorescence
    - Luminescence
    - Phosphorescence

Laser spectroscopy:

Rayleigh and Raman scattering

Rayleigh scattering , named after the British physicist Lord Rayleigh is the (dominantly) elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the radiation. Rayleigh scattering does not change the state of material and is, hence, a parametric process. The particles may be individual atoms or molecules. It can occur when light travels through transparent solids and liquids, but is most prominently seen in gases. Rayleigh scattering results from the electric polarizability of the particles. The oscillating electric field of a light wave acts on the charges within a particle, causing them to move at the same frequency. The particle therefore becomes a small radiating dipole whose radiation we see as scattered light. Rayleigh scattering of sunlight in the atmosphere causes diffuse sky radiation, which is the reason for the blue color of the sky and the yellow tone of the sun itself.

The amount of scattering is inversely proportional to the fourth power of the wavelength. Rayleigh scattering of molecular nitrogen and oxygen in the atmosphere includes elastic scattering as well as the inelastic contribution from rotational Raman scattering in air, since the changes in wavenumber of the scattered photon are typically smaller than 50 cm^{-1}.This can lead to changes in the rotational state of the molecules. Furthermore, the inelastic contribution has the same wavelengths dependency as the elastic part.

Scattering by particles similar to, or larger than, the wavelength of light is typically treated by the Mie theory, the discrete dipole approximation and other computational techniques. Rayleigh scattering applies to particles that are small with respect to wavelengths of light, and that are optically "soft". On the other hand, anomalous diffraction theory applies to optically soft but larger particles.

Raman scattering or the Raman effect is the inelastic scattering of a photon by molecules which are excited to higher vibrational or rotational energy levels.

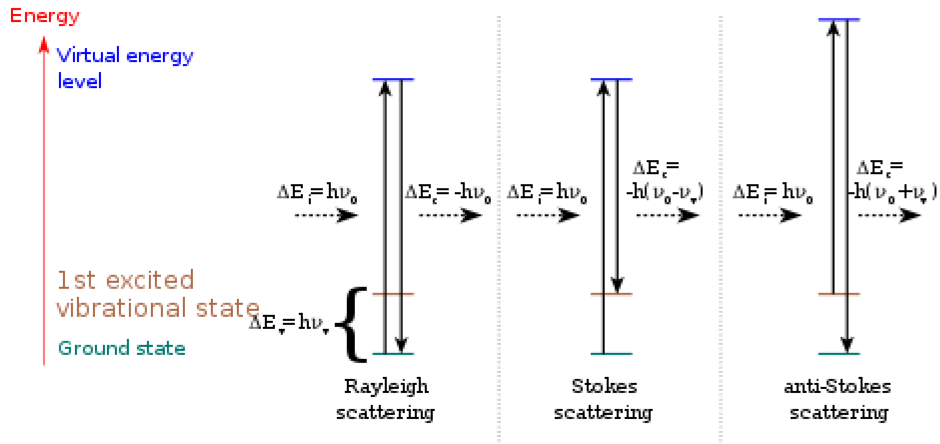
It was discovered C. V. Raman and K. S. Krishnan (who was a student of C.V. Raman) in liquids. When photons are scattered from an atom or molecule, most photons are elastically scattered (Rayleigh scattering), such that the scattered photons have the same energy (frequency and wavelength) as the incident photons. A small fraction of the scattered photons (approximately 1 in 10 million) are scattered inelastically by an excitation, with the scattered photons having a frequency and energy different from, and usually lower than, those of the incident photons. In a gas, Raman scattering can occur with a change in energy of a molecule due to a transition to another (usually higher) energy level. Chemists are primarily concerned with this "transitional" Raman Effect.

It is also possible to observe molecular vibrations by an inelastic scattering process. In inelastic (Raman) scattering, an absorbed photon is re-emitted with lower energy; the difference in energy between the incident photons and scattered photons corresponds to the energy required to excite a molecule to a higher vibrational mode.

Typically, in Raman spectroscopy high intensity laser radiation with wavelengths in either the visible or near-infrared regions of the spectrum is passed through a sample. Photons from the laser beam produce an oscillating polarization in the molecules, exciting them to a virtual energy state. The oscillating polarization of the molecule can couple with other possible polarizations of the molecule, including vibrational and electronic excitations. If the polarization in the molecule does not couple to these other possible polarizations, then it will not change the vibrational state that the molecule started in and the scattered photon will have the same energy as the original photon. This type of scattering is known as Rayleigh scattering.
When the polarization in the molecules couples to a vibrational state that is higher in energy than the state they started in, then the original photon and the scattered photon differ in energy by the amount required to vibrationally excite the molecule. In perturbation theory, the Raman effect corresponds to the absorption and subsequent emission of a photon via an intermediate quantum

state of a material. The intermediate state can be either a "real", i.e., stationary state or a virtual state.

Stokes and anti-Stokes scattering**[edit]**



The different possibilities of light scattering: Rayleigh scattering (no exchange of energy: incident and scattered photons have the same energy), Stokes Raman scattering (atom or molecule absorbs energy: scattered photon has less energy than the incident photon) and anti-Stokes Raman scattering (atom or molecule loses energy: scattered photon has more energy than the incident photon)

The Raman interaction leads to two possible outcomes:

the material absorbs energy and the emitted photon has a lower energy than the absorbed photon. This outcome is labeled Stokes Raman scattering in honor of George Stokes who showed in 1852 that fluorescence is due to light emission at longer wavelength (now known to correspond to lower energy) than the absorbed incident light.

the material loses energy and the emitted photon has a higher energy than the absorbed photon. This outcome is labeled anti-Stokes Raman scattering.

The energy difference between the absorbed and emitted photon corresponds to the energy difference between two resonant states of the material and is independent of the absolute energy of the photon.

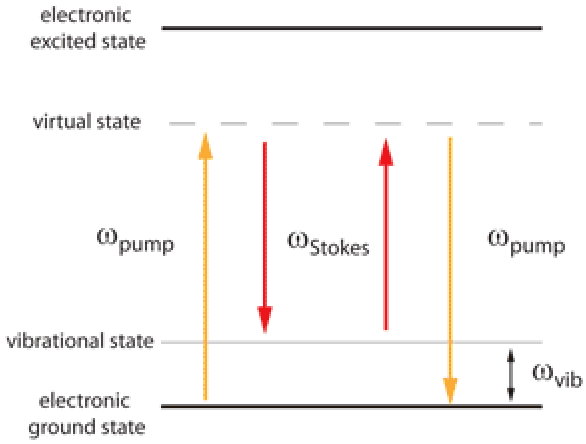
The spectrum of the scattered photons is termed the Raman spectrum. It shows the intensity of the scattered light as a function of its frequency difference $\Delta\nu$ to the incident photons. The locations of corresponding Stokes and anti-Stokes peaks form a symmetric pattern around $\Delta\nu=0$. The frequency shifts are symmetric because they correspond to the energy difference between the same upper and lower resonant states. The intensities of the pairs of features will typically differ, though. They depend on the populations of the initial states of the material, which in turn depend on the temperature. In thermodynamic equilibrium, the lower state will be more populated than the upper state. Therefore, the rate of transitions from the more populated lower state to the upper state (Stokes transitions) will be higher than in the opposite direction (anti-Stokes transitions). Correspondingly, Stokes scattering peaks are stronger than anti-Stokes scattering peaks. Their ratio depends on the temperature, and can therefore be exploited to measure it.

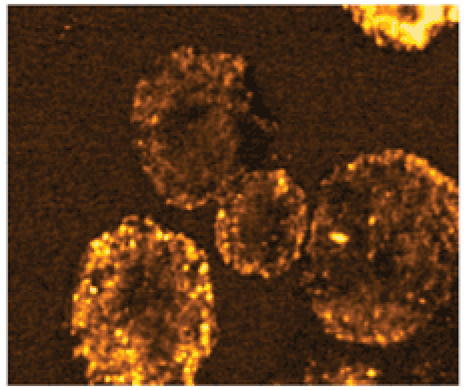
Stimulated Raman Effect

In SRS microscopy, like CARS microscopy, both the pump and Stokes photons are incident on the sample. If the frequency difference

$$\omega_{SRS} = \omega_{pump} - \omega_{Stokes}$$

matches a molecular vibration (ω_{vib}) stimulated excitation of the vibrational transition occurs. Unlike CARS, in SRS there is no signal at a wavelength that is different from the laser excitation wavelengths. Instead, the intensity of the scattered light at the pump wavelength experiences a stimulated Raman loss (SRL), with the intensity of the scattered light at the Stokes wavelength experiencing a stimulated Raman gain (SRG). The key advantage of SRS microscopy over CARS microscopy is that it provides background-free chemical imaging with improved image contrast, both of which are important for biomedical imaging applications where water represents the predominant source of nonresonant background signal in the sample.





Hyper-Raman effect

Hyper Raman scattering is a modified version of Raman scattering, where the scattered light occurs at frequencies somewhat lower than twice the frequency of the pump light. This means that two pump photons are converted into one photon of Raman scattered light and one phonon. This effect is usually fairly weak, but it has aspects which make it interesting for Raman spectroscopy. In particular, hyper-Raman spectra can provide vibrational information on molecules where ordinary Raman scattering is suppressed due to symmetry issues (silent modes). The scattering rate can be substantially enhanced near optical surfaces.

Coherent anti-stokes Raman Scattering(CARS)

Coherent anti-Stokes Raman spectroscopy, also called Coherent anti-Stokes Raman scattering spectroscopy (CARS), is a form of spectroscopy used primarily in chemistry, physics and related fields. It is sensitive to the same vibrational signatures of molecules as seen in Raman spectroscopy, typically the nuclear vibrations of chemical bonds. Unlike Raman spectroscopy, CARS employs multiple photons to address the molecular vibrations, and produces a coherent signal. As a result, CARS is orders of magnitude stronger than spontaneous Raman emission. CARS is a third-order nonlinear optical process involving three laser beams: a pump beam of frequency ω_p, a Stokes beam of frequency ω_S and a probe beam at frequency ω_{pr}. These beams interact with the sample and generate a coherent optical signal at the anti-Stokes frequency ($\omega_{pr}+\omega_p-\omega_S$). The latter is resonantly enhanced when the frequency difference between the pump and the Stokes beams (ω_p-ω_S) coincides with the frequency of a Raman resonance, which is the basis of the technique's intrinsic vibrational contrast mechanism.

Coherent Stokes Raman spectroscopy (CSRS pronounced as "scissors") is closely related to Raman spectroscopy and lasing processes. It is very similar to CARS except it uses an anti-Stokes frequency stimulation beam and a Stokes frequency beam is observed (the opposite of CARS).

PRINCIPLE

The CARS process can be physically explained by using either a classical oscillator model or by using a quantum mechanical model that incorporates the energy levels of the molecule. Classically, the Raman active vibrator is modeled as a (damped) harmonic oscillatorwith a characteristic frequency of ω_v. In CARS, this oscillator is not driven by a single optical wave, but by the difference frequency (ω_p-ω_S) between the pump and the Stokes beams instead. This driving mechanism is similar to hearing the low combination tone when striking two different high tone piano keys: your ear is sensitive to the difference frequency of the high tones. Similarly, the Raman oscillator is susceptible to the difference frequency of two optical waves. When the difference frequency ω_p-ω_S approaches ω_v, the oscillator is driven very efficiently. On a molecular level, this implies that the electron cloud surrounding the chemical bond is vigorously oscillating with the frequency ω_p-ω_S. These electron motions alter the optical properties of the sample, i.e. there is a periodic modulation of the refractive index of the material. This periodic modulation can be probed by a third laser beam, the probe beam. When the probe beam is propagating through the periodically altered medium, it acquires the same modulation. Part of the probe, originally at ω_{pr} will now get modified to ω_{pr}+ω_p-ω_S, which is the observed anti-Stokes emission. Under certain beam geometries, the anti-Stokes emission may diffract away from the probe beam, and can be detected in a separate direction.

While intuitive, this classical picture does not take into account the quantum mechanical energy levels of the molecule. Quantum mechanically, the CARS process can be understood as follows. Our molecule is initially in the ground state, the lowest energy state of the molecule. The pump beam excites the molecule to a virtual state. A virtual state is not an eigen state of the molecule and it can not be occupied but it does allow for transitions between otherwise unoccupied real states. If a Stokes beam is simultaneously present along with the pump, the virtual state can be used as an instantaneous gateway to address a vibrational eigen state of the molecule. The joint action of the pump and the Stokes has effectively established a coupling between the ground state and the vibrationally excited state of the molecule. The molecule is now in two states at the same time: it resides in a coherent superposition of states. This coherence between the states can be probed by the probe beam, which promotes the system to a virtual state. Again, the molecule cannot stay in the virtual state and will fall back instantaneously to the ground state under the emission of a photon at the anti-Stokes frequency. The molecule is no longer in a superposition, as it resides again in one state, the ground state. In the quantum mechanical model, no energy is deposited in the molecule during the CARS process. Instead, the molecule acts like a medium for converting the frequencies of the three incoming waves into a CARS signal (a parametric process). There are, however, related coherent Raman processes that occur simultaneously which do deposit energy into the molecule.

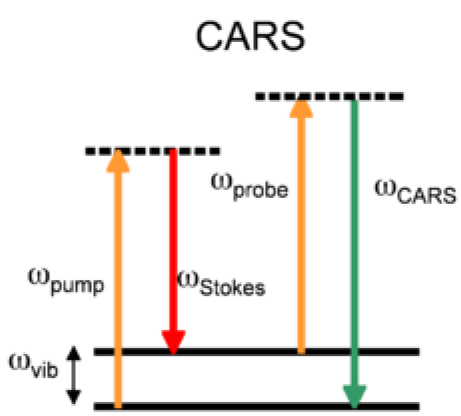


Photo-acoustic Raman spectroscopy

Photo acoustic spectroscopy is the measurement of the effect of absorbed electromagnetic energy (particularly of light) on matter by means of acoustic detection. The discovery of the photoacoustic effect dates to 1880 when Alexander Graham Bell showed that thin discs emitted sound when exposed to a beam of sunlight that was rapidly interrupted with a rotating slotted disk. The absorbed energy from the light causes local heating and through thermal expansion a pressure wave or sound. Later Bell showed that materials exposed to the non-visible portions of the solar spectrum (i.e., the infrared and the ultraviolet) can also produce sounds.

A photo acoustic spectrum of a sample can be recorded by measuring the sound at different wavelengths of the light. This spectrum can be used to identify the absorbing components of the sample. The photo acoustic effect can be used to study solids, liquids and gases.

Photo acoustic spectroscopy has become a powerful technique to study concentrations of gases at the part per billion or even part per trillion levels.[2] Modern photoacoustic detectors still rely on the same principles as Bell's apparatus; however, to increase the sensitivity, several modifications have been made.

USES AND TECHNIQUES

The use of intense lasers instead of the sun to illuminate the sample since the intensity of the generated sound is proportional to the light intensity; this technique is referred to as laser photo acoustic spectroscopy (LPAS). The ear has been replaced by sensitive microphones. The microphone signals are further amplified and detected using lock-in amplifiers by enclosing the gaseous sample in a cylindrical chamber, the sound signal is amplified by tuning the modulation frequency to an acoustic resonance of the sample cell.

EXAMPLE

The following example illustrates the potential of the photoacoustic technique: In the early 1970s, Patel and co-workers measured the temporal variation of the concentration of nitric oxide in the stratosphere at an altitude of 28 km with a balloon-borne photoacoustic detector. These measurements provided crucial data bearing on the problem of ozone depletion by man-made nitric oxide emission.

LASER APPLICATIONS

Isotope separation

This is the process of concentrating specific isotopes of a chemical element by removing other isotopes. The use of the nuclides produced is various. The largest variety is used in research (e.g. in chemistry where atoms of "marker" nuclide are used to figure out reaction mechanisms). By tonnage, separating natural uranium into enriched uranium and depleted uranium is the largest application. In the following text, mainly the uranium enrichment is considered. This process is a crucial one in the manufacture of uranium fuel for nuclear power stations, and is also required for the creation of uranium based nuclear weapons. Plutonium-based weapons use plutonium produced in a nuclear reactor, which must be operated in such a way as to produce plutonium already of suitable isotopic mix or grade. While different chemical elements can be purified through chemical processes, isotopes of the same element have nearly identical chemical properties, which makes this type of separation impractical, except for separation of deuterium.

There are three types of isotope separation techniques:

1.Those based directly on the atomic weight of the isotope.

2.Those based on the small differences in chemical reaction rates produced by different atomic weights.

3.Those based on properties not directly connected to atomic weight, such as nuclear resonances.

The third type of separation is still experimental; practical separation techniques all depend in some way on the atomic mass. It is therefore generally easier to separate isotopes with a larger relative mass difference. For example, deuterium has twice the mass of ordinary (light) hydrogen and it is generally easier to purify it than to separate uranium-235 from the more common uranium-238. On the other extreme, separation of fissile plutonium-239 from the common impurity plutonium-240, while desirable in that it would allow the creation of gun-type nuclear weapons from plutonium, is generally agreed to be impractical

In this method a laser is tuned to a wavelength which excites only one isotope of the material and ionizes those atoms preferentially. The resonant absorption of light for an isotope is dependent upon its mass and certain hyperfine interactions between electrons and the nucleus, allowing finely tuned lasers to interact with only one isotope. After the atom is ionized it can be removed from the sample by applying an electric field. This method is often abbreviated as AVLIS (atomic vapor laser isotope separation). This method has only recently been developed as laser technology has improved, and is currently not used extensively. However, it is a major concern to those in the field of nuclear proliferation because it may be cheaper and more easily hidden than other methods of isotope separation. Tunable lasers used in AVLIS include the dye laser and more recently diode lasers.

A second method of laser separation is known as molecular laser isotope separation (MLIS). In this method, an infrared laser is directed at uranium hexafluoride gas, exciting molecules that contain a U-235 atom. A second laser frees a fluorine atom, leaving uranium pentafluoride which then precipitates out of the gas. Cascading the MLIS stages is more difficult than with other methods because the UF_5 must be refluorinated (back to UF_6) before being introduced into the next MLIS stage. Alternative MLIS schemes are currently being developed (using a first laser in the near-infrared or visible region) where an enrichment of over 95% can be obtained in a single stage, but the methods have not (yet) reached industrial feasibility. This method is called OP-IRMPD (Overtone Pre-excitation—IR Multiple Photon Dissociation).

The SILEX process, developed by Silex Systems in Australia, has recently been licensed to General Electric for the development of a pilot enrichment plant. The method uses uranium hexafluoride as a feedstock, and uses magnets to separate the isotopes after one isotope is preferentially ionized. Further details of the process are not disclosed.Quite recently yet another scheme has been proposed for the deuterium separation using Trojan wavepackets in circularly polarized electromagnetic field. The process of Trojan wave packet formation by the adiabatic-rapid passage depends in ultra-sensitive way on the reduced electron and nucleus mass which with the same field frequency further leads to excitation of Trojan or anti-Trojan wavepacket depending on the kind of the isotope. Those and their giant, rotating electric dipole moments are then shifted in phase and the beam of such atoms splits in the gradient of the electric field in the analogy to Stern–Gerlach experiment.

Thermonuclear fusion

This is a way to achieve nuclear fusion by using extremely high temperatures. There are two forms of thermonuclear fusion: uncontrolled, in which the resulting energy is released in an uncontrolled manner, as it is in thermonuclear weapons ("hydrogen bombs") and in most stars; and controlled, where the fusion reactions take place in an environment allowing some or all of the energy released to be harnessed for constructive purposes.

Temperature is a measure of the average kinetic energy of particles, so by heating the material it will gain energy. After reaching sufficient temperature, given by the Lawson criterion, the energy of accidental collisions within the plasma is high enough to overcome the Coulomb barrier and the particles may fuse together. In a deuterium–tritium fusion reaction, for example, the energy necessary to overcome the Coulomb barrier is 0.1 MeV. Converting between energy and temperature shows that the 0.1 MeV barrier would be overcome at a temperature in excess of 1.2 billion kelvins.

There are two effects that lower the actual temperature needed. One is the fact that temperature is the average kinetic energy, implying that some nuclei at this temperature would actually have much higher energy than 0.1 MeV, while others would be much lower. It is the nuclei in the high-energy tail of the velocity distribution that account for most of the fusion reactions. The other effect is quantum tunneling. The nuclei do not actually have to have enough energy to overcome the Coulomb barrier completely. If they have nearly enough energy, they can tunnel through the remaining barrier. For these reasons fuel at lower temperatures will still undergo fusion events, at a lower rate.

Thermonuclear fusion is one of the methods being researched in the attempts to produce fusion power. If thermonuclear fusion becomes favorable to use, it would reduce the world's carbon footprint significantly.

Laser applications

Many scientific, military, medical and commercial laser applications have been developed since the invention of the laser in 1958. The coherency, high monochromaticity, and ability to reach extremely high powers are all properties which allow for these specialized applications.

In science, lasers are used in many ways, including: A wide variety of inter ferometric techniques, Raman spectroscopy, Laser induced breakdown spectroscopy, Atmospheric remote sensing, Investigating nonlinear optics phenomena and holographic techniques employing lasers also contribute to a number of measurement techniques.

Laser based lidar (light radar) technology has application in geology, seismology, remote sensing and atmospheric physics. Lasers have been used aboard spacecraft such as in the Cassini-Huygens mission. In astronomy, lasers have been used to create artificial laser guide stars, used as reference objects for adaptive optics telescopes.

Lasers may also be indirectly used in spectroscopy as a micro-sampling system, a technique termed Laser ablation (LA), which is typically applied to ICP-MS apparatus resulting in the powerful LA-ICP-MS.

Spectroscopy

Most types of laser are an inherently pure source of light; they emit near-monochromatic light with a very well defined range of wavelengths. By careful design of the laser components, the purity of the laser light (measured as the "linewidth") 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. Other spectroscopic techniques based on lasers can be used to make extremely sensitive detectors of various molecules, able to measure molecular concentrations in the parts-per-10^{12} (ppt) level. Due to the high power densities achievable by lasers, beam-induced atomic emission is possible: this technique is termed Laser induced breakdown spectroscopy (LIBS).

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. An inert, absorbent coating for laser heat treatment has also been developed that eliminates the fumes generated by conventional paint coatings during the heat-treating process with CO_2 laser beams.

One consideration crucial to the success of a heat treatment operation is control of the laser beam irradiance on the part surface. The optimal irradiance distribution is driven by the thermodynamics of the laser-material interaction and by the part geometry.

Typically, irradiances between 500-5000 W/cm^2 satisfy the thermodynamic constraints and allow the rapid surface heating and minimal total heat input required. For general heat treatment, a uniform square or rectangular beam is one of the best options. For some special applications or applications where the heat treatment is done on an edge or corner of the part, it may be better to have the irradiance decrease near the edge to prevent melting.

