Chapter I

1.0 Introduction

Recent research in Solid State Physics has revealed a new device called 'LASER' which means 'Light Amplification by Stimulated Emission of Radiation'. LASER works on the principle of quantum theory of radiation. When an electron in an orbit absorbs energy, it goes to an orbit of higher energy level. When the electron jumps back to a stable orbit, it emits radiations in the forms of electro-magnetic waves. The energy of each photon = hv. Towns and Schawlow in 1958 worked out the principle of a LASER is similar that of 'MASER' which means 'Micro wave Amplification by Stimulated Emission of Radiation'. Due to this reason LASER is also called ' Optical MASER'.

1.1 Optical MASER's

Stimulated emission be used an amplifying mechanism, devices employing this principle have become common in the microwave and optical regions of the spectrum. After these initial experiments, it was clear that stimulated emission could be used to build other amplifiers or oscillators. The original works led to the construction of an amplifier using ammonia gas, in which the inverted system was prepared by the electromagnetic separation of the excited ammonia molecules. The device was called a MASER, which is an acronym for Microwave Amplification by Stimulated Emission in the optical regions of the spectrum, an additional acronym came into use – "LASER" for Light Amplification by Stimulated Emission of Radiation. The extension from the microwave region of the optical portion of the spectrum of the use of stimulated emission as an amplifying mechanism followed an explicit proposal to use a 3 – level energy system for a MASER. In this suggestion, pumping or inversion was to be accomplished by an external energy source and stimulated emission was to occur between two of the three levels.

In the construction of oscillators the active material must be contained in a cavity with means the central the mode of oscillation. At frequencies < 10^{11}Hz cavities with all dimensions comparable to wavelengths can be built, making mode selection straight forward. This approach is not convenient at optical frequencies. The solution to the problem of control by using a multi mode cavity in the form of an interferometer and the natural line width of the transition.

As a consequence of the form of the cavity used, the output of a LASER is a beam with a well defined phase front. The angular divergence of the beam should be diffraction limited by the cavity aperture. Although clearly predicted, the output radiations of an optical MASER in the formed a well collimated beam of radiation is one of its most striking properties. The isolation of single oscillating modes from LASER's is now common practice. Accompanying the appearance of the directional beam, the spectral line width decreases. Within the narrow beam width of the output, the high radiation level occurs. Using Nd^{3+} doped glasses, LASER's have been constructed with peak power outputs of $\sim 10^{12}$ watts at 1.06μm for $\sim 3 \times 10^{-12}$ sec.

In addition to the requirement of mode selection, oscillation can be sustained only of the rate of supplying energy to mode through emission exceeds the rate of loss of energy from the cavity. Thus statement can be simply expressed in terms of the absorption coefficient. From thermodynamic considerations of an atom containing only two energy levels, each of statistical weight unity the probability that a light wave incident on an atom in the ground state will be absorbed is equal to the probability that the light wave will stimulated the emission of radiation from an atom in the upper state. It should be noted that the radiation produced by the stimulated emission will have the same phase and direction as the original radiation. Light passing through a crystal l cm long, containing N_0 atoms/cm all in the ground state, is attenuated by an amount $e^{-\sigma N_0 l}$, where σ is the cross section for absorption (or stimulated emission) at the wavelength of the radiation on the other hand, if all the atoms were in the upper state, the light would be amplified by $e^{+\sigma N_0 l}$. To sustain oscillation in a cavity the gain must exceed the loss and thus, with end reflectivity's R_1 and R_2

LASER lines. The coverage is not as dense from 1 to 10μm and from 10 to 370μm only 70 lines in H_2O, D_2O, NH_2, Ne, CN, BrCN and diethyl amine have been observed.

The output of a LASER generally consists of more than one axial mode with frequencies separated by $\frac{C}{2l}$. The simultaneous existence of more than one frequency in the output effects the properties of the beam when a single frequency axial and transition are emitted from a well controlled cavity the amplitude and frequency are stable to one part in 10^9. Fluctuations or noise occur largely as phase noise. With more than one frequency the output shows random fluctuations due to phase modulation between the separate frequencies. Through various techniques of mode locking it is possible to produce pulses separated by ~ 10^{-9} and 10^{-12} sec long.

1.2 LASER

Simplest form a LASER consists of a gain medium, a feedback mechanism, a source of input energy a method of coupling between the input energy and the actual gain medium, and a method of extracting power. The forms of input energy are:

(i) Optical energy from gas discharge or incandescent sources included Pump lamps. The first pump lamps used were the Xe flash lamps. Later lamps are included mercury vapor, tungsten, ribbons, the sun, light-emitting diodes and shock waves.

(ii) Electric discharges in the gaseous materials itself.

(iii) Thermal excitation of one species followed by excitation of the actual gain materials.

(iv) Direct electrical point injection of carriers in semiconductor junctions.

(v) Electron-beam excitation of solids, in these cases the incident electron-beam energy varies from ~50,000-300,000 electron volts.