Lunar laser ranging

When the Apollo astronauts visited the moon, they planted retro reflector arrays to make possible the Lunar Laser Ranging Experiment. Laser beams are focused through large telescopes on Earth aimed toward the arrays, and 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

Some laser systems, through the process of mode locking, can produce extremely brief pulses of light - as short as picoseconds or femtoseconds (10^{-12} - 10^{-15} seconds). Such 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, allowing the detection of short-lived intermediate molecules. 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*. This involves atom trapping, a method where a number of atoms are confined in a specially shaped arrangement of electric and magnetic fields. Shining particular wavelengths of light at the ions or atoms slows them down, thus *cooling* them. As this process is continued, they all are slowed and have the same energy level, forming an unusual arrangement of matter known as a Bose–Einstein condensate.

Nuclear fusion

Some of the world's 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, e.g. laboratory for laser energetics, National Ignition Facility, GEKKO XII, Nike laser, Laser Mégajoule, HiPER. These pulses are arranged such that they impact pellets of tritium–deuterium simultaneously from all directions, hoping that the squeezing effect of the impacts will induce atomic fusion in the pellets. This technique, known as "inertial confinement fusion", so far has not been able to achieve "breakeven", that is, so far the fusion reaction generates less power than is used to power the lasers, but research continues.

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 microdissection use lasers to procure specific cell populations from a tissue section under microscopic visualization.

Additional laser microscopy techniques include harmonic microscopy, four-wave mixing microscopy[2] and interferometric microscopy.[3]

Military

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

Directly as an energy weapon

Directed energy weapons are being developed, such as Boeing's Airborne Laser which was constructed inside a Boeing 747. Designated the YAL-1, it was intended to kill short- and intermediate-range ballistic missiles in their boost phase.[4]

Another example of direct use of a laser as a defensive weapon was researched for the Strategic Defense Initiative (SDI, nicknamed "Star Wars"), and its successor programs. This project would use ground-based or space-based laser systems to destroy incoming intercontinental ballistic missiles (ICBMs). The practical problems of using and aiming these systems were many; particularly the problem of destroying ICBMs at the most opportune moment, the *boost* *phase* just after launch. This would involve directing a laser through a large distance in the atmosphere, which, due to optical scattering and refraction, would bend and distort the laser beam, complicating the aiming of the laser and reducing its efficiency.

Another idea from the SDI project was the *nuclear-pumped X-ray laser*. This was essentially an orbiting atomic bomb, surrounded by laser media in the form of glass rods; when the bomb exploded, the rods would be bombarded with highly-energetic gamma-ray photons, causing spontaneous and stimulated emission of X-ray photons in the atoms making up the rods. This would lead to optical amplification of the X-ray photons, producing an X-ray laser beam that would be minimally affected by atmospheric distortion and capable of destroying ICBMs in flight. The X-ray laser would be a strictly one-shot device, destroying itself on activation. Some initial tests of this concept were performed with underground nuclear testing; however, the results were not encouraging. Research into this approach to missile defense was discontinued after the SDI program was cancelled.

Made by Northrop Grumman:

On March 18, 2009 Northrop Grumman announced that its engineers in Redondo Beach had successfully built and tested an electric laser capable of producing a 100-kilowatt ray of light, powerful enough to destroy cruise missiles, artillery, rockets and mortar rounds. An electric laser is theoretically capable, according to Brian Strickland, manager for the United States Army's Joint High Power Solid State Laser program, of being mounted in an aircraft, ship, or vehicle because it requires much less space for its supporting equipment than a chemical laser.

When engaged during the test that occurred off the coast of Central California in the Pacific Ocean test range, the laser gun was documented as having "a destructive effect on a high-speed cruising target", said Chief of Naval Research Admiral Nevin Carr. Northrop Grumman has announced the availability of a high-energy solid-state laser weapon system that they call FIRESTRIKE, introduced on 13 November 2008. The system is modular, using 15 kW modules that can be combined to provide various levels of power.

On 19 July 2010 an anti-aircraft laser described as the Laser Close-In Weapon System was unveiled at the Farnborough Airshow.[8]

Zeus laser weapon Is the first laser and the first energy weapon of any type to be used on a battlefield. It is used for neutralizing mines and unexploded ordnance.

Area Defense Anti-Munitions (ADAM) Lockheed Martin experimental fiber laser. 10 kilowatt tested against rockets.[9][10]

Mid-Infrared Advanced Chemical Laser (MIRACL) A U.S. Navy experimental deuterium fluoride laser. Was tested against an Air Force satellite in 1997.

In 2011, the U.S. Navy began to test the Maritime Laser Demonstrator (MLD), a laser for use aboard its warships.[11][12] By 2013, the Navy was announcing active deployment in 2014.

Personnel halting and stimulation response rifle (PHaSR) A non-lethal hand-held weapon developed by the United States Air Force [13] Its purpose is to "dazzle" or stun a target. It was developed by U.S. Air Force's Directed Energy Directorate.

Pulsed Energy Projectile A laser designed for riot control. A laser pulse ablates material causing a shockwave which stuns the targeted individual. Likely truck-mounted.

Tactical High Energy Laser (THEL) is a weaponized deuterium fluoride laser developed in a joint research project by Israel and the USA. It is designed to shoot down aircraft and missiles. See also National missile defense.

Beriev A-60 A Soviet/Russian CO_2 gas laser mounted on an Ilyushin Il-76MD transport.

The Russian truck mounted Almaz HEL[14]

Boeing Laser Avenger Mounted on an AN/TWQ-1 Avenger combat vehicle.

Airborne Laser, or Advanced Tactical Laser The U.S. Air Force's plan to mount a CO_2 gas laser or COIL chemical laser on a modified Boeing 747 to shoot down missiles.[15][16]

Portable Efficient Laser Testbed (PELT)[17]

Laser AirCraft CounterMeasures (ACCM)[*citation needed*]

Laser Weapon System (LAWS), which is intended to hold off approaching unmanned aerial vehicles and speedboats. Under development by the U.S. Navy. The system, which can burn through steel, reportedly costed $40 million and took six years to develop.[18]

High Energy Liquid Laser Area Defense System (HELLADS) A counter-RAM aircraft or truck mounted laser under development by General Atomics under a DARPA contract. 150 kilowatt goal. Uses a lasing medium immersed in an index matched coolant.

See also Electrolaser#Examples of electrolasers.

Defensive countermeasures

Defensive countermeasure applications can range from compact, low power infrared countermeasures to high power, airborne laser systems. IR countermeasure systems use lasers to confuse the seeker heads on infrared homing missiles.

Disorientation

Some weapons simply use a laser to disorient a person. One such weapon is the Thales Green Laser Optical Warner.

Guidance

Laser guidance is a technique of guiding a missile or other projectile or vehicle to a target by means of a laser beam.

Target designator

A target designator

Another military use of lasers is as a *laser target designator*. This is a low-power laser pointer used to indicate a target for a precision-guided munition, typically launched from an aircraft. The guided munition adjusts its flight-path to home in to the laser light reflected by the target, enabling a great precision in aiming. The beam of the laser target designator is set to a pulse rate that matches that set on the guided munition to ensure munitions strike their designated targets and do not follow other laser beams which may be in use in the area. The laser designator can be shone onto the target by an aircraft or nearby infantry. Lasers used for this purpose are usually infrared lasers, so the enemy cannot easily detect the guiding laser light.

Firearms

Laser sight used by the Defense Forces during commando training

Wesson revolver equipped with a laser sight mounted on the trigger guard.

The laser has in most firearms applications been used as a tool to enhance the targeting of other weapon systems. For example, a *laser sight* is a small, usually visible-light laser placed on a handgun or a rifle and aligned to emit a beam parallel to the barrel. Since a laser beam has low divergence, the laser light appears as a small spot even at long distances; the user places the spot on the desired target and the barrel of the gun is aligned (but not necessarily allowing for bullet drop, windage, distance between the direction of the beam and the axis of the barrel, and the target mobility while the bullet travels).

Most laser sights use a red laser diode. Others use an infrared diode to produce a dot invisible to the naked human eye but detectable with night vision devices. The firearms adaptive target acquisition module LLM01 laser light module combines visible and infrared laser diodes. In the late 1990s, green diode pumped solid state laser (DPSS) laser sights (532 nm) became available. Modern laser sights are small and light enough for attachment to the firearms.

Laser Max, a company specializing in manufacturing lasers for military and police firearms, introduced the first mass-production green laser available for small arms. This laser mounts to the underside of a handgun or long arm on the accessory rail. The green laser is supposed to be more visible than the red laser in bright lighting conditions because, for the same wattage, green light appears brighter than red light.

Eye-targeted lasers

A non-lethal laser weapon was developed a fire weapon or to otherwise threaten enemy forces. This unit illuminates an opponent with harmless low-power laser light and can have the effect of dazzling or disorienting the subject or causing them to flee. Several types of dazzlers are now available, and some have been used in combat.

There remains the possibility of using lasers to blind, since this requires such lower power levels, and is easily achievable in a man-portable unit to see Protocol on Blinding Laser Weapons .

In addition to the applications that crossover with military applications, a widely known law enforcement use of lasers is for glidar to measure the speed of vehicles.

Holographic weapon sight

A holographic weapon sight uses a laser diode to illuminate a hologram of a reticle built into a flat glass optical window of the sight. The user looks through the optical window and sees a cross hair reticle image superimposed at a distance on the field of view.

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_2, Er:YAG laser

Laser scalpel (General surgery, gynecological, urology, laparoscopic)

Photobiomodulation (i.e. laser therapy)

"No-Touch" removal of tumors, especially of the brain and spinal cord.

Intelligent laser speckle classification for skin health assessments (especially regarding damage caused through ageing)

In dentistry for caries removal, endodontic/periodontic procedures, tooth whitening, and oral surgery

Industrial and commercial

Lasers used for visual effects during a musical performance. (A laser light show.)

Levelling of ceramic tiles floor with a laser device

Industrial laser applications can be divided into two categories depending on the power of the laser: material processing and micro-material processing.

In material processing, lasers with average optical power above 1 kilowatt are used mainly for industrial materials processing applications. Beyond this power threshold there are thermal issues related to the optics that separate these lasers from their lower-power counterparts.[22]Laser systems in the 50-300W range are used primarily for pumping, plastic welding and soldering applications. Lasers above 300W are used in brazing, thin metal welding, and sheet metal cutting applications. The required brightness (as measured in by the beam parameter product) is higher for cutting applications than for brazing and thin metal welding.[23] High power applications, such as hardening, cladding, and deep penetrating welding, require multiple kW of optical power, and are used in a broad range of industrial processes.

Micro material processing is a category that includes all laser material processing applications under 1 kilowatt.[24] The use of lasers in Micro Materials Processing has found broad application in the development and manufacturing of screens for smartphones, tablet computers, and LED TVs.[25]

A detailed list of industrial and commercial laser applications includes:

- Laser cutting
- Laser welding
- Laser drilling
- Laser marking

Laser cladding, a surface engineering process applied to mechanical components for reconditioning, repair work or hardfacing

Photolithography

Optical communications over optical fiber or in free space

Laser peening

Guidance systems (e.g., ring laser gyroscopes)

Laser rangefinder / surveying,

Lidar / pollution monitoring,

Digital minilabs

Barcode readers

Laser engraving of printing plate

Laser bonding of additive marking materials for decoration and identification,

Laser pointers

Laser mice

Laser accelerometers

OLED display manufacturing

Holography

Bubblegrams

Optical tweezers

Writing subtitles onto motion picture films.[26]

Power beaming, which is a possible solution to transfer energy to the climber of a Space elevator

3D laser scanners for accurate 3D measurement

Laser line levels are used in surveying and construction. Lasers are also used for guidance for aircraft.

Extensively in both consumer and industrial imaging equipment.

In laser printers: gas and diode lasers play a key role in manufacturing high resolution printing plates and in image scanning equipment.

Diode lasers are used as a lightswitch in industry, with a laser beam and a receiver which will switch on or off when the beam is interrupted, and because a laser can keep the light intensity over larger distances than a normal light, and is more precise than a normal light it can be used for product detection in automated production.

Laser alignment

Additive manufacturing

Plastic welding

To store and retrieve data in optical discs, such as CDs and DVDs

Entertainment and recreation

Laser lighting displays accompany many music concerts

Laser tag

Laser harp: a musical instrument were the strings are replaced with laser beams

As a light source for digital cinema projectors[27]

Surveying and ranging

In surveying and construction, the laser level is affixed to a tripod, leveled and then spun to illuminate a horizontal plane. The laser beam projector employs a rotating head with a mirror for sweeping the laser beam about a vertical axis. If the mirror is not self-leveling, it is provided with visually readable level vials and manually adjustable screws for orienting the projector. A staff carried by the operator is equipped with a movable sensor, which can detect the laser beam and gives a signal when the sensor is in line with the beam (usually an audible beep). The position of the sensor on the graduated staff allows comparison of elevations between different points on the terrain.

A tower-mounted laser level is used in combination with a sensor on a wheel tractor-scraper in the process of land laser leveling to bring land (for example, an agricultural field) to near-flatness with a slight grade for drainage. The laser line level was invented in 1996 by Steve J. Orosz, Jr.[1] This type of level does not require a heavy motor to create the illusion of a line from a dot, rather, it uses a lens to transform the dot into a line.

Bird deterrent

Laser beams are used to disperse birds from agricultural land, industrial sites, rooftops and from airport runways. Birds tend to perceive the laser beam as a physical stick. By moving the laser beam towards the birds, they get scared and fly away. On the market are manual operated laser torches[28] or automated robots[29] to move the laser beam automatically.

Fiber-optic communication

This is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information.[1] Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference are required.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Researchers at Bell Labs have reached internet speeds of over 100 petabit×kilometer per second using fiber-optic communication.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. However, infrastructure development within cities was relatively difficult and time-consuming, and fiber-optic systems were complex and expensive to install and operate. Due to these difficulties, fiber-optic communication systems have primarily been installed in long-distance applications, where they can be used to their full transmission capacity, offsetting the increased cost.

Since 2000, the prices for fiber-optic communications have dropped considerably. The price for rolling out fiber to the home has currently become more cost-effective than that of rolling out a copper based network. Costs are low and housing density is high. when optical-amplification systems became commercially available, the telecommunications industry has laid a vast network of intercity and transoceanic fiber communication lines. an intercontinental network of 250,000 km of submarine communications cable with a capacity of 2.56 Tb/s was completed, and although specific network capacities are privileged information, telecommunications investment.

Pulse dispersion

This is the result of modal dispersion, which is an issue in systems employing multimode fiber (MMF). Such systems permit optical signals and signal components to propagate along multiple modes, or physical paths, within both the core and the cladding of a fiber.

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DEPARTMENT OF PHYSICS

II M.SC PHYSICS BATCH: 2017-2018

LASER AND ITS APPLICATIONS (16PHP302)

MULTIPLE CHOICE QUESTIONS

Questions	opt1	opt2	opt3	opt4
UNIT I				
The word Laser is an abbrevation for	Light Amplification by Stimulated Emission of Radiation	Light Amplification by Spontaneous Emission of Radiation	Light Attenuation by Stimulated Emission of Radiation	Light Attenuation by Spontaneous Emission of Radiation
The first laser was built in	1972	1960	1988	1994
Ground state of the atom is the minimum energy state and it is the most --------- state.	unstable	discrete	stable	none
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
The characteristics of laser beam is	Monochromatic	Coherent	Intense	All the above
The photons of energy hγ 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
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
The life time of atom in the excited state is normally	10^{-6} sec	10^{-12} sec	10^{-8} sec	10^{-3} sec
The life time of atom in the metastable state is normally	10^{-6} sec	10^{-12} sec	10^{-8} 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
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
In optical region, λ = ----------------	1000 A^o	3000 A^o	6000 A^o	5000 A^o
In micro wave region, λ = ----------------	5 cm	15 cm	25 cm	none
The pumping rate is represented by	Ω	Ω^{-1}	ω	ω^{-1}
The probability per unit time, where the atoms are excited to the upper level is called------------ rate	Normal pumping	Abnormal pumping	Pumping	None
The line shape function represents the -------------------- behaviour of kω	Amplitude	Frequency	Wavelength	None
Line broadening mechanisms can be classified as	Homogeneous& heterogeneous	Homogeneous & non homogeneous	Heterogeneous & non homogeneous	None
Which of the following is an example of non- homogeneous broadening?	Natural	Collision	Doppler	None
Schawlow & Townes suggested --------------- plane parallel reflecting surfaces as a suitable resonator	1	2	3	4
For non degenerate state	$g_n = g_m$	g_n/g_m	$g_n - g_m$	$g_n + g_m$
In transition between two energy states, the atom absorbs or emits a photon of energy is	hν	hν/2	2hν	none

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
The atoms are taken to the higher energy level with the help of light is called	optical pumping	pumping	induced absorption	induced emission
The atoms are taken to the higher energy level with the help of -----------	electrons	chemical reaction	induced absorption	light
Population inversion means, the no. of atoms in the excited state is --------------- the no. of atoms in the ground state	same	less than	greater than	none
The excited atoms return to the lower state without help of any external agency is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission
The excited atoms return to the lower state with help of photon is called	spontaneous absorption	stimulated absorption	stimulated emission	spontaneous emission
The photons produced by stimulated emission is called	Primary photon	secondary photon	spontaneous photon	none
The secondary photon is always ------------------ with the stimulating photons	out of phase	coherent	in phase	none
By laser action all the emitted photons are ---------- with each other	out of phase	coherent	in phase	none
In the microwave region wavelength=	.5 cm	15 cm	20 cm	10 cm
In microwave region, the stimulated emission rate is ------------- the spontaneous rate	equal to	higher than	smaller than	none
The spontaneous emission is more predominant in the ---------------- region	optical	IR	UV	microwave
Excited atoms undergo transition to the lower level by ------------emission	spontaneous	stimulated	both a and b	none
The population difference between the two levels in a steady state -------------on the decay time of the upper level	depends	independent	same	none
The probability per unit time, where the atoms are excited to the upper level is called---------rate	normal pumping	abnormal pumping	pumping	none
The pumping power is always ------------ upon decay time	same	independence	depends	none
The cavity which does not contain any active medium is called --------- resonator	active	passive	band pass	low pass
The cavity which contain active medium is called ---------resonator	active	passive	band pass	low pass
The atoms having same central frequency and the same atomic line shape is known as	homogeneous	heterogeneous	non- homogeneous	none
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
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
In optical region, hw/KT is approximately equal to	10	1000	1500	100
In microwave region, hw/KT is approximately equal to	$5x10^{-2}$	$5x10^{-6}$	$5x10^{-3}$	none
In threshold condition a is called ------gain coefficient	saturated	unsaturated	normal	none
The particular shape of the function g (w) -------------- on the phenomenon responsible for the line broadening	same	independence	depends	none

Line broadening mechanism can be classified as	homogeneous & heterogeneous	homogeneous & non homogeneous	heterogeneous & non homogeneous	none
Laser emits light in -------------- direction.	various	1	2	none
Laser radiations have --------------- degree of coherence.	low	high	medium	very low
Time incoherence is a characteristics of a ----------- beam of light	single	multiple	Both a and b	None of the above
Another name of temporal coherence is ----------- coherence	transverse	spatial	longitudinal	none of these
----------- is a best example of an optically pumped rare earth laser system	calcium ion	erbium ion	uranium ion	neodymium ion
The fluorescent quantum efficiency was found to be near --------	zero	less than unity	unity	greater than 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
Rayleigh range begins to spread linearly with distance because of ----------- effect	interference	dispersion	diffraction	refraction
Who determine the equation $2d \sin \theta = m\lambda$	Heisenberg	Bragg	Planck	None

Laser Systems:

Solid state lasers- the ruby laser, Nd:YAG laser, ND: Glass laser, semiconductor lasers – features of semiconductor lasers, intrinsic semiconductor lasers, Gas laser - neutral atom gas laser, He-Ne laser, molecular gas lasers, CO2 laser, Liquid lasers, dye lasers and chemical laser.

LASR SYSTEM

SOLID STATE LASER

A solid-state laser is a laser that uses a gain medium that is a solid, rather than a liquid such as in dye lasers or a gas as in gas lasers. Semiconductor-based lasers are also in the solid state, but are generally considered as a separate class from solid-state lasers. Generally, the active medium of a solid-state laser consists of a glass or crystalline "host" material, to which is added a "dopant" such as neodymium, chromium, erbium, thulium or ytterbium. Many of the common dopants are rare-earth elements, because the excited states of such ions are not strongly coupled with the thermal vibrations of their crystal lattices (phonons), and their operational thresholds can be reached at relatively low intensities of laser pumping.

There are many hundreds of solid-state media in which laser action has been achieved, but relatively few types are in widespread use. Of these, probably the most common is neodymium-doped yttrium aluminum garnet (Nd:YAG). Neodymium-doped glass (Nd:glass) and ytterbium-doped glasses or ceramics are used at very high power levels (tera watts) and high energies (mega joules), for multiple-beam inertial confinement fusion.The first material used for lasers was synthetic ruby crystals. Ruby lasers are still used for a few applications, but they are not common because of their low power efficiencies. At room temperature, ruby lasers emit only short pulses of light, but at cryogenic temperatures they can be made to emit a continuous train of pulses.

Some solid-state lasers can also be tunable using several intracavity techniques, which employ etalons, prisms, and gratings, or a combination of these. Sapphires widely used for its broad tuning range, 660 to 1080 nanometers. Alexandrite lasers are tunable from 700 to 820 nm and yield higher-energy pulses than titanium-sapphire lasers because of the gain medium's longer energy storage time and higher damage threshold.

Solid-state lasers are being developed as optional weapons for the F-35 Lightning II, and are reaching near-operational status, as well as the introduction of Northrop Grumman's FIRESTRIKE laser weapon system in high energy solid state laser. The exact range is classified, but they said it fired "miles not yards".

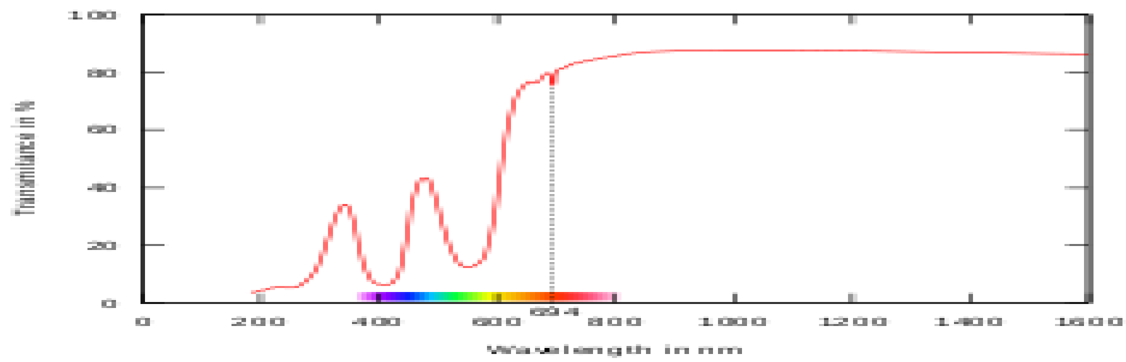
Uranium-doped calcium fluoride was the second type of solid state laser invented, in the 1960s. Peter Sorokin and Mirek Stevenson at IBM's laboratories in Yorktown Heights achieved lasing at 2.5 µm shortly after Maiman's ruby laser preparing to test a truck-mounted laser system using a 58 kW fiber laser .The scalability of the laser opens up use on everything from drones to massive ships at different levels of power. The new laser puts 40 percent of available energy into its beam, which is considered very high for solid-state lasers. Since more and more military vehicles and trucks are using advanced hybrid engine and propulsion systems that produce electricity for applications like lasers the applications are likely to proliferate in trucks, drones, ships, helicopters and planes.

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 1960. Ruby lasers produce pulses of coherent visible light at a wavelength of 694.3 nm, which is a deep red color. Typical ruby laser pulse lengths are on the order of a millisecond.

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 color, with a very narrow linewidth 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.



Transmittance of ruby in optical and near-IR spectra. Note the two broad blue and green absorption bands and the narrow absorption band at 694 nm, which is the wavelength of the ruby laser.

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 synthetic 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.

One of the first applications for the ruby laser was in range finding. By 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, because ruby's high-powered beam closely matches diamond's broad absorption band (the GR1 band) in the red. 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.

Nd :YAG LASER

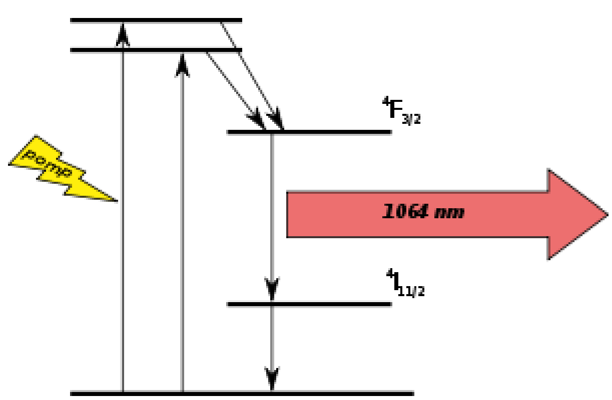
Nd:YAG (neodymium-doped yttrium aluminium garnet; Nd:$Y_3Al_5O_{12}$) is a crystal that is used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium, Nd(III), typically replaces a small fraction (1%) of the yttrium ions in the host crystal structure of the yttrium aluminium garnet (YAG), since the two ions are of similar size. It is the neodymium ion which provides the lasing activity in the crystal, in the same fashion as red chromium ion in ruby lasers.

Nd:YAG lasers are optically pumped using a flashtube or laser diodes. These are one of the most common types of laser, and are used for many different applications. Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 946, 1120, 1320, and 1440 nm. Nd:YAG lasers operate in both pulsed and continuous mode. Pulsed Nd:YAG lasers are typically operated in the so-called Q-switching mode.

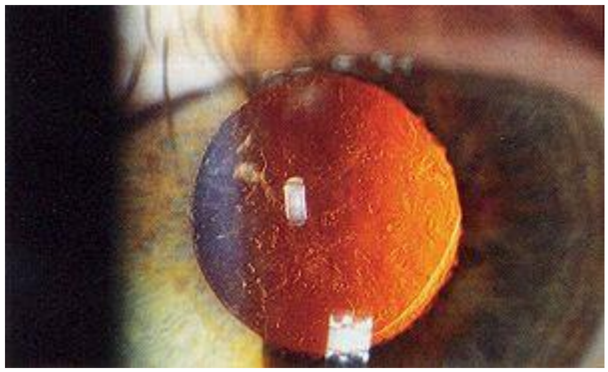
An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved. The high-intensity pulses may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355, 266 and 213 nm.

Nd:YAG absorbs mostly in the bands between 730–760 nm and 790–820 nm. At low current densities krypton flash lamps have higher output in those bands than do the more common xenon lamps, which produce more light at around 900 nm. The former are therefore more efficient for pumping Nd:YAG lasers.

The amount of the neodymium dopant in the material varies according to its use. For continuous wave output, the doping is significantly lower than for pulsed lasers. The lightly doped CW rods can be optically distinguished by being less colored, almost white, while higher-doped rods are pink-purplish. other common host materials for neodymium are: YLF (yttrium lithium fluoride, 1047 and 1053 nm), YVO_4 (yttrium orthovanadate, 1064 nm), and glass. A particular host material is chosen in order to obtain a desired combination of optical, mechanical, and thermal properties. Nd:YAG lasers and variants are pumped either by flashtubes, continuous gas discharge lamps, or near-infrared laser diodes (DPSS lasers). Prestabilized laser (PSL) types of Nd:YAG lasers have proved to be particularly useful in providing the main beams for gravitational wave interferometers such as LIGO, VIRGO, GEO600 and TAMA.



Neodymium ions in various types of ionic crystals, and also in glasses, act as a laser gain medium, typically emitting 1064 nm light from a particular atomic transition in the neodymium ion, after being "pumped" into excitation from an external source Medicine Slit lamp photo of posterior capsular opacification visible a few months after implantation of intraocular lens in eye, seen on retro illumination



Intraocular lens in eye.

Nd:YAG lasers are used in ophthalmology to correct posterior capsular opacification, a condition that may occur after cataractsurgery, and for peripheral iridotomy in patients with acute angle-closure glaucoma, where it has superseded surgical iridectomy.

Frequency-doubled Nd:YAG lasers (wavelength 532 nm) are used for pan-retinal photocoagulation in patients with diabetic retinopathy. In certain cases these lasers are also used to treat eye floaters.

Nd:YAG lasers emitting light at 1064 nm have been the most widely used laser for laser-induced thermotherapy, in which benign or malignant lesions in various organs are ablated by the beam.

In oncology, Nd:YAG lasers can be used to remove skin cancers. They are also used to reduce benign thyroid nodules, and to destroy primary and secondary malignant liver lesions.

To treat benign prostatic hyperplasia (BPH),

Nd:YAG lasers can be used for laser prostate surgery—a form of transurethral resection of the prostate.

These lasers are also used extensively in the field of cosmetic medicine for laser hair removal and the treatment of minor vascular defects such as spider veins on the face and legs. Recently used for Dissecting cellulitis of the scalp, a rare skin disease. Using hysteroscopy the Nd:YAG laser has been used for removal of uterine septa within the inside of the uterus.

In podiatry, the Nd:YAG laser is being used to treat onychomycosis, which is fungus infection of the toenail. The merits of laser treatment of these infections are not yet clear, and research is being done to establish effectiveness.

Dentistry

Nd:YAG dental lasers are used for soft tissue surgeries in the oral cavity, such as gingivectomy, periodontal sulcular debridement, LANAP, frenectomy, biopsy, and coagulation of graft donor sites.

Manufacturing

Nd:YAG lasers are used in manufacturing for engraving, etching, or marking a variety of metals and plastics, or for metal surface enhancement processes like laser peening.[16] They are extensively used in manufacturing for cutting and welding steel, semiconductors and various alloys. For automotive applications (cutting and welding steel) the power levels are typically 1–5 kW. Super alloy drilling (for gas turbine parts) typically uses pulsed Nd:YAG lasers (millisecond pulses, not Q-switched). Nd:YAG lasers are also employed to make subsurface markings in transparent materials such as glass or acrylic glass. Lasers of up to 2 kW are used for selective laser melting of metals in additive layered manufacturing. In aerospace applications, they can be used to drill cooling holes for enhanced air flow/heat exhaust efficiency.[*citation needed*]

Nd:YAG lasers are also used in the non-conventional rapid prototyping process laser engineered net shaping (LENS).

Laser peening typically uses high energy (10 to 40 Joule), 10 to 30 nanosecond pulse, flashed laser systems to generate gigawatts of power on the surface of a part by focusing the laser beam down to a few millimeters in diameter. Laser peening is unlike the other manufacturing processes in that it neither heats or adds material; it is a mechanical process of cold working the metallic component to impart compressive residual stresses. Laser peening is widely used in gas fired turbine engines in both aerospace and power generation for component damage tolerance improvement and fatigue life and strength increase.

Fluid dynamics

Nd:YAG lasers can be used for flow visualization techniques in fluid dynamics (for example particle image velocimetry or laser-induced fluorescence).

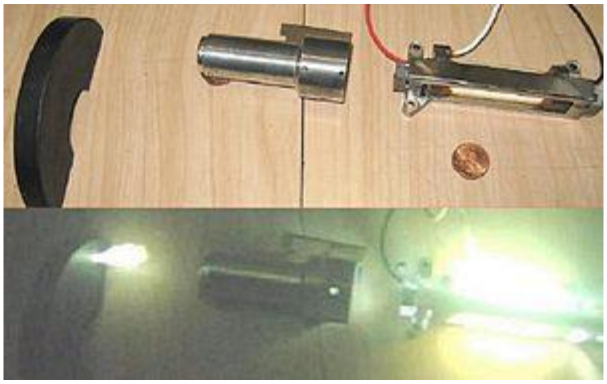
Biophysics Nd:YAG lasers are frequently used to build optical tweezers for biological applications. This is because Nd:YAG lasers mostly emit at a wavelength of 1064 nm. Biological samples have a low absorption coefficient at this wavelength, as biological samples are usually mostly made up of water. As such, using an Nd:YAG laser minimizes the damage to the biological sample being studied.

Automotive

The lasers use several 800 picosecond long pulses to ignite the fuel, producing faster and more uniform ignition. The researchers say that such igniters could yield better performance and fuel economy, with fewer harmful emissions.

Defence

Nd:YAG laser used for range finder firing.



The laser fires through a collimator, for focusing the beam, which blasts a hole through a rubber block, releasing a burst of plasma.The Nd:YAG laser is the most common laser used in laser designators and laser range finders. Cavity ring-down spectroscopy (CRDS) and Laser-induced breakdown spectroscopy (LIBS)

A range of Nd:YAG lasers are used in analysis of elements in the periodic table. Though the application by conventional methods such as XRF or ICP, it has proven to be less time consuming and a cheaper option to test element concentrations. A high-power Nd:YAG laser is focused onto the sample surface to produce plasma. Light from the plasma is captured by spectrometers and the characteristic spectra of each element can be identified, allowing concentrations of elements in the sample to be measured.

Laser pumping

Nd:YAG lasers, mainly via their second and third harmonics, are widely used to excite dye lasers either in the liquid or solid state. They are also used as pump sources for vibronically broadened solid-state lasers such as Cr^{4+}:YAG or via the second harmonic for pumping Ti:sapphire lasers.

GLASS LASER

Laser glass is the heart of the NIF laser system; it's the material that amplifies the laser light to the very high energies required for experiments.NIF's laser glass is a phosphate glass that contains a chemical additive with neodymium atoms (Nd:glass). Neodymium-doped laser glass is the preferred gain medium for use in high-peak-power lasers for fusion energy research.

The NIF laser system uses about 3,070 42-kilogram plates of laser glass. Each glass plate measures 3.4 by 46 by 81 centimeters (about three feet long and about half as wide). If stacked end-to-end, the plates would form a continuous ribbon of glass 1.5 miles long. The glass slabs are set on edge at a specific angle, known as Brewster's angle, so that the laser beams have very low reflective losses while propagating through the glass. laser glass at a rate 20 times faster, five times cheaper, and with two to three times better optical quality than with previous processes.

Flash lamps

The amplifier slabs are surrounded by vertical arrays of flashlamps. Measuring nearly 180 centimeters (6 feet) of arc length, NIF's 7,680 flashlamps are the largest commercial units ever made. Each is driven with about 50,000 joules of electrical energy. The flashlamps excite the neodymium in the glass slabs to provide optical gain at the infrared frequency of 1,053-nanometer wavelength, also referred to as "one omega," or 1ω, light. Some of the energy stored in the neodymium is released when the laser pulses from the injection laser system pass through the amplifier slabs

SEMICONDUCTING LASER

Semiconductor lasers or laser diodes play an important part in our everyday lives by providing cheap and compact-size lasers. They consist of complex multi-layer structures requiring nanometer scale accuracy and an elaborate design. Their theoretical description is important not only from a fundamental point of view, but also in order to generate new and improved designs. It is common to all systems that the laser is an inverted carrier density system. The carrier inversion results in an electromagnetic polarization which drives an electric field In most cases, the electric field is confined in a resonator, the properties of which are also important factors for laser performance.

In semiconductor laser theory, the optical gain is produced in a semiconductor material. The choice of material depends on the desired wavelength and properties such as modulation speed. It may be a bulk semiconductor, but more often a quantum hetero structure. Pumping may be electrically or optically (disk laser). All these structures can be described in a common framework and in differing levels of complexity and accuracy. Light is generated in a semiconductor laser by radiative recombination of electrons and holes. In order to generate more light by stimulated emission than is lost by absorption, the system has to be inverted, see the article on lasers. A laser is, thus, always a high carrier density system that entails many-body interactions. These cannot be taken into account exactly because of the high number of particles involved.

Various approximations can be made:

Hartree Fock approximation: To describe an interacting carrier system at any density, the semiconductor Bloch equations (SBEs) may be employed. These may be solved in the Hartree–Fock approximation. In this case, carrier–carrier interaction leads to renormalisation terms for band structure and electric field. The collision terms, using a relaxation time or T_2-time for the polarization.

Correlation effects: Taking the collision terms into account explicitly requires a large numerical effort, but can be done with state-of-the-art computers.[5] Technically speaking, the collision terms in the semiconductor Bloch equations are included in second-Born approximation.[3] This microscopic model has the advantage of having predictive character, i.e., it yields the correct linewidth for any temperature or excitation density. In the other models, the relaxation time has to be extracted from experiment, but depends on the actual parameters meaning the experiment has to be redone for any temperature and excitation intensity.

INTRINSIC SEMI CONDUCTING LASER

A semiconductor is a material whose conductivity lies between those of conductor and insulator. Semiconductors are of two types:

a) Intrinsic semiconductors or pure semiconductors

b) Extrinsic semiconductors or doped semiconductors

Extrinsic semiconductors are further classified into two types depending upon the type of majority carriers:

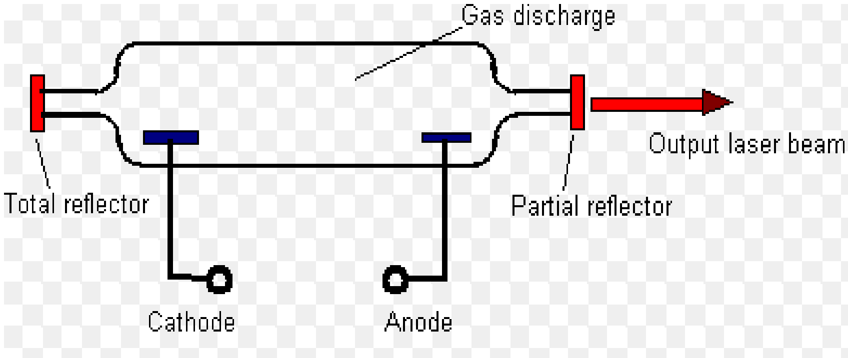
i) n-type semiconductors where electrons are majority carriers.

ii) p- type semiconductors where holes are majority carriers.

When a p-type semiconductor and a n- type semiconductor is joined by special techniques, there will be flow of electrons from n side to p side and flow of holes from p side to n side. After some time, an electric field will be created which will oppose this flow and flow stops. Thus, there will be formation of depletion region. This region is called so because it is depleted from charge carriers.

GAS LASER

A gas laser is a laser in which an electric current is discharged through a gas to produce coherent light. The gas laser was the first continuous-light laser and the first laser to operate on the principle of converting electrical energy to a laser light output. Gas Lasers are lasers that use an electric current discharged through a gas medium to produce a beam. Common Gas Lasers include helium neon, argon, or carbon dioxide. The type of gas used can determine or influence the laser'swavelength, efficiency.



TYPICAL GAS LASER

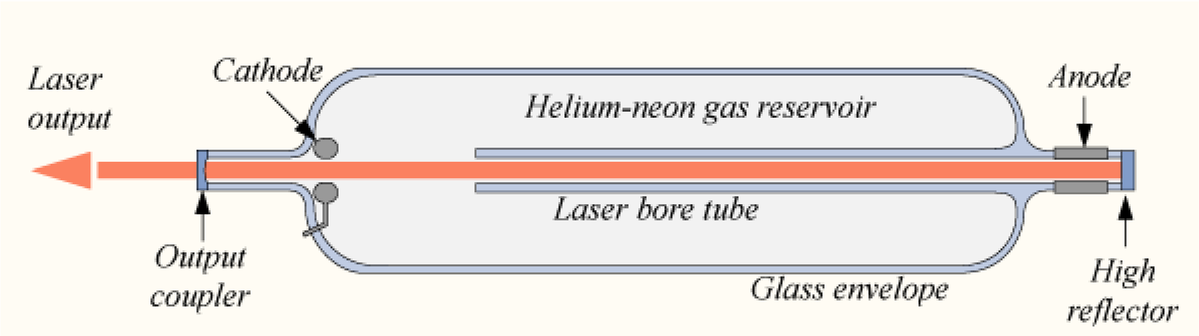
He -Ne LASER

A helium–neon laser or HeNe laser, is a type of gas laser whose gain medium consists of a mixture of 85% helium and 15% neon inside of a small bore capillary tube, usually excited by a DC electrical discharge. The best-known and most widely used HeNe laser operates at a wavelength of 632.8 nm, in the red part of the visible spectrum.

The gain medium of the laser, as suggested by its name, is a mixture of helium and neon gases, in approximately a 10:1 ratio, contained at low pressure in a glass envelope. The gas mixture is mostly helium, so that helium atoms can be excited. The excited helium atoms collide with neon atoms, exciting some of them to the state that radiates 632.8 nm. Without helium, the neon atoms would be excited mostly to lower excited states responsible for non-laser lines. A neon laser with no helium can be constructed but it is much more difficult without this means of energy coupling. Therefore, a HeNe laser that has lost enough of its helium (e.g., due to diffusion through the seals or glass) will lose its laser functionality because the pumping efficiency will be too low.

The energy or pump source of the laser is provided by a high voltage electrical discharge passed through the gas between electrodes (anode and cathode) within the tube. A DC current of 3 to 20 mA is typically required for CW operation.

The optical cavity of the laser usually consists of two concave mirrors or one plane and one concave mirror, one having very high (typically 99.9%) reflectance and the output coupler mirror allowing approximately 1% transmission.

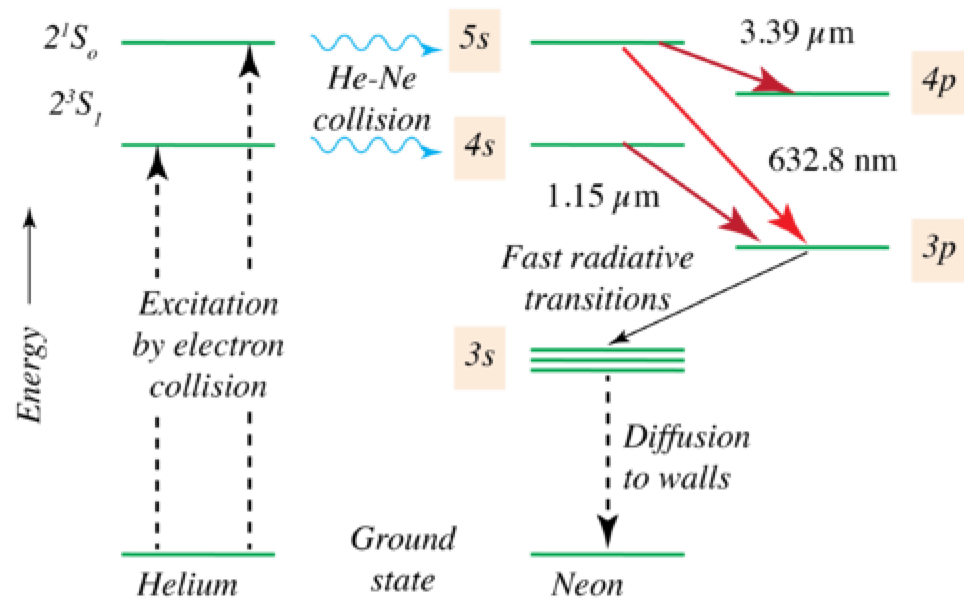


Schematic diagram of a helium–neon laser

Commercial He-Ne lasers are relatively small devices, among gas lasers, having cavity lengths usually ranging from 15 cm to 50 cm (but sometimes up to about 1 metre to achieve the highest powers), and optical output power levels ranging from 0.5 to 50 mW. The red HeNe laser wavelength of 633 nm has an actual vacuum wavelength of 632.991 nm, or about 632.816 nm in air.

The wavelengths of the stimulated emission modes lie within about 0.001 nm above or below this value, and the wavelengths of those modes shift within this range due to thermal expansion and contraction of the cavity. Frequency-stabilized versions enable the wavelength of a single mode to be specified to within 1 part in 10^8 by the technique of comparing the powers of two longitudinal modes in opposite polarizations.

Absolute stabilization of the laser's frequency (or wavelength) as fine as 2.5 parts in 10^{11}can be obtained through use of an iodine absorption cell.