(vi) Chemical dissociation into excited states.

(vii) Exothermic chemical reaction producing molecules are in excited states.

(viii) Thermodynamic processes e.g. rapid expansion of gases.

Although the feedback mechanism in reflection, the metallic mirrors used in the first LASER's have been replaced by multilayer dielectrics with the reflectivity maximum matched to the wavelength of interest. Another device commonly used for reflectors is the multiple reflections from an etalon of transparent plates.

1.2.1 Principle of LASER

An assembly of atoms of some kind that have metastable states of excitation energy is hv. Suppose we some how raise a majority of the atoms to the metastable level. If we now shine light of frequency v on the assembly, there will be more induced emission from the metastable level than induced absorption by the lower level. The result will be an amplification of the original light. This is the concept that underlines the operation of the LASER

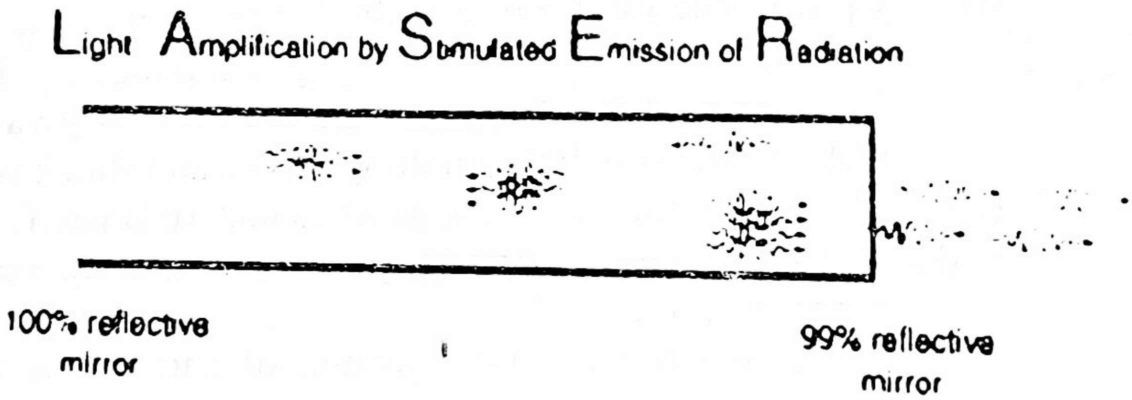


Fig.-1.2

A fluorescent substance is one which light when it has been exposed to electromagnetic radiation. The frequency of the emitted light is generally found to be lower than that the exposing radiation.

A. L. Schawlow and C. H. Towns in 1958 proposed a method of constructing a MASER for optical wavelength by using a resonant cavity whose dimensions were millions of times the wavelength of light. In the optical MASER, the reflecting box into which energized ammonia atoms were fed in Town's original ammonia MASER was replaced by a device in which two small mirrors were used which faced each other. In each succeeding passage of the wave it would grow in intensity until it were strong enough to burst through one of the mirrors as a flash of coherent light. Such a system is called a Febry-Perot resonator.

The stimulated emission of light is the crucial quantum process necessary for the operation of a LASER.

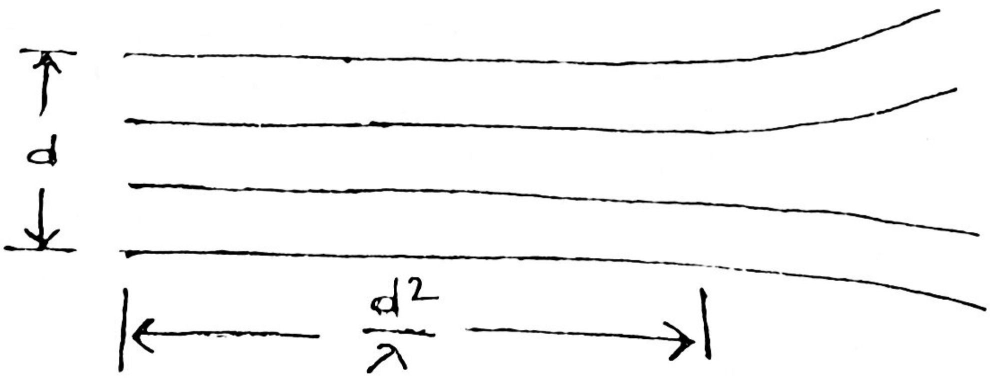
1.3 History of LASER

LASER is the enormous difference between the ``character of its light and the light from other sources such as the sun, a flame or an incandescent lamp. The most striking features of LASER are:

(i) its directionality
(ii) its high intensity
(iii) its extraordinary monochromacity
(iv) its high degree of coherence.

1.3.1 Directionality

The directionality of LASER beams is usually expressed in terms of the full angle beam divergence, which is twice the angle that the outer edge of the beam makes with the axis of the beam.