Energy levels in a He-Ne Laser

The mechanism producing population inversion and light amplification in a HeNe laser plasma originates with inelastic collision of energetic electrons with ground state helium atoms in the gas mixture. As shown in the accompanying energy level diagram, these collisions excite helium atoms from the ground state to higher energy excited states, among them the 2^3S_1 and 2^1S_0 (LS or Russell-Saunder coupling, front number 2 tells that an excited electron is n = 2 state) in long-lived metastable states. Because of a fortuitous near coincidence between the energy levels of the two He metastable states, and the $5s_2$ and $4s_2$(Paschen notation [9]) levels of neon, collisions between these helium metastable atoms and ground state neon atoms results in a selective and efficient transfer of excitation energy from the helium to neon. This excitation energy transfer process is given by the reaction equations:

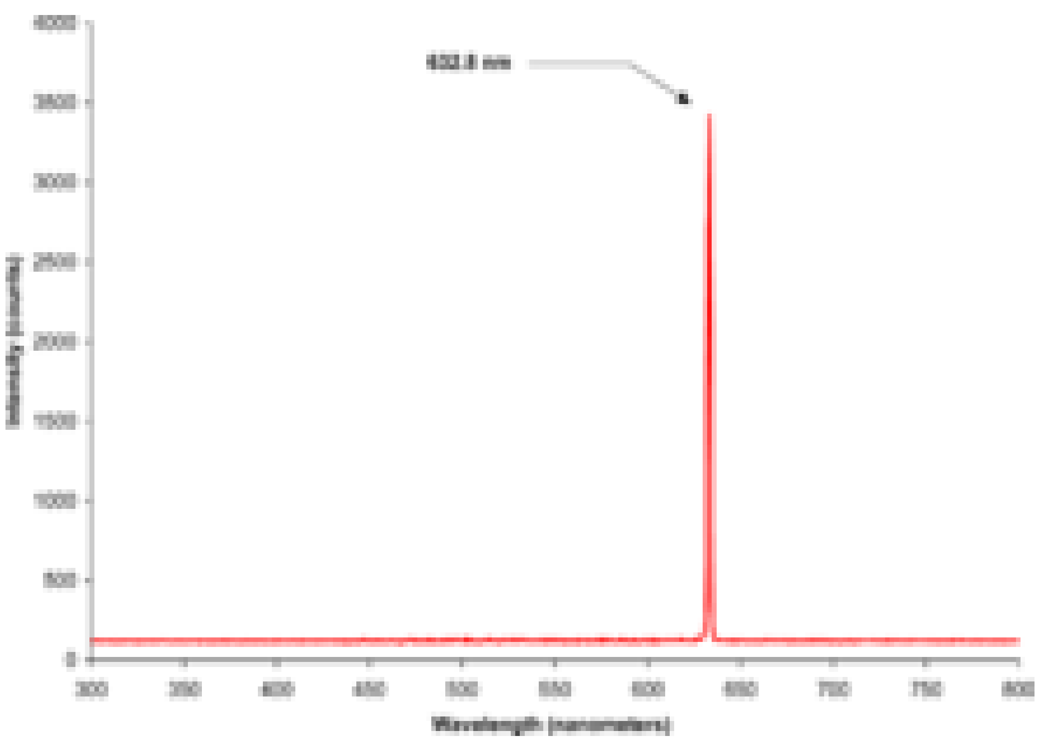
$$He^*(2^3S_1) + Ne^1S_0 \rightarrow He(^1S_0) + Ne^*4s_2 + \Delta E$$

and

$$He^*(2^1S) + Ne^1S_0 + \Delta E \rightarrow He(^1S_0) + Ne^*5s_2$$

where (*) represents an excited state, and ΔE is the small energy difference between the energy states of the two atoms, of the order of 0.05 eV or 387 cm^{-1}, which is supplied by kinetic energy. Excitation energy transfer increases the population of the neon $4s_2$ and $5s_2$levels manyfold. When the population of these two upper levels exceeds that of the corresponding lower level neon state, $3p_4$ to which they are optically connected, population inversion is present. The medium becomes capable of amplifying light in a narrow band at 1.15 μm (corresponding to the $4s_2$ to $3p_4$ transition) and in a narrow band at 632.8 nm (corresponding to the $5s_2$ to $3p_4$ transition at 632.8 nm). The $3p_4$ level is efficiently emptied by fast radiative decay to the 1s state, eventually reaching the ground state.

The remaining step in utilizing optical amplification to create an optical oscillator is to place highly reflecting mirrors at each end of the amplifying medium so that a wave in a particular spatial mode will reflect back upon itself, gaining more power in each pass than is lost due to transmission through the mirrors and diffraction. When these conditions are met for one or more longitudinal modes then radiation in those modes will rapidly build up until gain saturation occurs, resulting in a stable continuous laser beam output through the front (typically 99% reflecting) mirror.



Spectrum of a helium neon laser illustrating its very high spectral purity (limited by the measuring apparatus).

The 0.002 nm bandwidth of the stimulated emission medium is well over 10,000 times narrower than the spectral width of a light-emitting diode (whose spectrum is shown here for comparison), with the bandwidth of a single longitudinal mode being much narrower still.

The gain bandwidth of the He-Ne laser is dominated by Doppler broadening rather than pressure broadening due to the low gas pressure, and is thus quite narrow: only about 1.5 GHz full width for the 633 nm transition. With cavities having typical lengths of 15 cm to 50 cm, this allows about 2 to 8 longitudinal modes to oscillate simultaneously (however single longitudinal mode units are available for special applications). The visible output of the red He-Ne laser, long coherence length, and its excellent spatial quality, makes this laser a useful source for holography and as a wavelength reference for spectroscopy. A stabilized He-Ne laser is also one of the benchmark systems for the definition of the meter. Prior to the invention of cheap, abundant diode lasers, red He-Ne lasers were widely used in barcode scanners at supermarket checkout counters. Laser gyroscopes have employed He-Ne lasers operating at 0.633 μm in a ring laser configuration.

He-Ne lasers are generally present in educational and research optical laboratories.

Red He-Ne lasers have many industrial and scientific uses. They are widely used in laboratory demonstrations in the field of optics because of their relatively low cost and ease of operation compared to other visible lasers producing beams of similar quality in terms of spatial coherence (a single-mode Gaussian beam) and long coherence length . A consumer application of the red He-Ne laser is the Laser Disc player. The laser is used in the device to read the optical disk.

MOLECULAR GAS LASER

In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.

In CO2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

C02 Molecular Gas Laser

It was the first molecular gas laser developed by Indian born American scientist Prof.C.K.N.Pillai.

It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser

ENERGY LEVELS OF CO_2 MOLECULES

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

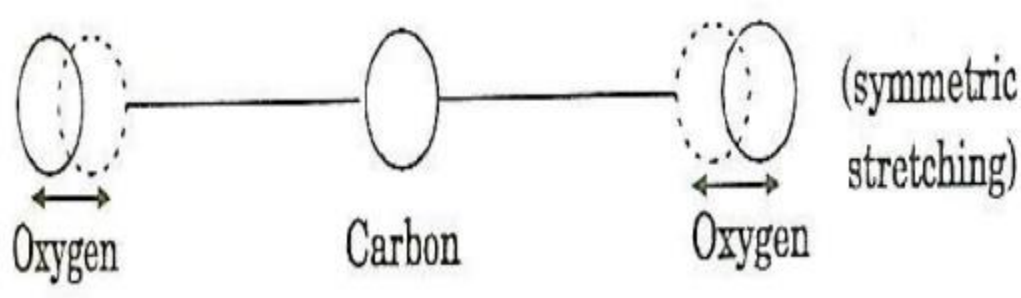
a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

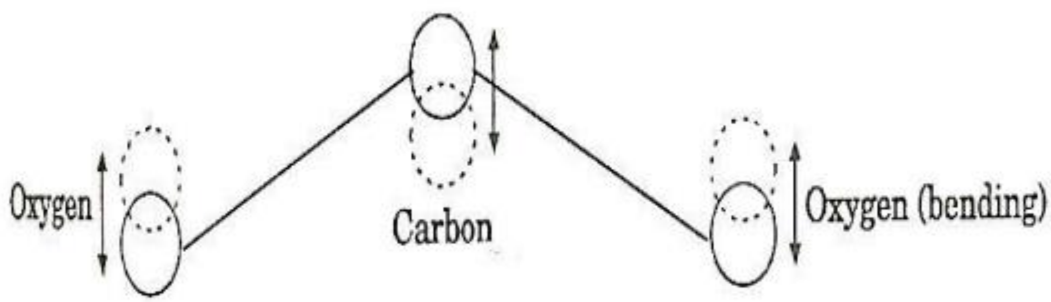
SYMMETRY STRETCHING MODE

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

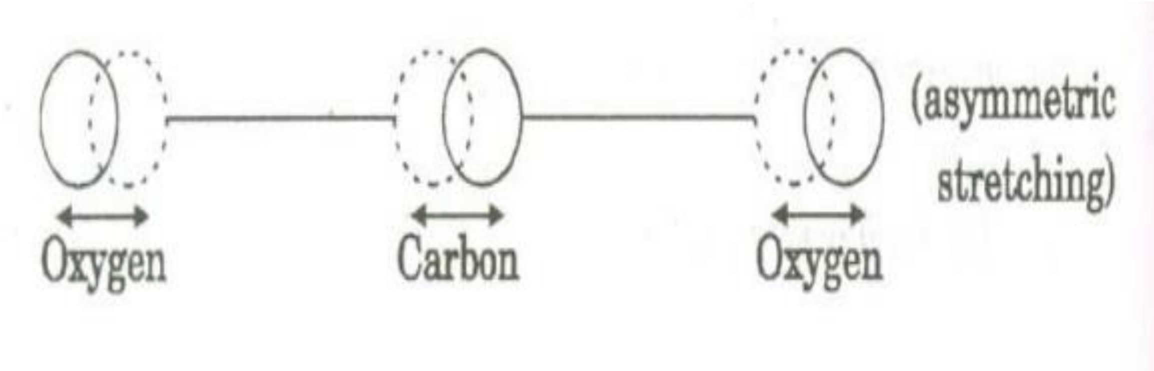


b. Bending mode:

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.



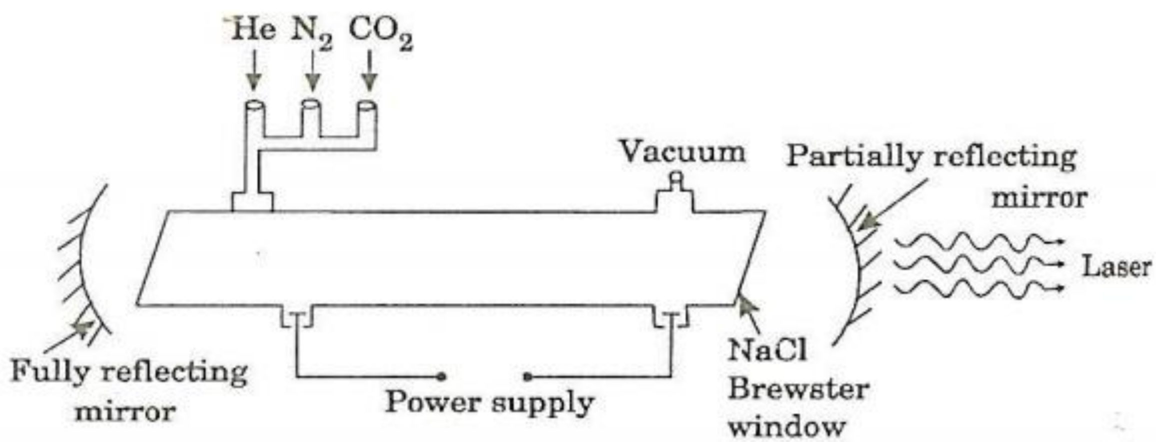
c. Asymmetric stretching mode:



In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

Principle:

The active medium is a gas mixture of CO_2, N_2 and He. The laser transition takes place between the vibrational states of CO_2molecules.



Construction:

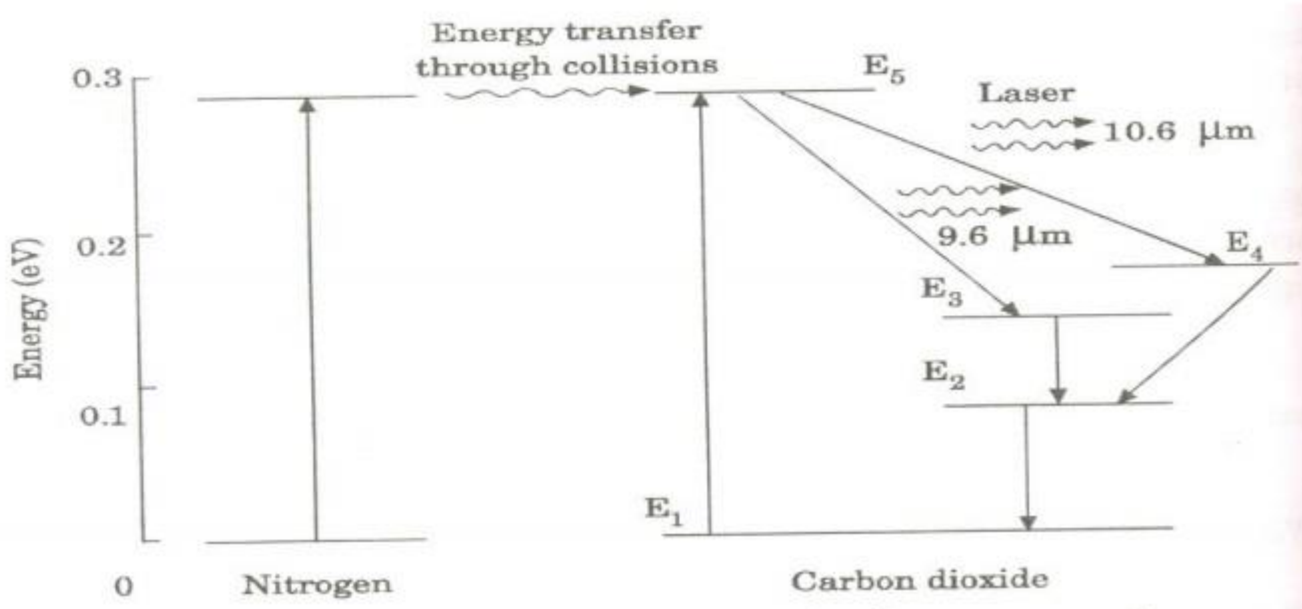
It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2 (active medium), helium and nitrogen with suitable partial pressures.

The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.

Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working:

Figure shows energy levels of nitrogen and carbon dioxide molecules.



When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$$N_2 + e^* = N_2^* + e$$

N_2 = Nitrogen molecule in ground state e^* = electron with kinetic energy

N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

Now N_2 molecules in the excited state collide with Co_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.

This process is represented by the equation $N_2* + Co_2 = Co_2* + N_2$

N2* = Nitrogen molecule in excited state. CO_2 = Carbon dioxide atoms in ground state CO_2* = Carbon dioxide atoms in excited state N_2 = Nitrogen molecule in ground state.

Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases.

As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1.Transition E5 to E4 :

This will produce a laser beam of wavelength 10.6µm

2.Transition E5 to E3

This transition will produce a laser beam of wavelength 9.6µm. Normally 10.6µm transition is more intense than 9.6µm transition. The power output from this laser is 10kW.

Characteristics:

1. Type: It is a molecular gas laser.

2. Active medium: A mixture of CO2 , N2 and helium or water vapour is used as active medium

3. Pumping method: Electrical discharge method is used for Pumping action

4. Optical resonator: Two concave mirrors form a resonant cavity

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5. Power output: The power output from this laser is about 10kW.

6. Nature of output: The nature of output may be continuous wave or pulsed wave.

7. Wavelength of output: The wavelength of output is 0.6μm and 10.6μm.

Advantages:

1. The construction of CO_2 laser is simple

2. The output of this laser is continuous.

3. It has high efficiency

4. It has very high output power.

5. The output power can be increased by extending the length of the gas tube.

Disadvantages:

1. The contamination of oxygen by carbon monoxide will have some effect on laser action

2. The operating temperature plays an important role in determining the output power of laser.

3. The corrosion may occur at the reflecting plates.

4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

Applications:

1. High power CO_2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6μm makes CO_2 laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.
5. It is mostly used in neuro surgery and general surgery.
6. It is used to perform microsurgery and bloodless operation

LIQUID LASER

A liquid-crystal laser is a laser that uses a liquid crystal as the resonator cavity, allowing selection of emission wavelength and polarization from the active laser medium. The lasing medium is usually a dye doped into the liquid crystal. Liquid-crystal lasers are comparable in size to diode lasers, but provide the continuous wide spectrum of dye lasers while maintaining a large coherence area. The tuning range is typically several tens of nanometers. Self-organization at micrometer scales reduces manufacturing complexity compared to using layered photonic meta materials. It can be achieved by doping the liquid crystal with a chiral molecule. For light circularly polarized with the same handedness, this regular modulation of the refractive index yields selective reflection of the wavelength given by the helical pitch, allowing the liquid-crystal laser to serve as its own resonator cavity. Photonic crystals are amenable to band theory methods, with the periodic dielectric structure playing the role of the periodic electric potential and a photonic band gap (reflection notch) corresponding to forbidden frequencies. The lower photon group velocity and higher density of states near the photonic band gap suppresses spontaneous emission and enhances stimulated emission, providing favorable conditions for lasing. If the electronic band edge falls in the photonic band gap, electron-hole recombination is strictly suppressed. This allows for devices with high lasing efficiency, low lasing threshold, and stable frequency, where the liquid-crystal laser acts its own waveguide. "Colossal" nonlinear change in refractive index is achievable in doped nematic-phase liquid crystals, that is the refractive index can change with illumination intensity at a rate of about $10^3 cm^2/W$ of illumination intensity. Most systems use a semiconductor pumping laser to achieve population inversion, though flash lamp and electrical pumping systems are possible.[15]

Tuning of the output wavelength is achieved by smoothly varying the helical pitch: as the winding changes, so does the length scale of the crystal. This in turn shifts the band edge and changes the optical path length in the lasing cavity. Applying a static electric field perpendicular to the dipole moment of the local nematic phase rotates the rod-like subunits in the hexagonal plane and reorders the chiral phase, winding or unwinding the helical pitch.[16] Similarly, optical tuning of the output wavelength is available using laser light far from the pick-up frequency of the gain medium, with degree of rotation governed by intensity and the angle between the polarization of the incident light and the dipole moment. Reorientation is stable and reversible. The chiral pitch of a cholesteric phase tends to unwind with increasing temperature, with a disorder-order transition to the higher symmetry nematic phase at the high end. By applying a temperature gradient perpendicular to the direction of emission varying the location of stimulation, frequency may be selected across a continuous spectrum. Similarly, a quasi-continuous doping gradient yields multiple laser lines from different locations on the same sample. Spatial tuning may also be accomplished using a wedge cell. The boundary conditions of the narrower cell squeeze the helical pitch by requiring a particular orientation at the edge, with discrete jumps where the outer cells rotate to the next stable orientation; frequency variation between jumps is continuous.

If a defect is introduced into the liquid crystal to disturb the periodicity, a single allowed mode may be created inside of the photonic bandgap, reducing power leeching by spontaneous emission at adjacent frequencies.

Applications

Biomedical sensing: small size, low cost, and low power consumption offer a variety of advantages in biomedical sensing applications. Potentially, liquid-crystal lasers could form the basis for "lab on a chip" devices that provide immediate readings without sending a sample away to a separate lab.

Medical: low emission power limits such medical procedures as cutting during surgeries, but liquid-crystal lasers show potential to be used in microscopy techniques and techniques such as photodynamic therapy.

Display screens:

liquid-crystal-laser-based displays offer most of the advantages of standard liquid-crystal displays, but the low spectral spread gives more precise control over color. Individual elements are small enough to act as single pixels while retaining high brightness and color definition. A system in which each pixel is a single spatially tuned device could avoid the sometimes long relaxation times of dynamic tuning, and could emit any color using spatial addressing and the same monochromatic pumping source.

Environmental sensing: using a material with a helical pitch highly sensitive to temperature, electric field, magnetic field, or mechanical strain, color shift of the output laser provides a simple, direct measurement of environmental conditions.

DYE LASER

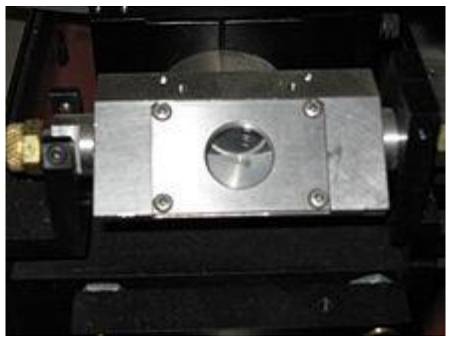
A dye laser is a laser which uses an organic dye as the lasing medium, usually as a liquid solution. Compared to gasesand most solid state lasing media, a dye can usually be used for a much wider range of wavelengths, often spanning 50 to 100 nanometers or more. The wide bandwidth makes them particularly suitable for tunable lasers and pulsed lasers. The dye rhodamine 6G, for example, can be tuned from 635 nm (orangish-red) to 560 nm (greenish-yellow), and produce pulses as short as 16 femtoseconds.[1] Moreover, the dye can be replaced by another type in order to generate an even broader range of wavelengths with the same laser, from the near-infrared to the near-ultraviolet, although this usually requires replacing other optical components in the laser as well, such as dielectric mirrors or pump lasers.

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.

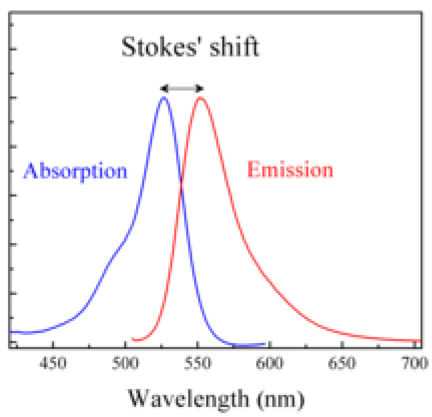
A dye laser uses a gain medium consisting of an organic dye, which is a carbon-based, soluble stain that is often fluorescent, such as the dye in a high lighter pen. The dye is mixed with a compatible solvent, allowing the molecules to diffuse evenly throughout the liquid. The dye solution may be circulated 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 flashtube 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 99.9% 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 flashtube 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 often a thin tube approximately equal in length to the flashtube, with both windows and an inlet or outlet for the liquid on each end. The dye cell is usually side-pumped, with one or more flashtubes 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 flashtube produces. Axial pumped lasers have a hollow, annular-shaped flashtube 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 flashtube, for even better transfer efficiency, but have a lower gain due to diffraction losses. Flash pumped lasers can be used only for pulsed output applications.

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 laser, 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.



A cuvette used in a dye laser. A thin sheet of liquid is passed between the windows at high speeds. The windows are set at Brewster's angle (air-to-glass interface) for the pump laser, and at Brewster's angle (liquid-to-glass interface) for the emitted beam.



Stokes shift in Rhodamine 6G during broadband absorption or emission. In laser operation, the Stokes shift is the difference between the pump wavelength and the output.

The dyes used in these lasers contain rather large, organic molecules which fluoresce. Most dyes have a very short time between the absorption and emission of light, referred to as the fluorescence lifetime, which is often on the order of a few nanoseconds. (In comparison, most solid-state lasers have a fluorescence lifetime ranging from hundreds of microseconds to a few milliseconds.) Under standard laser-pumping conditions, the molecules emit their energy before a population inversion can properly build up, so dyes require rather specialized means of pumping. Liquid dyes have an extremely high lasing threshold. In addition, the large molecules are subject to complex excited state transitions during which the spin can be "**flipped**", quickly changing from the useful, fast-emitting "**singlet**" state to the slower "triplet" state.

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 partially opaque. 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. Due to their high absorption, the pumping energy may often be concentrated into a rather small volume of liquid.

Now days 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 more-complicated alignment.

Liquid dyes have very high gain as laser media. The beam needs to make only 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 reflections from the dye-cell walls or flashlamp reflector cause parasitic oscillations, dramatically reducing 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.[11] A benefit of organic dyes is their high fluorescence efficiency. The greatest losses in many lasers and other fluorescence devices is not from the transfer efficiency (absorbed versus reflected/transmitted energy) or quantum yield (emitted number of photons per absorbed number), but from the losses when high-energy photons are absorbed and reemitted as photons of longer wavelengths. Because the energy of a photon is determined by its wavelength, the emitted photons will be of lower energy; a phenomenon called the Stokes shift. The absorption centers of many dyes are very close to the emission centers. Sometimes the two are close enough that the absorption profile slightly overlaps the emission profile. As a result, most dyes exhibit very small Stokes shifts and consequently allow for lower energy losses than many other laser types due to this phenomenon. The wide absorption profiles make them particularly suited to broadband pumping, such as from a flashtube. It also allows a wide range of pump lasers to be used for any certain dye and, conversely, many different dyes can be used with a single pump laser 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 vapor laser isotope separation manufacturing medicine
- spectroscopy

Medical application

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.

spectroscopy

In spectroscopy, dye lasers can be used to study the absorption and emission spectra of various materials. Their tunablities 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, femtosecond 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.

Tunable lasers are used in swept-frequency metrology to enable measurement of absolute distances with very high accuracy. A two axis interferometer is set up and by sweeping the frequency, the frequency of the light returning from the fixed arm is slightly different from the frequency returning from the distance measuring arm. This produces a beat frequency which can be detected and used to determine the absolute difference between the lengths of the two arms.

CHEMICAL LASER

A chemical laser is a laser that obtains its energy from a chemical reaction. Chemical lasers can reach continuous wave output with power reaching to megawatt levels. They are used in industry for cutting and drilling.

Common examples of chemical lasers are the chemical oxygen iodine laser (COIL), all gas-phase iodine laser (AGIL), and the hydrogen fluoride (HF) and deuterium fluoride (DF) lasers, all operating in the mid-infrared region. There is also a DF–CO_2 laser (deuterium fluoride–carbon dioxide), which, like COIL, is a "transfer laser." The HF and DF lasers are unusual, in that there is several molecular energy transitions with sufficient energy to cross the threshold required for lasing. Since the molecules do not collide frequently enough to re-distribute the energy, several of these laser modes operate either simultaneously, or in extremely rapid succession, so that an HF or DF laser appears to operate simultaneously on several wavelengths unless a wavelength selection device is incorporated into the resonator.

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DEPARTMENT OF PHYSICS

II M.SC PHYSICS

LASER AND ITS APPLICATIONS (16PHP302)

MULTIPLE CHOICE QUESTIONS

Questions

UNIT-II

In which type of lasers, atomic transitions have been used	ruby	He-Ne	dye	CO_2
In He –Ne laser action, which atoms assists in the pumping process	Ne	He	Both a & b	none
In medicine, the lasers are used for ----------- and cauterizing	cutting	welding	drilling	none
The carbon dioxide laser is operated in ----------- mode	no flow	fast flow	slow axial flow	All the above
Lasers are found to be very effective in cutting ------------- types of material.	different	same	invariant	identical
The hologram contains in the form of the ---------- pattern	Interference	diffraction	scattering	refraction
The reference beam of the balancing of the plate would be proportional to ----------	$\| E_{0ê}^{3}$	$\| E_{0ê}^{2}$	$\| E_0 \|$	$E_0^{\ 2}$
The virtual image produced by a hologram appears in complete ---------------- dimensional form.	4	2	3	6
With the help of ---------- laser the astronomers have been able to extend range of observation.	CO_2 laser	ruby laser	dye laser	He-Ne laser
Who determine the equation 2d sin θ = mλ	Heisenberg	Bragg	Planck	None
Who discovered ruby laser?	Theodore Maiman	Brillouin	Raman	None
-----------contains in the form of the interference pattern	maser	laser	hologram	none
The first working laser was made by Theodore Maiman in ------	1950	1955	1960	1965
The first laser diode was demonstrated by --------.	Robert N. Hall	Donald Herriot	Ali Javan	William R. Bennett
The first laser diode was demonstrated by Robert N. Hall in ------	1959	1960	1961	1962
------- lasers are powered by a chemical reaction involving an excited dimer.	He-Ne	Excimer	Ruby	Dye
The efficiency of a CO_2 laser is over ------.	5%	10%	15%	20%
Elastic and inelastic scatterings are referred as ____________.	Hyper and Hyper Raman Rayleigh	Raman and stokes	Rayleigh and stokes	Rayleigh and anti stokes
The ruby laser was first demonstrated in the year of	1967	1987	1950	1960
Nd:YAG is an ----------- level laser system.	two	four	three	none
Nd:YAG lasers are mostliy used in --------- applications.	military	range finding	target destination	All the above
In Nd Glass lasers, ---------- type of glasses are used.	oxide glasses	halide glasses	chalcogenide glasses	All the above
What is the lifetime of ns state of Ne?	100ns	50ns	150ns	200ns
What kind of mirrors are used in co2 lasers?	Si coated with Al	Ni coated with Al	Fe coated with Al	none
What is the voltage used in co2 laser?	10-30kV	20-30kV	10-20kV	around 50kV
What is the Current used in co2 laser?		30mA	50mA	70mA
What kind of pumping is used in semiconductor laser?	electrical	optical pumping	thermal	none
Is the ruby laser is CW or pulsed?	CW	pulsed	both	none
Solid state masers have noise level ____________ than hat of ammonium laser.	higher	stable	lower	unstable
Solid state maser uses ____________ as an active element.	chromium	nickel	aluminium	copper

The image of a 3 dimensional object is recorded on a ___________ dimensional photography plate.	1	2	3	both a & b
Holography means ___________	complete decoding	partial recording	complete recording	partial decoding
Holography works under the principle of ___________.	interference	diffraction	dispersion	refraction
Light waves with ___________ degree of coherence is required in holography.	medium	low	high	none of these
The fine structure of interference fringes required photographic emulsion with a ___________ special resolution	high	low	medium	none of these
A major drawback of conventional holographic process is requirement of___________ in the image construction.	incoherent illumination	coherent illumination	incoherent emission	coherent emission
Volume hologram is a ___________ grating.	1-D	2-D	3-D	none of these
Rainbow hologram can be viewed with a ___________ source.	white light	red light	green light	both a and b
Volume hologram, the colour light will be ___________ at a particular angle by hologram.	reflected	refracted	diffracted	scattered
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
___________ is a pulsed laser.	1 level	2 level	3 level	4 level
The conduction for gases remains absorptive is ___________.	n1> n2	n1<n2	n1=n2	both a and b
A continuous maser operation is possible in a ___________.	1 level	2 level	3 level	none of these
The absorption transition will continue as long as the gas remains	absorptive	refractive	reflective	dispersive
In three level maser ___________ is used.	separation in space	frequency separation	amplitude separation	none of these
The basic element of the early maser was ___________.	gaseous ammonia	liquid ammonia	gaseous nitrogen	liquid nitrogen
The ammonia molecule ___________ in structure.	linear	tetrahedral	hexagonal	octahedral
The energy of a symmetric state in ammonia molecule is ___________.	$1/\sqrt{2}\,(\psi 1+\psi 2)$	$\frac{1}{2}(\psi 1+\psi 2)$	$\frac{1}{2}(\psi 1-\psi 2)$	$1/\sqrt{2}\,(\psi 1-\psi 2)$
The antisymmetric state has ___________ energy than the symmetric state.	higher	lower	stable	none of the above
The wavelength of radiation in ammonia maser is ___________.	1cm	1.25 cm	1.30 cm	1.5 cm
An example for two level maser system is ___________.	fibre maser	He-Ne maser	ammonia maser	CO_2 maser
Ammonia maser is ___________ maser system.	2 level	3 level	4 level	none of these
For efficient maser action it is imperative that a cavity losses are as ___________ as possible.	high	small	medium	none of these
The losses depend upon the ___________ of the cavity.	intensity	energy stored	energy lost	Q-factor
Ammonia masers have ___________ power output.	very low	very high	medium	none of these
Ammonium masers have power output around ___________ watt.	10^{-3}	10^{+3}	10^{-9}	10^{+9}
The splitting of state increases with ___________ field.	increasing	decreasing	stable	none of these
The coherence of maser radiation produces a ___________ line width	broad	narrow	medium	none of these
What is the lifetime of electron hole pair in a semiconductor laser?	1-5ns	1-10ns	1-3ns	none
What is the active material in dye lasers?	methanol	glycerol	both a and b	none
What is the concentration of dye molecules?	1 part in 1000	1 part in 100	1 part in 10000	none
The lifetime of lower vibrational level of S1 is about	1ns	3ns	4ns	7ns
The lifetime of higher vibrational level of S1 is about	10(-10)s	10(-12)s	10(-19)s	10(-15)s

Advances in laser Physics :

Production of giant pulse -Q-switching, giant pulse dynamics, laser amplifiers, mode locking and pulling, Non-linear optics, Harmonic generation, second harmonic generation, Phase matching, third harmonic generation, optical mixing, parametric generation and self-focusing of light.

ADVANCE IN LASER PHYSICS

Q switching

Q-switching, sometimes known as giant pulse formation or Q-spoiling, is a technique by which a laser can be made to produce a pulsed output beam. The technique allows the production of light pulses with extremely high (giga watt) peak power, much higher than would be produced by the same laser if it were operating in a continuous wave (constant output) mode. Compared to mode locking, another technique for pulse generation with lasers, Q-switching leads to much lower pulse repetition rates, much higher pulse energies, and much longer pulse durations. The two techniques are sometimes applied together.

Q-switching was first switched Kerr cell shutters in a ruby laser, Q-switching is achieved by putting some type of variable attenuator inside the laser's optical resonator. When the attenuator is functioning, light which leaves the gain medium does not return, and lasing cannot begin. This attenuation inside the cavity corresponds to a decrease in the Q factor or quality factor of the optical resonator. A high Q factor corresponds to low resonator losses per round trip, and vice versa. The variable attenuator is commonly called a "Q-switch", when used for this purpose.

Initially the laser medium is pumped while the Q-switch is set to prevent feedback of light into the gain medium (producing an optical resonator with low Q). This produces a population inversion, but laser operation cannot yet occur since there is no feedback from the resonator. Since the rate of stimulated emission is dependent on the amount of light entering the medium, the amount of energy stored in the gain medium increases as the medium is pumped. Due to losses from spontaneous emission and other processes, after a certain time the stored

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energy will reach some maximum level; the medium is said to be gain saturated. At this point, the Q-switch device is quickly changed from low to high Q, allowing feedback and the process of optical amplification by stimulated emission to begin. Because of the large amount of energy already stored in the gain medium, the intensity of light in the laser resonator builds up very quickly; this also causes the energy stored in the medium to be depleted almost as quickly. The net result is a short pulse of light output from the laser, known as a giant pulse, which may have a very high peak intensity.

Applications

Q-switched lasers are often used in applications which demand high laser intensities in nanosecond pulses, such as metal cutting or pulsed holography. Nonlinear optics often takes advantage of the high peak powers of these lasers, offering applications such as 3D optical data storage and 3D micro fabrication.

Q-switched lasers can also be used for measurement purposes, such as for distance measurements (range finding) by measuring the time it takes for the pulse to get to some target and the reflected light to get back to the sender. It can be also used in chemical dynamic study, e.g. temperature jump relaxation study.

Q-switched lasers are also used to remove tattoos by shattering ink pigments into particles that are cleared by the body's lymphatic system. Full removal can take between six and twenty treatments depending on the amount and colour of ink, spaced at least a month apart, using different wavelengths for different coloured inks. Nd:YAG lasers are currently the most favoured lasers due to their high peak powers, high repetition rates and relatively low costs. introduced based on clinical research which appears to show better clearance with 'difficult' colours such as green and light blue.

Q-switch laser is also used by beauticians around the world to treat skin-related issues like acne, pigmentation, dark spots, and fixes for ant-aging. Q switch is a more effective alternative than most other techniques.

LASER AMPLIFIER

An optical amplifier is a device which receives some input signal and generates an output signal with higher optical power. Typically, inputs and outputs are laser beams, either propagating as Gaussian beams in free space or in a fiber. The amplification occurs in a so-called gain medium, which has to be "pumped" (i.e., provided with energy) from an external source. Most optical amplifiers are either optically or electrically pumped.

Multimode and Single-mode Amplifiers

Some types of optical amplifiers are intrinsically multimode devices. For example, an amplifier based on bulk laser crystal can amplify multimode beams and can also handle beams with different angular positions and directions in certain ranges, which makes it possible to construct a multipass amplifier.

Other optical amplifiers are single-mode devices. For example, many fiber amplifiers and semiconductor optical amplifiers are based on a single-mode fiber or waveguide. In such cases, only a single mode can be amplified, and that has to be mode-matched to the amplifier.

When a single-mode laser amplifier provides a high gain within some bandwidth, it inevitably generates a substantial level of amplified spontaneous emission (ASE). In a multimode amplifier, this effect is correspondingly stronger. Even if ASE is negligible (for lower gain), a multimode amplifier typically exhibits more power losses by spontaneous emission (and thus has a lower gain efficiency) because a larger amount of laser-active material has to be kept in the excited state.

Important Parameters of an Optical Amplifier

Important parameters of an optical amplifier include:

The maximum gain, specified as an amplification factor or in decibels (dB)

The saturation power, which is related to the gain efficiency

The saturated output power (for a given pump power)

The power efficiency and pump power requirements

The saturation energy

the time of energy storage (→ upper-state lifetime)

The gain bandwidth (and possibly smoothness of gain spectrum)

The noise figure and possibly more detailed noise specifications

The sensitivity to back-reflections

The number of modes it can amplify

Applications

Typical applications of optical amplifiers are:

An amplifier can boost the (average) power of a laser output to higher levels (→ master oscillator power amplifier = MOPA).

It can generate extremely high peak powers, particularly in ultrashort pulses, if the stored energy is extracted within a short time.

It can amplify weak signals before photo detection, and thus reduce the detection noise, unless the added amplifier noise is large.

In long fiber-optic links for optical fiber communications, the optical power level has to be raised between long sections of fiber before the information is lost in the noise.

MODE LOCKING AND PULLING

Mode-locking is a technique in optics by which a laser can be made to produce pulses of light of extremely short duration, on the order of picoseconds (10^{-12} s) or femtoseconds (10^{-15} s).The basis of the technique is to induce a fixed-phase relationship between the longitudinal modes of the laser's resonant cavity. The laser is then said to be 'phase-locked' or 'mode-locked'. Interference between these modes causes the laser light to be produced as a train of pulses. Depending on the properties of the laser, these pulses may be of extremely brief duration, as short as a few femtoseconds.

In a simple laser, each of these modes oscillates independently, with no fixed relationship between each other, in essence like a set of independent lasers all emitting light at slightly different frequencies. The individual phase of the light waves in each mode is not fixed, and may vary randomly due to such things as thermal changes in materials of the laser. In lasers with only a few oscillating modes, interference between the modes can cause beating effects in the laser output, leading to fluctuations in intensity; in lasers with many thousands of modes, these interference effects tend to average to a near-constant output intensity.

If instead of oscillating independently, each mode operates with a fixed phase between it and the other modes the laser output behaves quite differently. Instead of random or constant output intensity, the modes of the laser will periodically all constructively interfere with one another, producing an intense burst or pulse of light. Such a laser is said to be 'mode-locked' or 'phase-locked'.

These pulses occur separated in time by

$$\boldsymbol{\tau = 2L/c},$$

where τ is the time taken for the light to make exactly one round trip of the laser cavity.
This time corresponds to a frequency exactly equal to the mode spacing of the laser,

$$\boldsymbol{\Delta\nu = 1/\tau}.$$

The duration of each pulse of light is determined by the number of modes which are oscillating in phase (in a real laser, it is not necessarily true that all of the laser's modes will be phase-locked). If there are N modes locked with a frequency separation $\Delta\nu$, the overall mode-locked bandwidth is $N\Delta\nu$, and the wider this bandwidth, the shorter the pulse durationfrom the laser. In practice, the actual pulse duration is determined by the shape of each pulse, which is in turn determined by the exact amplitude and phase relationship of each longitudinal mode. For example, for a laser producing pulses with a Gaussian temporal shape, the minimum possible pulse duration Δt is given by

$$\Delta t = \frac{0.441}{N\Delta\nu}.$$

The value 0.441 is known as the 'time-bandwidth product' of the pulse, and varies depending on the pulse shape. For ultra-short pulse lasers, a hyperbolic-secant-squared (sech^2) pulse shape is often assumed, giving a time-bandwidth product of 0.315.
Using this equation, the minimum pulse duration can be calculated consistent with the measured laser spectral width. For the He-Ne laser with a 1.5-GHz spectral width, the shortest Gaussian pulse consistent with this spectral width would be around 300 picoseconds; for the 128-THz bandwidth Ti sapphire laser, this spectral width would be only 3.4 femtoseconds. These values represent the shortest possible Gaussian pulses consistent with the laser's line width; in a real mode-locked laser, the actual pulse duration depends on many other factors, such as the actual pulse shape, and the overall dispersion of the cavity.
Subsequent modulation could in principle shorten the pulse width of such a laser further; however, the measured spectral width would then be correspondingly increased.

Applications

Nuclear fusion. (inertial confinement fusion).*Nonlinear optics,* such as second-harmonic generation, parametric down-conversion, optical parametric oscillators, and generation of Terahertz radiation

Optical Data Storage uses lasers, and the emerging technology of 3D optical data storage generally relies on nonlinear photochemistry. For this reason, many examples use mode-locked lasers, since they can offer a very high repetition rate of ultrashort pulses.

Femtosecond laser nanomachining – The short pulses can be used to nanomachine in many types of materials.

An example of pico- and femtosecond micromachining is drilling the silicon jet surface of ink jet printers

Two-photon microscopy

Corneal Surgery.

Femtosecond lasers can create bubbles in the cornea, if multiple bubbles are created in a planar fashion parallel to the corneal surface then the tissue separates at this plane and a flap like the one in LASIK is formed (Intralase: Intralasik or SBK (Sub Bowman Keratomileusis) if the flap thickness is equal or less than 100 micrometres). If done in multiple layers a piece of corneal tissue between these layers can be removed (Visumax: FLEX Femtosecond Lenticle Extraction).

A laser technique has been developed that renders the surface of metals deep black. A femtosecond laser pulse deforms the surface of the metal forming nanostructures. The immensely increased surface area can absorb virtually all the light that falls on it thus rendering it deep black. This is one type of black gold[3]

Photonic Sampling, using the high accuracy of lasers over electronic clocks to decrease the sampling error in electronic ADCs.

NONLINEAR OPTICS

Nonlinear optics (NLO) is the branch of optics that describes the behavior of light in *nonlinear media*, that is, media in which the dielectric polarization P responds nonlinearly to the electric field E of the light. The nonlinearity is typically observed only at very high light intensities (values of the electric field comparable to interatomic electric fields, typically 10^8V/m) such as those provided by lasers. Above the Schwinger limit, the vacuum itself is expected to become nonlinear. In nonlinear optics, the superposition principle no longer holds. Nonlinear optics remained unexplored until the discovery in 1961 of second-harmonic generation by Peter Franken *et al.* at University of Michigan, shortly after the construction of the first laser by Theodore Harold Maiman.[1] However, some nonlinear effects were discovered before the development of the laser.[2] The theoretical basis for many nonlinear processes were first described in Bloembergen's monograph "Nonlinear Optics".

Example uses for non linear optics

Frequency doubling

One of the most commonly used frequency-mixing processes is frequency doubling, or second-harmonic generation. With this technique, the 1064 nm output from Nd:YAG lasersor the 800 nm output from Ti:sapphire lasers can be converted to visible light, with wavelengths of 532 nm (green) or 400 nm (violet) respectively.

Practically, frequency doubling is carried out by placing a nonlinear medium in a laser beam. While there are many types of nonlinear media, the most common media are crystals. Commonly used crystals are BBO (β-barium borate), KDP (potassium dihydrogen phosphate), KTP (potassium titanyl phosphate), and lithium niobate. These crystals have the necessary properties of being strongly birefringent (necessary to obtain phase matching, see below), having a specific crystal symmetry, being transparent for both the impinging laser light and the frequency-doubled wavelength, and having high damage thresholds, which makes them resistant against the high-intensity laser light.

Optical phase conjugation

It is possible, using nonlinear optical processes, to exactly reverse the propagation direction and phase variation of a beam of light. The reversed beam is called a conjugate beam, and thus the technique is known as optical phase conjugation (also called time reversal, wavefront reversal and retro reflection).

One can interpret this nonlinear optical interaction as being analogous to a real-time holographic process.[18] In this case, the interacting beams simultaneously interact in a nonlinear optical material to form a dynamic hologram (two of the three input beams), or real-time diffraction pattern, in the material. The third incident beam diffracts at this dynamic hologram, and, in the process, reads out the phase-conjugate wave. In effect, all three incident beams interact (essentially) simultaneously to form several real-time holograms, resulting in a set of diffracted output waves that phase up as the "time-reversed" beam. In the language of nonlinear optics, the interacting beams result in a nonlinear polarization within the material, which coherently radiates to form the phase-conjugate wave.

SECOND HARMONIC GENERATION

Second harmonic generation (also called frequency doubling or abbreviated SHG) is a nonlinear optical process, in which photons with the same frequency interacting with a nonlinear material are effectively "combined" to generate new photons with twice the energy, and therefore twice the frequency and half the wavelength of the initial photons. Second harmonic generation, as an even-order nonlinear optical effect, is only allowed in media without inversion symmetry. It is a special case of sum frequency generation and is the inverse of half-harmonic generation.

Second harmonic generation was first demonstrated by Peter Franken, A. E. Hill, Peters, The demonstration was made possible by the invention of the laser, which created the required high intensity coherent light. They focused a ruby laser with a wavelength of 694 nm into a quartz sample. They sent the output light through a spectrometer, recording the spectrum on photographic paper, which indicated the production of light at 347 nm. The formulation of SHG was initially described by N. Bloembergen and P. S. Pershan at Harvard in 1962. In their extensive evaluation of Maxwell's equations at the planar interface between a linear and nonlinear medium, several rules for the interaction of light in non-linear mediums were elucidated.

Generating the second harmonic, often called frequency doubling, is also a process in radio communication; it was developed early in the 20th century, and has been used with frequencies in the megahertz range. It is a special case of frequency multiplication.

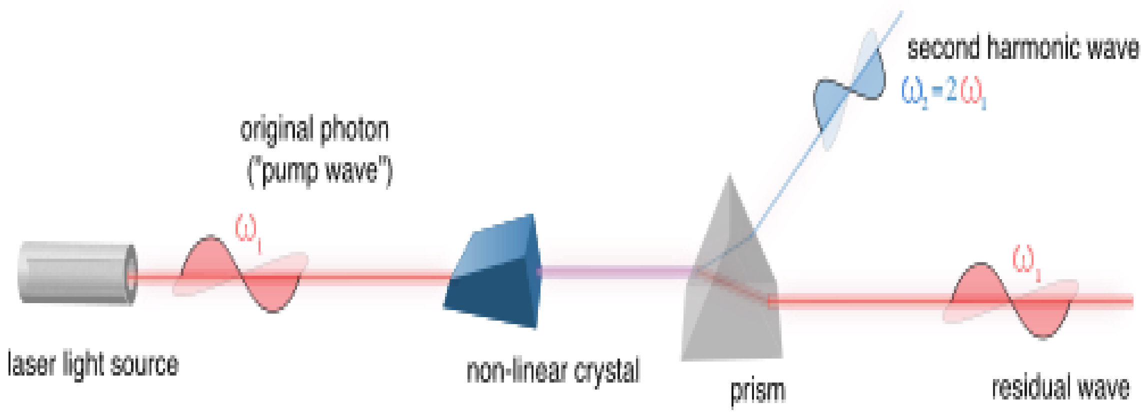


Diagram of the second harmonic generation process.

Derivation of SHG

The simplest case for analysis of second harmonic generation is a plane wave of amplitude *E(ω)* traveling in a nonlinear medium in the direction of its *k* vector. A polarization is generated at the second harmonic frequency

$$P(2\omega) = \epsilon_0 \chi^{(2)} E^2(\omega) = 2\epsilon_0 d_{\text{eff}}(2\omega;\omega,\omega) E^2(\omega),$$

where d_{eff} is the effective nonlinear optical coefficient which is dependent on specific components of $\chi^{(2)}$ that are involved in this particular interaction. The wave equation at 2ω (assuming negligible loss and asserting the slowly varying envelope approximation) is

$$\frac{\partial E(2\omega)}{\partial z} = -\frac{i\omega}{n_{2\omega}c} d_{\text{eff}} E^2(\omega) e^{i\Delta kz}$$

where $\Delta k = k(2\omega) - 2k(\omega)$.

At low conversion efficiency (*E(2ω) << E(ω)*) the amplitude $E(\omega)$ remains essentially constant over the interaction length, l. Then, with the boundary condition $E(2\omega, z=0) = 0$ we obtain

$$E(2\omega, z=l) = -\frac{i\omega d_{\text{eff}}}{n_{2\omega}c} E^2(\omega) \int_0^l e^{i\Delta kz} dz = -\frac{i\omega d_{\text{eff}}}{n_{2\omega}c} E^2(\omega) l \frac{\sin(\Delta kl/2)}{\Delta kl/2} e^{i\Delta kl/2}$$

In terms of the optical intensity, $I = n/2\sqrt{\epsilon_0/\mu_0}|E|^2$, this is,

$$I(2\omega, l) = \frac{2\omega^2 d_{\text{eff}}^2 l^2}{n_{2\omega} n_\omega^2 c^3 \epsilon_0} \left(\frac{\sin(\Delta kl/2)}{\Delta kl/2}\right)^2 I^2(\omega)$$

This intensity is maximized for the phase matched condition *Δk* = 0. If the process is not phase matched, the driving polarization at 2ω goes in and out of phase with generated wave *E*(2ω) and conversion oscillates as sin(*Δkl*/2). The coherence length is defined as $l_c = \frac{\pi}{\Delta k}$. It does not pay to use a nonlinear crystal much longer than the coherence length.

PHASE MATCHING

Quasi-phase-matching is a technique in nonlinear optics which allows a positive net flow of energy from the pump frequency to the signal and idler frequencies by creating a periodic structure in the nonlinear medium. Momentum is conserved, as is necessary for phase-matching, through an additional momentum contribution corresponding to the wavem vector of the periodic structure. Consequently, in principle any three-wave mixing process that satisfies energy conservation can be phase-matched. For example, all the optical frequencies involved can be collinear, can have the same polarization, and travel through the medium in arbitrary directions.

This allows one to use the largest nonlinear coefficient of the material in the nonlinear interaction. Quasi-phase-matching ensures that there is positive energy flow from the pump frequency to signal and idler frequencies even though all the frequencies involved are not phase locked with each other. Energy will always flow from pump to signal as long as the phase between the two optical waves is less than 180 degrees. Beyond 180 degrees, energy flows back from the signal to the pump frequencies. The coherence length is the length of the medium in which the phase of pump and the sum of idler and signal frequencies are 180 degrees from each other. At each coherence length the crystal axes are flipped which allows the energy to continue to positively flow from the pump to the signal and idler frequencies.

The most commonly used technique for creating quasi-phase-matched crystals has been periodic poling. More recently, continuous phase control over the local nonlinearity was achieved using nonlinear meta surfaces with homogeneous linear optical properties but spatially varying effective nonlinear polarizability.

OPTICAL MIXING

An optical mix is when you create paint colors not by mixing them on the palette (or physically), but through knowledge of color theory and how the eye perceives colors that abut or overlay each other. Glazing is the most common optical mix technique used in painting.

PARAMETRIC GENERATION AND SELF-FOCUSING OF LIGHT

A parametric process is an optical process in which light interacts with matter in such a way as to leave the quantum state of the material unchanged. As a direct consequence of this there can be no net transfer of energy, momentum, or angular momentum between the optical field and the physical system. In contrast a non-parametric process is a process in which any part of the quantum state of the system changes.

Self-focusing is a non-linear optical process induced by the change in refractive index of materials exposed to intense electromagnetic radiation.[1][2] A medium whose refractive index increases with the electric field intensity acts as a focusing lens for an electromagnetic wave characterised by an initial transverse intensity gradient, as in a laser beam.[3] The peak intensity of the self-focused region keeps increasing as the wave travels through the medium, until defocusing effects or medium damage interrupt this process. Self-focusing of light was discovered by Gurgen Askaryan.

Self-focusing is often observed when radiation generated by femtosecond lasers propagates through many solids, liquids and gases. Depending on the type of material and on the intensity of the radiation, several mechanisms produce variations in the refractive index which result in self-focusing: the main cases are Kerr-induced self-focusing and plasma self-focusing.

KARPAGAM ACADAMY OF HIGHER EDUCATION, COIMBATORE-21
DEPARTMENT OF PHYSICS
II M.SC PHYSICS
LASER AND ITS APPLICATIONS (16PHP302)
MULTIPLE CHOICE QUESTIONS
Questions
UNIT-III

Second harmonic generation was first demonstrated by	P. A. Franken	C. W. Peters	G. Weinreich	All the above
SHG has been extended to ------------ applications	biological	scientific	medical	industrial
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
The inverse phenomenon the nonlinear broadening of a light beam is called	focussing	parametic generation	self-focussing	defocussing
Light energy can be transmitted over long distances by means of ----------	fibers	wave guide	radar	none
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
----------- Laser is used in the Radio telescope.	He-Ne	CO_2	ruby	XY laser
A Q-switched ___________ laser is used for excitation of source.	Ruby	He-Ne	CO2	dye
___________ spectra have been observed in water molecule.	Hyper Raman spectra	Raman spectra	Rayleigh spectra	none
In holography a light wave is a carrier of information and it is recorded in terms of	wave parameters	electrons	photons	none of these
In holography ___________ light is recorded.	refracted	reflected	diffracted	dispersive
In recording of the hologram spacing between the fringes is as ___________.	0.001mm	0.01mm	0.1 mm	1mm
In reconstruction of the image the real image formed is known as ___________.	pseudoscopic image	reflected wave	real image	virtual image
Which rays are not used for recording?	acoustic radiation	X-ray	electron beam	uv ray
The virtual image produced by a hologram appears in complete ___________ form.	1 dimensional	2 dimensional	3 dimensional	none of these
___________ electrons in paramagnetic substance make solid state masers possible.	paired	unpaired	valance	excited
The magnetic moment is associated with the ___________ spin of the atom.	molecular	orbital	nuclear	electronic
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
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
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
A Q-switched ___________ laser is used for excitation of source.	Ruby	He-Ne	CO2	dye
___________ spectra have been observed in water molecule.	Hyper Raman spectra	Raman spectra	Rayleigh spectra	none

CCl3 and methane molecules have been observed ___________ spectra.	Raman	Rayleigh	a and b	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
A device that amplifies a laser beam by stimulated emission is called a ------------	ruby laser	dye laser	laser amplifier	chemical laser
Optical absorption and emission occur through the interaction of optical radiation with ----------	photons	electrons	ions	phonons
A coherent optical amplifier is a device that increases the -------------- of an optical field while maintaining its phase.	amplitude	intensity	energy	wavelength
an incoherent optical amplifier increases the intensity of an optical wave without preserving its phase.	amplitude	intensity	energy	wavelength
Q-switching, sometimes known as	giant pulse formation	Q-spoiling	both a and b	none
Q-switching was first proposed in -----------	1987	1876	1958	1976
Q-switching was first demonstrated by using electrically switched ------------ shutters in a ruby laser	kerr cell	leclanche cell	solar cell	none
The optical response of a material is expressed in terms of the	induced polarization	diffraction	interference	none
Nonlinear optics (NLO) is the branch of optics that describes the behavior of --------- in non-linear media.	sound	light	current	none
The another name of second harmonic generation is ------------	phase matching	optical mixing	frequency doubling	self focussing
In a non-linear material, the material polarization will have a component at twice the optical ------------	frequency	intensity	energy	none
In many cases, the nonlinear mixing products can be efficiently accumulated over a greater length of crystal only if ------------ is achieved.	phase matching	optical mixing	self-focussing	none
In non-linear optics, the electric polarization is proportional to the --------	frequency	wavelength	electric field strength	electric potential
A delayed nonlinear response is associated with ---------	Raman scattering	Brillouin scattering.	rayleigh scattering	both a and b
Self-focusing is a non-linear optical process induced by the change in ---------- of materials exposed to intense electromagnetic radiation	refractive index	intensity	amplitude	none
The most widely used dye is	Azines	Acridines	Colmarins	Xanthene
The inter system crossing will ------- the no. of molecules available in the upper state for laser action	Reduce	Increase	Both a & b	None
The --------- laser operates between two fully allowed transitions with no metastable state	CO_2	He- Ne	dye	Excimer
The operating frequencies of -------------- laser are determined by energy levels in atoms & molecules	Free- electron	HCl	He –Ne	Dye
The frequencies of --------------- laser is tunable by variation of electric energy	Free- electron	HCl	He –Ne	Dye
The self pumping laser is ---------------------	Excimer	He-Ne	Colour	Chemical
In which type of lasers, atomic transitions have been used	ruby	He-Ne	dye	CO_2
In He –Ne laser action, which atoms assists in the pumping process	Ne	He	Both a & b	none
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
The pumping power is always ------------ upon decay time	same	independence	depends	none
The cavity which does not contain any active medium is called ---------resonator	active	passive	band pass	low pass

The cavity which contain active medium is called ---------resonator	active	passive	band pass	low pass
The atoms having same central frequency and the same atomic line shape is known as	homogeneous	heterogeneous	non- homogeneous	none
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
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
What principle is responsible for light spreading as it passes through a narrow slit?	refraction	polarization	diffraction	interference
What principle is responsible for alternating light and dark bands when light passes through two or more narrow slits?	refraction	polarization	diffraction	interference
What principle is responsible for the fact that certain sunglasses can reduce glare from reflected surfaces?	refraction	polarization	diffraction	total internal reflection
The principle which allows a rainbow to form is	refraction	polarization	dispersion	total internal reflection
Light has a wavelength of 600 nm in a vacuum. It passes into glass, which has an index of refraction of 1.50. What is the wavelength of the light in the glass?	600 nm	500 nm	400 nm	300 nm
All___________ active bands are hyper Raman active.	infra red	micro wave	ultra violet	none

Unit – IV

Multi-photon processes; multi-quantum photoelectric effect, Theory of two-photon process, three-photon process, second harmonic generation, parametric generation of light, Laser spectroscopy : Rayleigh and Raman scattering, Stimulated Raman effect, Hyper-Raman effect, Coherent anti-stokes Raman Scattering, Photo-acoustic Raman spectroscopy

Multi quantum photo electric effect

The photoelectric effect is the emission of electrons or other free carriers when light is shone onto a material. Electrons emitted in this manner can be called photo electrons. The phenomenon is commonly studied in electronic physics, as well as in fields of chemistry, such as quantum chemistry or electrochemistry.

According to classical electromagnetic theory, this effect can be attributed to the transfer of energy from the light to an electron. From this perspective, an alteration in the intensity of light would induce changes in the kinetic energy of the electrons emitted from the metal. Furthermore, according to this theory, a sufficiently dim light would be expected to show a time lag between the initial shining of its light and the subsequent emission of an electron. However, the experimental results did not correlate with either of the two predictions made by classical theory.

Instead, electrons are dislodged only by the impingement of photons when those photons reach or exceed a threshold frequency(energy). Below that threshold, no electrons are emitted from the material regardless of the light intensity or the length of time of exposure to the light (rarely, an electron will escape by absorbing two or more quanta. However, this is extremely rare because by the time it absorbs enough quanta to escape, the electron will probably have emitted the rest of the quanta.). To make sense of the fact that light can eject electrons even if its intensity is low, Albert Einstein proposed that a beam of light is not a wave propagating through space, but rather a collection of discrete wave packets (photons), each with energy hν. This shed light on Max Planck's previous discovery of the Planck relation (E = hν) linking energy (E) and frequency (ν) as arising from quantization of energy. The factor h is known as the Planck constant.

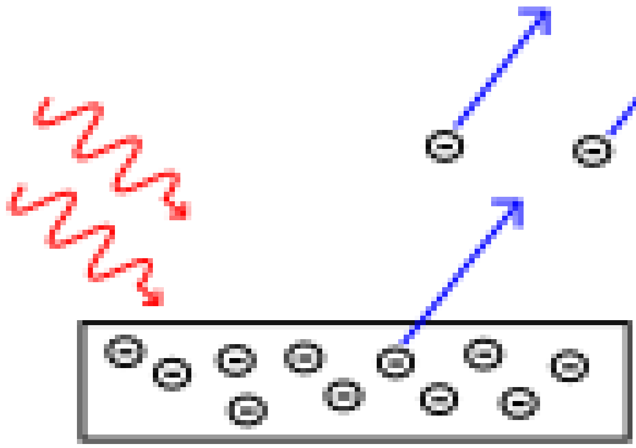
In 1887, Heinrich Hertz[2][3] discovered that electrodes illuminated with ultraviolet light create electric sparks more easily. In 1900, while studying black-body radiation, the German physicist Max Planck suggested that the energy carried by electromagnetic waves could only be released in "packets" of energy. In 1905, Albert Einstein published a paper advancing the hypothesis that light energy is carried in discrete quantized packets to explain experimental data from the photoelectric effect. This model contributed to the development of quantum mechanics.

In 1914, Robert Millikan's experiment supported Einstein's model of the photoelectric effect. Einstein was awarded the Nobel Prize in 1921 for "his discovery of the law of the photoelectric effect", and Millikan was awarded the Nobel Prize in 1923 for "his work on the elementary charge of electricity and on the photoelectric effect".

The photoelectric effect requires photons with energies approaching zero (in the case of negative electron affinity) to over 1 MeV for core electrons in elements with a high atomic number. Emission of conduction electrons from typical metals usually requires a few electron-volts, corresponding to short-wavelength visible or ultraviolet light. Study of the photoelectric effect led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave–particle duality.[1] Other phenomena where light affects the movement of electric charges include the photoconductive effect (also known as photoconductivity or photo resistivity), the photovoltaic effect, and the photo electrochemical effect.

Photoemission can occur from any material, but it is most easily observable from metals or other conductors because the process produces a charge imbalance, and if this charge imbalance is not neutralized by current flow (enabled by conductivity), the potential barrier to emission increases until the emission current ceases. It is also usual to have the emitting surface in a vacuum, since gases impede the flow of photoelectrons and make them difficult to observe. Additionally, the energy barrier to photoemission is usually increased by thin oxide layers on metal surfaces if the metal has been exposed to oxygen, so most practical experiments and devices based on the photoelectric effect use clean metal surfaces in a vacuum.

When the photoelectron is emitted into a solid rather than into a vacuum, the term internal photoemission is often used, and emission into a vacuum distinguished as external photoemission.



Theory of two-photon process

Two-photon absorption (TPA) is the simultaneous absorption of two photons of identical or different frequencies in order to excite a moleculefrom one state (usually the ground state) to a higher energy electronic state. The energy difference between the involved lower and upper states of the molecule is equal to the sum of the photon energies of the two photons. Two-photon absorption is a third-order process several orders of magnitude weaker than linear absorption at low light intensities. It differs from linear absorption in that the atomic transition rate due to TPA depends on the square of the light intensity, thus it is a nonlinear optical process, and can dominate over linear absorption at high intensities.

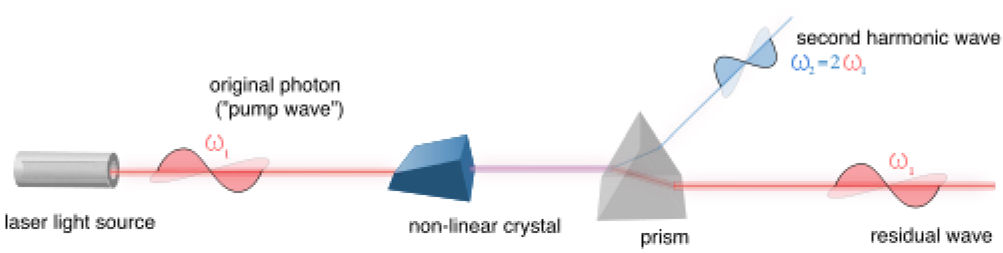
The opposite process of TPA is two-photon emission (TPE), which is a single electron transition accompanied by the emission of a photon pair. The energy of each individual photon of the pair is not determined, while the pair as a whole conserves the transition energy. The spectrum of TPE is therefore very broad and continuous.[16] TPE is important for applications in astrophysics, contributing to the continuum radiation from planetary nebulae (theoretically predicted for them in [17] and observed in [18]). TPE in condensed matter and specifically in semiconductors was only recently observed,[19] with emission rates nearly 5 orders of magnitude weaker than one-photon spontaneous emission, with potential applications in quantum information.

SECOND HARMONIC GENERATION

Second harmonic generation (also called frequency doubling or abbreviated SHG) is a nonlinear optical process, in which photons with the same frequency interacting with a nonlinear material are effectively "combined" to generate new photons with twice the energy, and therefore twice the frequency and half the wavelength of the initial photons. Second harmonic generation, as an even-order nonlinear optical effect, is only allowed in media without inversion symmetry. It is a special case of sum frequency generation and is the inverse of half-harmonic generation.

Second harmonic generation was first demonstrated by Peter Franken, A. E. Hill, C. W. Peters. The demonstration was made possible by the invention of the laser, which created the required high intensity coherent light. They focused a ruby laser with a wavelength of 694 nm into a quartz sample. They sent the output light through a spectrometer, recording the spectrum on photographic paper, which indicated the production of light at 347 nm.the dim spot (at 347 nm) on the photographic paper as a speck of dirt and removed it from the publication. The formulation of SHG was initially described by N. Bloembergen and P. S. Pershan at Harvard in 1962. In their extensive evaluation of Maxwell's equations at the planar interface between a linear and nonlinear medium, several rules for the interaction of light in non-linear mediums were elucidated.

Generating the second harmonic, often called frequency doubling, is also a process in radio communication; it was developed early in the 20th century, and has been used with frequencies in the megahertz range. It is a special case of frequency multiplication.



Parametric generation of light

A parametric process is an optical process in which light interacts with matter in such a way as to leave the quantum state of the material unchanged. As a direct consequence of this there can be no net transfer of energy, momentum, or angular momentum between the optical field and the physical system. In contrast a non-parametric process is a process in which any part of the quantum state of the system changes. Since a parametric process prohibits a net change in the energy state of the system, parametric processes are considered to be 'instantaneous' processes. This can be seen as follows: if an atom absorbs a photon with energy E, the atom's energy will increase by $\Delta E = E$. Since we are assuming this is a parametric process, the quantum state cannot change and thus this energy state must be a virtual state. By the Heisenberg Uncertainty Principle we know that $\Delta E \Delta t \sim \hbar/2$, thus the lifetime of a parametric process is roughly $\Delta t \sim \hbar/2\Delta E$, which is appreciably small for any non-zero ΔE.

In linear optics a parametric process will act as a lossless dielectric with the following effects:

- Refraction
- Diffraction
- Elastic scattering
- Rayleigh scattering
- Mie scattering
- Alternatively, non-parametric processes often involve loss (or gain) and give rise to:

➢ Absorption
➢ Inelastic scattering
➢ Raman scattering
➢ Brillouin scattering
➢ Various optical emission processes
  - Photoluminescence
  - Fluorescence
  - Luminescence
  - Phosphorescence

Laser spectroscopy:

Rayleigh and Raman scattering

Rayleigh scattering , named after the British physicist Lord Rayleigh is the (dominantly) elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the radiation. Rayleigh scattering does not change the state of material and is, hence, a parametric process. The particles may be individual atoms or molecules. It can occur when light travels through transparent solids and liquids, but is most prominently seen in gases. Rayleigh scattering results from the electric polarizability of the particles. The oscillating electric field of a light wave acts on the charges within a particle, causing them to move at the same frequency. The particle therefore becomes a small radiating dipole whose radiation we see as scattered light. Rayleigh scattering of sunlight in the atmosphere causes diffuse sky radiation, which is the reason for the blue color of the sky and the yellow tone of the sun itself.

The amount of scattering is inversely proportional to the fourth power of the wavelength. Rayleigh scattering of molecular nitrogen and oxygen in the atmosphere includes elastic scattering as well as the inelastic contribution from rotational Raman scattering in air, since the changes in wavenumber of the scattered photon are typically smaller than 50 cm^{-1}.This can lead to changes in the rotational state of the molecules. Furthermore, the inelastic contribution has the same wavelengths dependency as the elastic part.

Scattering by particles similar to, or larger than, the wavelength of light is typically treated by the Mie theory, the discrete dipole approximation and other computational techniques. Rayleigh scattering applies to particles that are small with respect to wavelengths of light, and that are optically "soft". On the other hand, anomalous diffraction theory applies to optically soft but larger particles.

Raman scattering or the Raman effect is the inelastic scattering of a photon by molecules which are excited to higher vibrational or rotational energy levels.

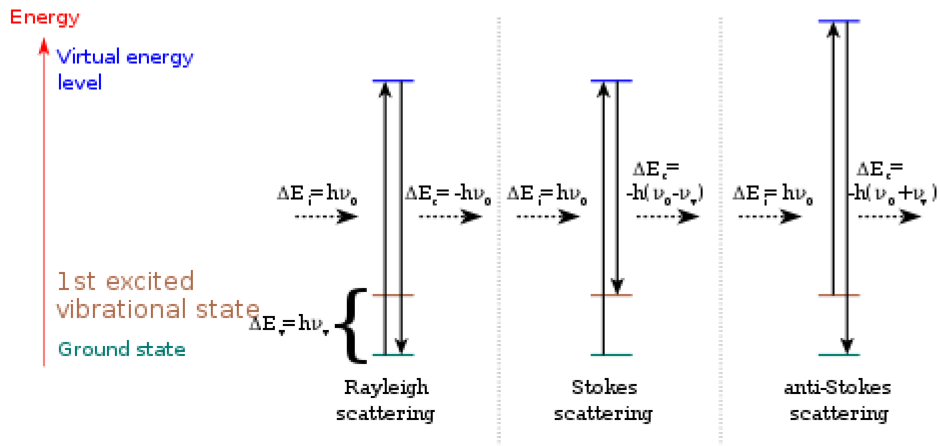
It was discovered C. V. Raman and K. S. Krishnan (who was a student of C.V. Raman) in liquids. When photons are scattered from an atom or molecule, most photons are elastically scattered (Rayleigh scattering), such that the scattered photons have the same energy (frequency and wavelength) as the incident photons. A small fraction of the scattered photons (approximately 1 in 10 million) are scattered inelastically by an excitation, with the scattered photons having a frequency and energy different from, and usually lower than, those of the incident photons. In a gas, Raman scattering can occur with a change in energy of a molecule due to a transition to another (usually higher) energy level. Chemists are primarily concerned with this "transitional" Raman Effect.

It is also possible to observe molecular vibrations by an inelastic scattering process. In inelastic (Raman) scattering, an absorbed photon is re-emitted with lower energy; the difference in energy between the incident photons and scattered photons corresponds to the energy required to excite a molecule to a higher vibrational mode.

Typically, in Raman spectroscopy high intensity laser radiation with wavelengths in either the visible or near-infrared regions of the spectrum is passed through a sample. Photons from the laser beam produce an oscillating polarization in the molecules, exciting them to a virtual energy state. The oscillating polarization of the molecule can couple with other possible polarizations of the molecule, including vibrational and electronic excitations. If the polarization in the molecule does not couple to these other possible polarizations, then it will not change the vibrational state that the molecule started in and the scattered photon will have the same energy as the original photon. This type of scattering is known as Rayleigh scattering.
When the polarization in the molecules couples to a vibrational state that is higher in energy than the state they started in, then the original photon and the scattered photon differ in energy by the amount required to vibrationally excite the molecule. In perturbation theory, the Raman effect

corresponds to the absorption and subsequent emission of a photon via an intermediate quantum state of a material. The intermediate state can be either a "real", i.e., stationary state or a virtual state.

Stokes and anti-Stokes scattering[**edit**]



The different possibilities of light scattering: Rayleigh scattering (no exchange of energy: incident and scattered photons have the same energy), Stokes Raman scattering (atom or molecule absorbs energy: scattered photon has less energy than the incident photon) and anti-Stokes Raman scattering (atom or molecule loses energy: scattered photon has more energy than the incident photon)

The Raman interaction leads to two possible outcomes:

The material absorbs energy and the emitted photon has a lower energy than the absorbed photon. This outcome is labeled Stokes Raman scattering in honor of George Stokes who showed in 1852 that fluorescence is due to light emission at longer wavelength (now known to correspond to lower energy) than the absorbed incident light.

The material loses energy and the emitted photon has a higher energy than the absorbed photon. This outcome is labeled anti-Stokes Raman scattering.

The energy difference between the absorbed and emitted photon corresponds to the energy difference between two resonant states of the material and is independent of the absolute energy of the photon.

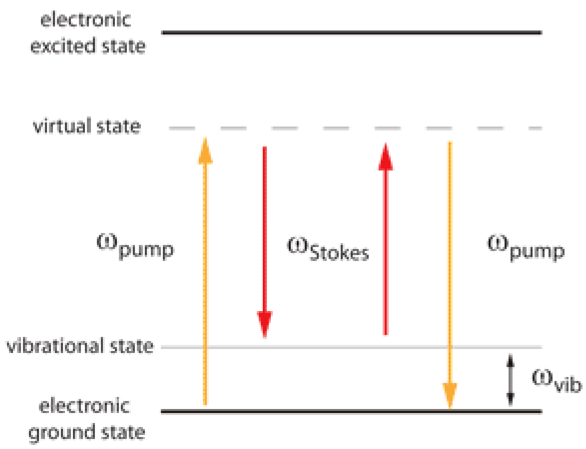
The spectrum of the scattered photons is termed the Raman spectrum. It shows the intensity of the scattered light as a function of its frequency difference $\Delta\nu$ to the incident photons. The locations of corresponding Stokes and anti-Stokes peaks form a symmetric pattern around $\Delta\nu=0$. The frequency shifts are symmetric because they correspond to the energy difference between the same upper and lower resonant states. The intensities of the pairs of features will typically differ, though. They depend on the populations of the initial states of the material, which in turn depend on the temperature. In thermodynamic equilibrium, the lower state will be more populated than the upper state. Therefore, the rate of transitions from the more populated lower state to the upper state (Stokes transitions) will be higher than in the opposite direction (anti-Stokes transitions). Correspondingly, Stokes scattering peaks are stronger than anti-Stokes scattering peaks. Their ratio depends on the temperature, and can therefore be exploited to measure it.

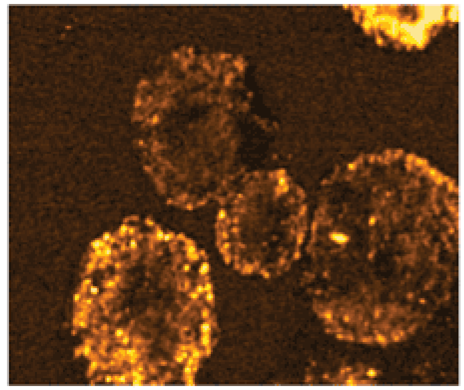
Stimulated Raman Effect

In SRS microscopy, like CARS microscopy, both the pump and Stokes photons are incident on the sample. If the frequency difference

$$\omega_{SRS} = \omega_{pump} - \omega_{Stokes}$$

matches a molecular vibration (ω_{vib}) stimulated excitation of the vibrational transition occurs. Unlike CARS, in SRS there is no signal at a wavelength that is different from the laser excitation wavelengths. Instead, the intensity of the scattered light at the pump wavelength experiences a stimulated Raman loss (SRL), with the intensity of the scattered light at the Stokes wavelength experiencing a stimulated Raman gain (SRG). The key advantage of SRS microscopy over CARS microscopy is that it provides background-free chemical imaging with improved image contrast, both of which are important for biomedical imaging applications where water represents the predominant source of nonresonant background signal in the sample.





Hyper-Raman effect

Hyper Raman scattering is a modified version of Raman scattering, where the scattered light occurs at frequencies somewhat lower than **twice** the frequency of the pump light. This means that two pump photons are converted into one photon of Raman scattered light and one phonon. This effect is usually fairly weak, but it has aspects which make it interesting for Raman spectroscopy. In particular, hyper-Raman spectra can provide vibrational information on molecules where ordinary Raman scattering is suppressed due to symmetry issues (**silent modes**). The scattering rate can be substantially enhanced near optical surfaces.

Coherent anti-stokes Raman Scattering(CARS)

Coherent anti-Stokes Raman spectroscopy, also called Coherent anti-Stokes Raman scattering spectroscopy (CARS), is a form of spectroscopy used primarily in chemistry, physics and related fields. It is sensitive to the same vibrational signatures of molecules as seen in Raman spectroscopy, typically the nuclear vibrations of chemical bonds. Unlike Raman spectroscopy, CARS employs multiple photons to address the molecular vibrations, and produces a coherent signal. As a result, CARS is orders of magnitude stronger than spontaneous Raman emission. CARS is a third-order nonlinear optical process involving three laser beams: a pump beam of frequency ω_p, a Stokes beam of frequency ω_S and a probe beam at frequency ω_{pr}. These beams interact with the sample and generate a coherent optical signal at the anti-Stokes frequency ($\omega_{pr}+\omega_p-\omega_S$). The latter is resonantly enhanced when the frequency difference between the pump and the Stokes beams ($\omega_p-\omega_S$) coincides with the frequency of a Raman resonance, which is the basis of the technique's intrinsic vibrational contrast mechanism.

Coherent Stokes Raman spectroscopy (CSRS pronounced as "scissors") is closely related to Raman spectroscopy and lasing processes. It is very similar to CARS except it uses an anti-Stokes frequency stimulation beam and a Stokes frequency beam is observed (the opposite of CARS).

PRINCIPLE

The CARS process can be physically explained by using either a classical oscillator model or by using a quantum mechanical model that incorporates the energy levels of the molecule. Classically, the Raman active vibrator is modeled as a (damped) harmonic oscillatorwith a characteristic frequency of ω_v. In CARS, this oscillator is not driven by a single optical wave, but by the difference frequency ($\omega_p-\omega_S$) between the pump and the Stokes beams instead. This driving mechanism is similar to hearing the low combination tone when striking two different high tone piano keys: your ear is sensitive to the difference frequency of the high tones. Similarly, the Raman oscillator is susceptible to the difference frequency of two optical waves. When the difference frequency $\omega_p-\omega_S$ approaches ω_v, the oscillator is driven very efficiently. On a molecular level, this implies that the electron cloud surrounding the chemical bond is vigorously oscillating with the frequency $\omega_p-\omega_S$. These electron motions alter the optical properties of the sample, i.e. there is a periodic modulation of the refractive index of the material. This periodic modulation can be probed by a third laser beam, the probe beam. When the probe beam is propagating through the periodically altered medium, it acquires the same modulation. Part of the probe, originally at ω_{pr} will now get modified to $\omega_{pr}+\omega_p-\omega_S$, which is the observed anti-Stokes emission. Under certain beam geometries, the anti-Stokes emission may diffract away from the probe beam, and can be detected in a separate direction.

While intuitive, this classical picture does not take into account the quantum mechanical energy levels of the molecule. Quantum mechanically, the CARS process can be understood as

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follows. Our molecule is initially in the ground state, the lowest energy state of the molecule. The pump beam excites the molecule to a virtual state. A virtual state is not an eigen state of the molecule and it can not be occupied but it does allow for transitions between otherwise unoccupied real states. If a Stokes beam is simultaneously present along with the pump, the virtual state can be used as an instantaneous gateway to address a vibrational eigen state of the molecule. The joint action of the pump and the Stokes has effectively established a coupling between the ground state and the vibrationally excited state of the molecule. The molecule is now in two states at the same time: it resides in a coherent superposition of states. This coherence between the states can be probed by the probe beam, which promotes the system to a virtual state. Again, the molecule cannot stay in the virtual state and will fall back instantaneously to the ground state under the emission of a photon at the anti-Stokes frequency. The molecule is no longer in a superposition, as it resides again in one state, the ground state. In the quantum mechanical model, no energy is deposited in the molecule during the CARS process. Instead, the molecule acts like a medium for converting the frequencies of the three incoming waves into a CARS signal (a parametric process). There are, however, related coherent Raman processes that occur simultaneously which do deposit energy into the molecule.

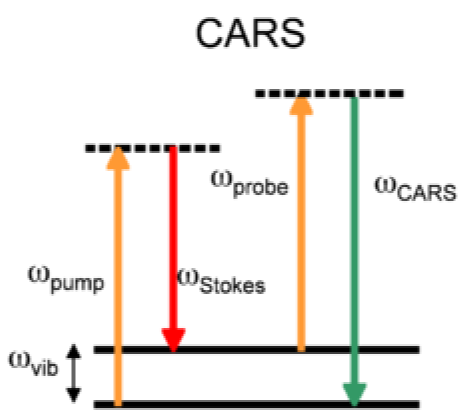

Photo-acoustic Raman spectroscopy

Photo acoustic spectroscopy is the measurement of the effect of absorbed electromagnetic energy (particularly of light) on matter by means of acoustic detection.

The discovery of the photoacoustic effect dates to 1880 when Alexander Graham Bell showed that thin discs emitted sound when exposed to a beam of sunlight that was rapidly interrupted with a rotating slotted disk. The absorbed energy from the light causes local heating and through thermal expansion a pressure wave or sound. Later Bell showed that materials exposed to the non-visible portions of the solar spectrum (i.e., the infrared and the ultraviolet) can also produce sounds.

A photo acoustic spectrum of a sample can be recorded by measuring the sound at different wavelengths of the light. This spectrum can be used to identify the absorbing components of the sample. The photo acoustic effect can be used to study solids, liquids and gases.

Photo acoustic spectroscopy has become a powerful technique to study concentrations of gases at the part per billion or even part per trillion levels.[2] Modern photoacoustic detectors still rely on the same principles as Bell's apparatus; however, to increase the sensitivity, several modifications have been made.

USES AND TECHNIQUES

The use of intense lasers instead of the sun to illuminate the sample since the intensity of the generated sound is proportional to the light intensity; this technique is referred to as laser photo acoustic spectroscopy (LPAS). The ear has been replaced by sensitive microphones. The microphone signals are further amplified and detected using lock-in amplifiers by enclosing the gaseous sample in a cylindrical chamber, the sound signal is amplified by tuning the modulation frequency to an acoustic resonance of the sample cell.

EXAMPLE

The following example illustrates the potential of the photo acoustic technique: In the early 1970s, Patel and co-workers measured the temporal variation of the concentration of nitric oxide in the stratosphere at an altitude of 28 km with a balloon-borne photo acoustic detector. These measurements provided crucial data bearing on the problem of ozone depletion by man-made nitric oxide emission.

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DEPARTMENT OF PHYSICS

II M.SC PHYSICS

LASER AND ITS APPLICATIONS (16PHP302)

MULTIPLE CHOICE QUESTIONS

Questions

UNIT-IV

The photoelectric effect depends upon both frequency and intesity is known as ------------	multiquantum effect	raman effect	rayleigh scattering	none
Photoacoustic spectroscopy is the measurement of the effect of absorbed ------------- on matter by means of acoustic detection.	electrical energy	magnetic energy	electromagnetic energy	none
A photoacoustic spectrum of a sample can be recorded by measuring the sound at different ---------- of the light.	frequency	amplitude	intensity	wavelength
The Photoelectric effect depends upon the ------------------- of the incident radiation.	Frequency	Wavelength	Intensity	Velocity
The time delay between incident radiation and emission of electrons in Photoelectric effect is	$3x10^{-8}$Sec	$3x10^{-9}$Sec	$3x10^{-7}$Sec	$3x10^{-5}$Sec
Maximum kinetic energy of photoelectron is ------------- intensity of incident radiation	Directly proportional to	Inversely proportional to	Independent of	None of the above
If the frequency of incident radiation is more than threshold frequency, the process of photoelectric effect takes place ----------	Slowly	Rapidly	Instantaneously	Gradually
The absorbed energy of incident photon is used in two ways. One part is used as a work function and the remaining part is converted to --------------	Kinetic energy	Potential energy	Binding energy	Electrical energy
The mass of a photon is	0	Depends on its frequency	Depends on its wavelength	Depends on its energy
In vacuum, all photons have the same -----------------	Frequency	Speed	Energy	Velocity
When ultraviolet light was incident on a neutral zinc plate, the plate became --------------- charged.	Positive	Negative	Neutral	none of these
Which type of scattering results in a longer wavelength than the incident light?	Rayleigh	Stoke’s	Anti stoke’s	none
Raman effect is due to the collision between	Photons with electrons	Photons with molecules	Electrons with photons	Electrons with molecules
In Rayleigh scattering, there is no change in ----------------	energy	wavelength	intensity	Velocity
Raman effect supports	corpuscular theory	wave theory	quantum theory	electromagnetic theory
In Raman spectrum, if λ is the wavelength of incident radiation, then the Anti-Stoke’s lines will have wavelength equal to	λ	$\lambda + \Delta\lambda$	$\lambda - \Delta\lambda$	λ2
Sun appears red at sun rise and sunset. This is due to scattering of	longer wavelengths	shorter wavelengths	lower frequencies	all frequencies
In Raman spectrum, if λ is the wavelength of incident radiation, then the Stoke’s lines will have wavelength equal to	λ	$\lambda + \Delta\lambda$	$\lambda - \Delta\lambda$	λ2
Tyndall effect is the scattering of the light by	air particles	solid particles	liquid particles	colloidal particles
In 1928,Sir C.V.Raman was studying the	diffraction of light	interference	scattering of light	reflection of light
Coefficient of scattering of light in any medium is inversely proportional to the fourth power of the	wavelength of light	frequency of light	velocity of light	none of these
Raman lines had frequencies lower than that of the incident line are called	stokes lines	antistokes lines	both a and b	excitation line

Raman lines had frequencies higher than that of the incident line are called	stokes lines	antistokes lines	both a and b	excitation line
Low frequency side and high frequency side Raman lines are referred to as	stokes lines	antistokes lines	stokes and antistokes lines respectively	unmodified line
In Rayleigh scattering, there is a change in the intensity of the scattered light, there is no change in the	spectral character	wavelength	frequency	all the above
Rayleigh scattering is also called	incoherent scattering	coherent scattering	diffraction	compton scattering
Light from a helium discharge tube filtered by nickel oxide glass gives a light of wavelength	3880Å	3888Å	3800Å	4888Å
The apparatus used in the study of Raman effect in liquids was first designed by	Wood	Rayleigh	Raman	Newton
Raman got nobel prize in	1939	1932	1931	1930
The modified frequencies observed in the scattering process was given the name	Compton effect	Raman effect	Scattering effect	Rayleigh scattering
Quinine sulphate solution contained in a novial glass vessel is used as a filter to obtain the line of	4350Å	4340Å	4300Å	4358Å
Which filter is found to be a very satisfactory to get 4046Å	a solution of iodine in carbon tetrachloride	quinine sulphate solution	nickel oxide glass	Copper oxide
The mercury arc is placed as close to the Raman tube as possible, which results in a large	intensity of the incident light	frequency of incident light	wavelength of the incident light	velocity of the incident light
Which reflector is used to enhance the intensity of illumination still further	semi-cylindrical aluminium	quartz	glass	none of these
Diamond exhibits a	broad line	very strong line	very sharp line	strong and sharp line
All the Raman lines move inward towards the parent line with	decrease of temperature	increase of temperature	increase of intensity	decrease of intensity
The variations in intensity are of great significance in the study of	molecular structure	chemical constitution	shape and size	both a and b
Which is used to separate the vertical and horizontal components in the scattered light	quartz crystal	calcite	double image prism	suitably oriented double image prism
Crystalline quartz should not be used for	condenser	spectrographs	windows	all the above
Menzies has investigated the polarisation of the Raman lines in	solids	liquids	gases	all the above
For the vibrational Raman lines, the depolarisation factor varies from	0 to 0.86	0 to 0.70	0 to 0.80	0 to 0.60
A simple and satisfactory explanation on the quantum theory was put forwar by	Sir C.V.Raman	Prof.Smekal	Rayleigh	Bhagavantam
Which would result in the appearance of the unmodified line in the scattered beam	The photon without absorbing energy	absorb part of the energy of the incident photon	molecule imparts some of its intrinsic energy to the incident photon	all the above
The frequency shift is the	difference between stokes and antistokes lines	difference between the incident and scattered lines	addition between the incident and scattered lines	any of the above
Raman spectra are determined by	the number of atoms in the molecule	the masses of the atoms	the strength of the chemical bonds between the atoms	all the above
Carbon dioxide has two very strong bands in the infra-red absorption spectrum at	668 and 2349 cm-1	600 and 3349 cm-1	700 and 2349 cm-1	668 and 2900 cm-1
Nitrous oxide molecule has the same number of electrons as	CO2	CO	water	carbon disulphide
The band at 589cm-1 has not been recorded in the Raman spectrum of nitrous oxide due to	weak frequency	weak intensity	strong intensity	strong frequency
nitrous oxide has a	unsymmetrical structure	symmetrical structure	center of symmetry	either a or b

According to theory, all triatomic molecules of bent symmetrical structure should give rise to	two Raman lines	one Raman lines	no Raman lines	three Raman lines
Depolarization factor is the ratio of the	Frequencies of the vertical and horizontal components	Frequencies of the horizontal and vertical components	Intensities of the horizontal and vertical components	Intensities of the vertical and horizontal components
The natural frequency of vibration is given by	ν=1/2π(F)^1/2	ν=1/2π(F/μ)^1/2	ν=(F/μ)^1/2	ν=1/2π(μ/F)^1/2
The polarisation of Raman line is decided by the	Symmetry of the oscillation	Crystal oscillation	Dipole moment	All the above
The intensity of the scattered light must increase rapidly as the wavelength	increases	remains constant	decreases+G56	increases and then decreases
The triad of stokes and antistokes lines equally spaced on either side of the exciting 4358Å line was observed in	Calcite	Benzene	carbon tetrachloride	HCL gas
What bands are found in well purified water	two broad bands	one broad band	sharp band	weak band
Solutions of salts in water give Raman spectra characteristic of the	only salts	only water	both salts and water	either salts or water

LASER APPLICATIONS

Isotope separation

This is the process of concentrating specific isotopes of a chemical element by removing other isotopes. The use of the nuclides produced is various. The largest variety is used in research (e.g. in chemistry where atoms of "marker" nuclide are used to figure out reaction mechanisms). By tonnage, separating natural uranium into enriched uranium and depleted uranium is the largest application. In the following text, mainly the uranium enrichment is considered. This process is a crucial one in the manufacture of uranium fuel for nuclear power stations, and is also required for the creation of uranium based nuclear weapons. Plutonium-based weapons use plutonium produced in a nuclear reactor, which must be operated in such a way as to produce plutonium already of suitable isotopic mix or grade. While different chemical elements can be purified through chemical processes, isotopes of the same element have nearly identical chemical properties, which make this type of separation impractical, except for separation of deuterium.

There are three types of isotope separation techniques:

1. Those based directly on the atomic weight of the isotope.
2. Those based on the small differences in chemical reaction rates produced by different atomic weights.
3. Those based on properties not directly connected to atomic weight, such as nuclear resonances.

The third type of separation is still experimental; practical separation techniques all depend in some way on the atomic mass. It is therefore generally easier to separate isotopes with a larger relative mass difference. For example, deuterium has twice the mass of ordinary (light) hydrogen and it is generally easier to purify it than to separate uranium-235 from the more common uranium-238. On the other extreme, separation of fissile plutonium-239 from the common impurity plutonium-240, while desirable in that it would allow the creation of gun-type nuclear weapons from plutonium, is generally agreed to be impractical

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In this method a laser is tuned to a wavelength which excites only one isotope of the material and ionizes those atoms preferentially. The resonant absorption of light for an isotope is dependent upon its mass and certain hyperfine interactions between electrons and the nucleus, allowing finely tuned lasers to interact with only one isotope. After the atom is ionized it can be removed from the sample by applying an electric field. This method is often abbreviated as AVLIS (atomic vapor laser isotope separation). This method has only recently been developed as laser technology has improved, and is currently not used extensively. However, it is a major concern to those in the field of nuclear proliferation because it may be cheaper and more easily hidden than other methods of isotope separation. Tunable lasers used in AVLIS include the dye laser and more recently diode lasers.

A second method of laser separation is known as molecular laser isotope separation (MLIS). In this method, an infrared laser is directed at uranium hexafluoride gas, exciting molecules that contain a U-235 atom. A second laser frees a fluorine atom, leaving uranium pentafluoride which then precipitates out of the gas. Cascading the MLIS stages is more difficult than with other methods because the UF_5 must be refluorinated (back to UF_6) before being introduced into the next MLIS stage. Alternative MLIS schemes are currently being developed (using a first laser in the near-infrared or visible region) where an enrichment of over 95% can be obtained in a single stage, but the methods have not (yet) reached industrial feasibility. This method is called OP-IRMPD (Overtone Pre-excitation—IR Multiple Photon Dissociation).

The SILEX process, developed by Silex Systems in Australia, has recently been licensed to General Electric for the development of a pilot enrichment plant. The method uses uranium hexafluoride as a feedstock, and uses magnets to separate the isotopes after one isotope is preferentially ionized. Further details of the process are not disclosed. Quite recently yet another scheme has been proposed for the deuterium separation using Trojan wave packets in circularly polarized electromagnetic field. The process of Trojan wave packet formation by the adiabatic-rapid passage depends in ultra-sensitive way on the reduced electron and nucleus mass which with the same field frequency further leads to excitation of Trojan or anti-Trojan wavepacket depending on the kind of the isotope. Those and their giant, rotating electric dipole moments are then shifted in phase and the beam of such atoms splits in the gradient of the electric field in the analogy to Stern–Gerlach experiment.

Thermonuclear fusion

This is a way to achieve nuclear fusion by using extremely high temperatures. There are two forms of thermonuclear fusion: uncontrolled, in which the resulting energy is released in an uncontrolled manner, as it is in thermonuclear weapons ("hydrogen bombs") and in most stars; and controlled, where the fusion reactions take place in an environment allowing some or all of the energy released to be harnessed for constructive purposes.

Temperature is a measure of the average kinetic energy of particles, so by heating the material it will gain energy. After reaching sufficient temperature, given by the Lawson criterion, the energy of accidental collisions within the plasma is high enough to overcome the Coulomb barrier and the particles may fuse together. In a deuterium–tritium fusion reaction, for example, the energy necessary to overcome the Coulomb barrier is 0.1 MeV. Converting between energy and temperature shows that the 0.1 MeV barrier would be overcome at a temperature in excess of 1.2 billion kelvins.

There are two effects that lower the actual temperature needed. One is the fact that temperature is the average kinetic energy, implying that some nuclei at this temperature would actually have much higher energy than 0.1 MeV, while others would be much lower. It is the nuclei in the high-energy tail of the velocity distribution that account for most of the fusion reactions. The other effect is quantum tunneling. The nuclei do not actually have to have enough energy to overcome the Coulomb barrier completely. If they have nearly enough energy, they can tunnel through the remaining barrier. For these reasons fuel at lower temperatures will still undergo fusion events, at a lower rate.

Thermonuclear fusion is one of the methods being researched in the attempts to produce fusion power. If thermonuclear fusion becomes favorable to use, it would reduce the world's carbon footprint significantly.

Laser applications

Many scientific, military, medical and commercial laser applications have been developed since the invention of the laser in 1958. The coherency, high monochromaticity, and ability to reach extremely high powers are all properties which allow for these specialized applications.

In science, lasers are used in many ways, including: A wide variety of inter ferometric techniques, Raman spectroscopy, Laser induced breakdown spectroscopy, Atmospheric remote sensing, Investigating nonlinear optics phenomena and holographic techniques employing lasers also contribute to a number of measurement techniques.

Laser based lidar (light radar) technology has application in geology, seismology, remote sensing and atmospheric physics. Lasers have been used aboard spacecraft such as in the Cassini-Huygens mission. In astronomy, lasers have been used to create artificial laser guide stars, used as reference objects for adaptive optics telescopes.

Lasers may also be indirectly used in spectroscopy as a micro-sampling system, a technique termed Laser ablation (LA), which is typically applied to ICP-MS apparatus resulting in the powerful LA-ICP-MS.

Spectroscopy

Most types of laser are an inherently pure source of light; they emit near-monochromatic light with a very well defined range of wavelengths. By careful design of the laser components, the purity of the laser light (measured as the "linewidth") 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. Other spectroscopic techniques based on lasers can be used to make extremely sensitive detectors of various molecules, able to measure molecular concentrations in the parts-per-10^{12} (ppt) level. Due to the high power densities achievable by lasers, beam-induced atomic emission is possible: this technique is termed Laser induced breakdown spectroscopy (LIBS).

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. An inert, absorbent coating for laser heat treatment has also been developed that eliminates the fumes generated by conventional paint coatings during the heat-treating process with CO_2 laser beams.

One consideration crucial to the success of a heat treatment operation is control of the laser beam irradiance on the part surface. The optimal irradiance distribution is driven by the thermodynamics of the laser-material interaction and by the part geometry.

Typically, irradiances between 500-5000 W/cm^2 satisfy the thermodynamic constraints and allow the rapid surface heating and minimal total heat input required. For general heat treatment, a uniform square or rectangular beam is one of the best options. For some special applications or applications where the heat treatment is done on an edge or corner of the part, it may be better to have the irradiance decrease near the edge to prevent melting.

Lunar laser ranging

When the Apollo astronauts visited the moon, they planted retro reflector arrays to make possible the Lunar Laser Ranging Experiment. Laser beams are focused through large telescopes on Earth aimed toward the arrays, and 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

Some laser systems, through the process of mode locking, can produce extremely brief pulses of light - as short as picoseconds or femtoseconds (10^{-12} - 10^{-15} seconds). Such 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, allowing the detection of short-lived intermediate molecules. 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*. This involves atom trapping, a method where a number of atoms are confined in a specially shaped arrangement of electric and magnetic fields. Shining particular wavelengths of light at the ions or atoms slows them down, thus *cooling* them. As this process is continued, they all are slowed and have the same energy level, forming an unusual arrangement of matter known as a Bose–Einstein condensate.

Nuclear fusion

Some of the world's 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, e.g. laboratory for laser energetics, National Ignition Facility, GEKKO XII, Nike laser, Laser Mégajoule, HiPER. These pulses are arranged such that they impact pellets of tritium–deuterium simultaneously from all directions, hoping that the squeezing effect of the impacts will induce atomic fusion in the pellets. This technique, known as "inertial confinement fusion", so far has not been able to achieve "breakeven", that is, so far the fusion reaction generates less power than is used to power the lasers, but research continues.

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 microdissection use lasers to procure specific cell populations from a tissue section under microscopic visualization.

Additional laser microscopy techniques include harmonic microscopy, four-wave mixing microscopy and interferometric microscopy.

Military

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

Directly as an energy weapon

Directed energy weapons are being developed, such as Boeing's Airborne Laser which was constructed inside a Boeing 747. Designated the YAL-1, it was intended to kill short- and intermediate-range ballistic missiles in their boost phase.

Another example of direct use of a laser as a defensive weapon was researched for the Strategic Defense Initiative (SDI, nicknamed "Star Wars"), and its successor programs. This project would use ground-based or space-based laser systems to destroy incoming intercontinental ballistic missiles (ICBMs). The practical problems of using and aiming these systems were many; particularly the problem of destroying ICBMs at the most opportune moment, the *boost phase* just after launch. This would involve directing a laser through a large distance in the atmosphere, which, due to optical scattering and refraction, would bend and distort the laser beam, complicating the aiming of the laser and reducing its efficiency.

Nuclear (nuclear weapon) project was mostly they used to produce x-ray in field of the nuclear-pumped X-*ray laser*. This was essentially an orbiting atomic bomb, surrounded by laser media in the form of glass rods; when the bomb exploded, the rods would be bombarded with highly-energetic gamma-ray photons, causing spontaneous and stimulated emission of X-ray photons in the atoms making up the rods. This would lead to optical amplification of the X-ray photons, producing an X-ray laser beam that would be minimally affected by atmospheric distortion and capable of destroying ICBMs in flight. The X-ray laser would be a strictly one-shot device, destroying itself on activation. Some initial tests of this concept were performed with underground nuclear testing; however, the results were not encouraging. Research into this approach to missile defense was discontinued after the SDI program was cancelled.

Made by Northrop Grumman:

On March 18, 2009 Northrop Grumman announced that its engineers in Redondo Beach had successfully built and tested an electric laser capable of producing a 100-kilowatt ray of light, powerful enough to destroy cruise missiles, artillery, rockets and mortar rounds. An electric laser is theoretically capable, according to Brian Strickland, manager for the United States Army's Joint High Power Solid State Laser program, of being mounted in an aircraft, ship, or vehicle because it requires much less space for its supporting equipment than a chemical laser.

When engaged during the test that occurred off the coast of Central California in the Pacific Ocean test range, the laser gun was documented as having "a destructive effect on a high-speed cruising target", said Chief of Naval Research Admiral Nevin Carr. Northrop Grumman has announced the availability of a high-energy solid-state laser weapon system that they call FIRESTRIKE, introduced on 13 November 2008. The system is modular, using 15 kW modules that can be combined to provide various levels of power.

On 19 July 2010 an anti-aircraft laser described as the Laser Close-In Weapon System was unveiled at the Farnborough Airshow.

Zeus laser weapon Is the first laser and the first energy weapon of any type to be used on a battlefield. It is used for neutralizing mines and unexploded ordnance.

Area Defense Anti-Munitions (ADAM) Lockheed Martin experimental fiber laser. 10 kilowatt tested against rockets.[9][10]

Mid-Infrared Advanced Chemical Laser (MIRACL) A U.S. Navy experimental deuterium fluoride laser. Was tested against an Air Force satellite in 1997.

In 2011, the U.S. Navy began to test the Maritime Laser Demonstrator (MLD), a laser for use aboard its warships. By 2013, the Navy was announcing active deployment in 2014.

Personnel halting and stimulation response rifle (PHaSR) A non-lethal hand-held weapon developed by the United States Air Force Its purpose is to "dazzle" or stun a target. It was developed by U.S. Air Force's Directed Energy Directorate.

Pulsed Energy Projectile A laser designed for riot control. A laser pulse ablates material causing a shockwave which stuns the targeted individual. Likely truck-mounted.

Tactical High Energy Laser (THEL) is a weaponized deuterium fluoride laser developed in a joint research project by Israel and the USA. It is designed to shoot down aircraft and missiles. See also National missile defense.

Beriev A-60 A Soviet/Russian CO_2 gas laser mounted on an Ilyushin Il-76MD transport.

The Russian truck mounted Almaz HEL.Boeing Laser Avenger Mounted on an AN/TWQ-1 Avenger combat vehicle.

Airborne Laser, or Advanced Tactical Laser The U.S. Air Force's plan to mount a CO_2 gas laser or COIL chemical laser on a modified Boeing 747 to shoot down missiles. Portable Efficient Laser Testbed (PELT).

Laser AirCraft CounterMeasures (ACCM)

Laser Weapon System (LAWS), which is intended to hold off approaching unmanned aerial vehicles and speedboats. Under development by the U.S. Navy. The system, which can burn through steel, reportedly costed $40 million and took six years to develop. High Energy Liquid Laser Area Defense System (HELLADS) A counter-RAM aircraft or truck mounted laser under development by General Atomics under a DARPA contract.

Defensive countermeasures

Defensive countermeasure applications can range from compact, low power infrared countermeasures to high power, airborne laser systems. IR countermeasure systems use lasers to confuse the seeker heads on infrared homing missiles.

Disorientation

Some weapons simply use a laser to disorient a person. One such weapon is the Thales Green Laser Optical Warner.

Guidance

Laser guidance is a technique of guiding a missile or other projectile or vehicle to a target by means of a laser beam.

Target designator

A target designator

Another military use of lasers is as a *laser target designator*. This is a low-power laser pointer used to indicate a target for a precision-guided munition, typically launched from an aircraft. The guided munition adjusts its flight-path to home in to the laser light reflected by the target, enabling a great precision in aiming. The beam of the laser target designator is set to a pulse rate that matches that set on the guided munition to ensure munitions strike their designated targets and do not follow other laser beams which may be in use in the area. The laser designator can be shone onto the target by an aircraft or nearby infantry. Lasers used for this purpose are usually infrared lasers, so the enemy cannot easily detect the guiding laser light.

Firearms

Laser sight used by the Defense Forces during commando training

Wesson revolver equipped with a laser sight mounted on the trigger guard.

The laser has in most firearms applications been used as a tool to enhance the targeting of other weapon systems. For example, a *laser sight* is a small, usually visible-light laser placed on a handgun or a rifle and aligned to emit a beam parallel to the barrel. Since a laser beam has low divergence, the laser light appears as a small spot even at long distances; the user places the spot on the desired target and the barrel of the gun is aligned (but not necessarily allowing for bullet drop, windage, distance between the direction of the beam and the axis of the barrel, and the target mobility while the bullet travels).

Most laser sights use a red laser diode. Others use an infrared diode to produce a dot invisible to the naked human eye but detectable with night vision devices. The firearms adaptive target acquisition module LLM01 laser light module combines visible and infrared laser diodes. In the late 1990s, green diode pumped solid state laser (DPSS) laser sights (532 nm) became available. Modern laser sights are small and light enough for attachment to the firearms.

Laser Max, a company specializing in manufacturing lasers for military and police firearms, introduced the first mass-production green laser available for small arms. This laser mounts to the underside of a handgun or long arm on the accessory rail. The green laser is supposed to be more visible than the red laser in bright lighting conditions because, for the same wattage, green light appears brighter than red light.

Eye-targeted lasers

A non-lethal laser weapon was developed a fire weapon or to otherwise threaten enemy forces. This unit illuminates an opponent with harmless low-power laser light and can have the effect of dazzling or disorienting the subject or causing them to flee. Several types of dazzlers are now available, and some have been used in combat.

There remains the possibility of using lasers to blind, since this requires such lower power levels, and is easily achievable in a man-portable unit to see Protocol on Blinding Laser Weapons .

In addition to the applications that crossover with military applications, a widely known law enforcement use of lasers is for glidar to measure the speed of vehicles.

Holographic weapon sight

A holographic weapon sight uses a laser diode to illuminate a hologram of a reticle built into a flat glass optical window of the sight. The user looks through the optical window and sees a cross hair reticle image superimposed at a distance on the field of view.

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_2, Er:YAG laser

Laser scalpel (General surgery, gynecological, urology, laparoscopic)

Photobiomodulation (i.e. laser therapy)

"No-Touch" removal of tumors, especially of the brain and spinal cord.

Intelligent laser speckle classification for skin health assessments (especially regarding damage caused through ageing)

In dentistry for caries removal, endodontic/periodontic procedures, tooth whitening, and oral surgery

Industrial and commercial

Lasers used for visual effects during a musical performance. (A laser light show.)

Levelling of ceramic tiles floor with a laser device

Industrial laser applications can be divided into two categories depending on the power of the laser: material processing and micro-material processing.

In material processing, lasers with average optical power above 1 kilowatt are used mainly for industrial materials processing applications. Beyond this power threshold there are thermal issues related to the optics that separate these lasers from their lower-power counterparts.[22]Laser systems in the 50-300W range are used primarily for pumping, plastic welding and soldering applications. Lasers above 300W are used in brazing, thin metal welding, and sheet metal cutting applications. The required brightness (as measured in by the beam parameter product) is higher for cutting applications than for brazing and thin metal welding.[23] High power applications, such as hardening, cladding, and deep penetrating welding, require multiple kW of optical power, and are used in a broad range of industrial processes.

Micro material processing is a category that includes all laser material processing applications under 1 kilowatt.[24] The use of lasers in Micro Materials Processing has found broad application in the development and manufacturing of screens for smartphones, tablet computers, and LED TVs.[25]

A detailed list of industrial and commercial laser applications includes:

Laser cutting

Laser welding

Laser drilling

Laser marking

Laser cladding, a surface engineering process applied to mechanical components for reconditioning, repair work or hardfacing

Photolithography

Optical communications over optical fiber or in free space

Laser peening

Guidance systems (e.g., ring laser gyroscopes)

Laser rangefinder / surveying,

Lidar / pollution monitoring,

Digital minilabs

Barcode readers

Laser engraving of printing plate

Laser bonding of additive marking materials for decoration and identification,

Laser pointers

Laser mice

Laser accelerometers

OLED display manufacturing

Holography (3D) picture.

Bubble grams

Optical tweezers Writing subtitles onto motion picture films.

Power beaming, which is a possible solution to transfer energy to the climber of a Space elevator

3D laser scanners for accurate 3D measurement

Laser line levels are used in surveying and construction. Lasers are also used for guidance for aircraft.

Extensively in both consumer and industrial imaging equipment.

In laser printers: gas and diode lasers play a key role in manufacturing high resolution printing plates and in image scanning equipment.

Diode lasers are used as a lights witch in industry, with a laser beam and a receiver which will switch on or off when the beam is interrupted, and because a laser can keep the light intensity over larger distances than a normal light, and is more precise than a normal light it can be used for product detection in automated production.

Laser alignment

Additive manufacturing

Plastic welding

To store and retrieve data in optical discs, such as CDs and DVDs

Entertainment and recreation

Laser lighting displays accompany many music concerts

Laser tag (laser guide missile)

Laser harp: a musical instrument were the strings are replaced with laser beams

As a light source for digital cinema projectors (digital film projector in dts theater)

Surveying and ranging. In surveying and construction, the laser level is affixed to a tripod, leveled and then spun to illuminate a horizontal plane. The laser beam projector employs a rotating head with a mirror for sweeping the laser beam about a vertical axis. If the mirror is not self-leveling, it is provided with visually readable level vials and manually adjustable screws for orienting the projector. A staff carried by the operator is equipped with a movable sensor, which can detect the laser beam and gives a signal when the sensor is in line with the beam (usually an audible beep). The position of the sensor on the graduated staff allows comparison of elevations between different points on the terrain.

A tower-mounted laser level is used in combination with a sensor on a wheel tractor-scraper in the process of land laser leveling to bring land (for example, an agricultural field) to near-flatness with a slight grade for drainage. This type of level does not require a heavy motor to create the illusion of a line from a dot rather, it uses a lens to transform the dot into a line.

Bird deterrent

Laser beams are used to disperse birds from agricultural land, industrial sites, roof tops and from airport runways. Birds tend to perceive the laser beam as a physical stick. By moving the laser beam towards the birds, they get scared and fly away. On the market are manual operated laser torches or automated robots to move the laser beam automatically.

Fiber-optic communication

This is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference are required.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Researchers at Bell Labs have reached internet speeds of over 100 petabit×kilometer per second using fiber-optic communication.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. However, infrastructure development within cities was relatively difficult and time-consuming, and fiber-optic systems were complex and expensive to install and operate. Due to these difficulties, fiber-optic communication systems have primarily been installed in long-distance applications, where they can be used to their full transmission capacity, offsetting the increased cost.

Since 2000, the prices for fiber-optic communications have dropped considerably. The price for rolling out fiber to the home has currently become more cost-effective than that of rolling out a copper based network. Costs are low and housing density is high. when optical-amplification systems became commercially available, the telecommunications industry has laid a vast network of intercity and transoceanic fiber communication lines. an intercontinental network of 250,000 km of submarine communications cable with a capacity of 2.56 Tb/s was completed, and although specific network capacities are privileged information, telecommunications investment.

Pulse dispersion

This is the result of modal dispersion, which is an issue in systems employing multimode fiber (MMF). Such systems permit optical signals and signal components to propagate along multiple modes, or physical paths, within both the core and the cladding of a fiber.

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DEPARTMENT OF PHYSICS

II M.SC PHYSICS

LASER AND ITS APPLICATIONS (16PHP302)

MULTIPLE CHOICE QUESTIONS

Questions

UNIT V

The total acceptance angle is	twice the minimum of acceptance angle	twice the maximum of acceptance angle	half the maximum of acceptance angle	half the minimum of acceptance angle
Single mode step index fibres support propagation of	meridinal rays	skew rays	helical rays	all the three rays
Micro bends and small cracks present in the optical fibre cause	change in internal reflection angles	mode coupling	loss of light intensity	all the above
Loss of light intensity in optical fibres is due to	scattering	absorption	refraction	(a) or (b)
High information carrying capability of optical fibres is measured with their	low losses	high band width	low costs	high efficiency
Preferable source of light used in fibre optic communications is	LED	sodium lamp	Laser	Cadmium red light
Optical fibre sensing applications mostly use the phenomenon of	refraction	interference	polarization	reflection
For wide band width and long distance communication system, the fibres that are needed should be	high quality, low loss, graded index fibre	plastic with large cores	highly dispersive and step indexed	fluoride fibres working in infrared region
Optical fibres are made of	metallic conductor	plastics doped with metallic impurities	dielectric materials	magnetic oxides
Graded index fibres will have ___________ attenuation than the step index fibres.	lower	higher	equal	none of the above
Step index fibre has a band width of	10 MHz	50 MHz	100 MHz	150 MHz
____________ is called the figure of merit of the fibre.	acceptance angle	numerical aperture	total internal reflection	mode coupling
The cladding diameter of a single mode step index fibre should be	75 mm	100 mm	125 mm	150 mm
Optical fibres have ___________ transmission losses.	very low	low	high	very high
Connectivity is a concept related to	transmitting information, either by computer or by phone	the interconnections within a computer	using computer networks to link people and resources	being in an active session with your computer
One of the most dramatic changes in connectivity and communications in the past five years has been ________ __ .__	mobile or wireless telephones	public and private discussion	satellite uplinks	running programs on remote computers
The four basic elements of any communication system include	peer-to-peer, videoconferencing, online photo-conferencing, net optical	sending and receiving devices, communication channel, connection device, and data transmission specifications	telephone lines, coaxial cables, fiber-optics cables, and communication channel	software, hardware, communication channel, network

An older type of data communications channel, using multiple copper wires, is called ________ technology.	microwave	fiber-optic cable	coaxial cable	twisted pair
A communications channel that is made up of a single copper core with a ground sheath around it is called a ________.	twisted pair channels	microwave	coaxial cable	fiber-optic cable
Data is transmitted using light through a(n) ________ cable.	twisted pair	fiber-optic	coaxial	microwave
Which physical connection is the fastest?	twisted pair	coaxial cable	fiber-optics	microwaves
Communication in a straight line is accomplished using ________.	twisted pairs	fiber-optics	coaxial cables	infrared
Most Web-enabled devices follow a standard known as	FireWire	Bluetooth	TCP/IP	Wi-FI
A relatively new technology that allows wireless connectivity is called ________.	Bluetooth	Blacktooth	Blueband	Broadband
An optical fibre is a transparent rod usually made of	clear plastic	glass	copper	either a or b
Optical fibres whether made of glass or plastic, are	fragile	brittle	insulators	leaky
An optical fibre excels at rejecting	electromagnetic interference	radio frequency interference	cross talk	diffraction
Fibre systems are particularly suited for transmission of ___________ data such as that generated by computers.	digital	analogue	binary	modulated
The velocity of light is independent of	wavelength	medium refractive index	frequency	all of the above
Total internal reflection can take place when light travels from	air to glass	glass to air	rarer to a denser medium	denser to rarer medium
In an optical fibre, the propagation angle of light must be equal to or less than the __________ angle	acceptance	incident	critical	refraction
The numerical aperture of an optical fibre depends on ----------------	core refractive index	critical angle	both of the above	none of the above
The main energy losses in an optical fibre consists of ___________	material loss	loss due to light scattering	bend loss	all the above
Optical fibres are coated with __________ immediately being drawn	buffer	plastic	kevlar	polyurethene
The structure of an optical fibre consists of	multimode step index	graded index	single mode step index	all of the above
Amongst different types of fibres, single mode step index fibre has	highest data rate	lowest attenuation	highest thickness	both a and b
____________ is called the figure of merit of the fibre.	acceptance angle	numerical aperture	total internal reflection	mode coupling
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