Directionality of The LASER beam

Fig.-1.3

The strength of the beam has dropped to $\frac{1}{e}$ times its value at the centre when a beam with planar wavefront radiates from an aperture of diameter (d), the beam propagates as a parallel beam for a distance of about $\frac{d^2}{\lambda}$, which is sometimes called Rayleigh range and then begins to spread linearly with distance because of the unavoidable effects of diffraction.

The angular spread $\Delta\theta$ of the far field beam is related to the aperture diameter d by

$$\Delta\theta = \frac{\lambda}{d} \qquad (1.3)$$

For a typical LASER, the beam divergence is less than 0.01milliradian. That is, the beam spreads less than 0.01mm for every meter output in a LASER beam is many millions of times more concentrated than the best search light available.

1.3.2 Intensity

The light from a lamp streams out more or less uniformly in all directions. If we look at a 100 watt lamp filament at a distance of 30cm, the power entering the eye is less than a thousand of a watt. Let us compare the photon output of a LASER with that of a very hot body. The power ouput from a small gas LASER is ~ 10^{-3}W, while that from a pulsed solid state LASER may be as high as 10^{9}W. Since one photon of visible light represent ~ 10^{-19}J of energy. The photon output of LASER's range over:

$$LASERphoton/\sec = \frac{P}{\hbar\omega} \approx 10^{16} to 10^{28} \qquad (1.4)$$

The amount of energy emitted by a black body per unit area per unit time in the range of frequency between ω and $\omega + d\omega$, its intensity is given by

$$e(\omega,T)d\omega = \frac{1}{4}\rho(\omega,T)c\,d\omega$$

$$= \frac{1}{4}\frac{\hbar\omega^3}{\pi^2 c^2}\frac{1}{e^{\hbar\omega/KT}-1}d\omega, \qquad (1.5)$$

where $\rho(\omega,T)$ is the radiation density for the band width given by Planck's formula

$$\rho(\omega,T)d\omega = \frac{\hbar\omega^3}{\pi^2 c^3}\frac{1}{e^{\hbar\omega/KT}-1}d\omega \qquad (1.6)$$

$$Thermalphoton/_{\sec} = \frac{\omega^2}{4\pi^2 c^2}\frac{1}{e^{\hbar\omega/KT}-1}d\omega \qquad (1.7)$$

Let us assume the band width of a line in the visible region, λ = $6000A^0$, to be $1000A^0$ and the temperature to be 1000K.

$$\omega = 2\pi\nu = 2\pi\times 5\times 10^{14} \qquad (1.8)$$

$$d\omega = \frac{2\pi}{12}\times 10^{15} \qquad (1.9)$$

Substituting these values in the formula obtained above, we find the emission from an area equal to 1 Sq-cm of the hot body to be

$$Thermalphotons/_{Sq-cm-\sec} \approx 10^{12} \qquad (1.10)$$

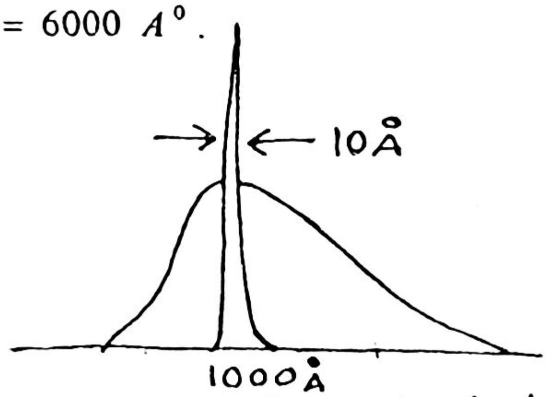
1.3.3 Monochromacity

The light emitted by a LASER is vastly more monochromatic than that of any conventional monochromatic source. An inspection of a line emitted by the latter shows that it is never perfectly sharp, but it spreads over a frequency range of the order of thousands of megacycles per second.

The degree of monochromacity of light, we characterize the spread in frequency of a line by the line width $\Delta\nu$. The degree of non-monochromacity of a wave may be defined and its relative band width given by

$$\xi = \frac{\Delta \nu}{\nu_0}, \qquad (1.11)$$

where ν_0 is the central frequency of the light beam. Absolute monochromacity for which $\Delta\nu = 0$ is unattainable goal. The LASER light has a higher degree of monochromacity. The output from a LASER is very nearly a perfectly monochromatic sine wave with a very small bandwidth about 1kcycle/sec. The output from a high quality stable gas LASER, locked to the centre of the absorption line has a bandwidth, $\Delta\nu \approx 500 Hz$,i.e. $\Delta\lambda = 10^{-8} A^0$ at $\lambda = 6000\ A^0$.



Normal and LASER band width

Fig.-1.4

Even poor quality solid state LASER can have a band width of $\Delta\nu = 10^9 Hz$ i.e. $\Delta\lambda = 10^{-2} A^0$. For example, the line width of a line emitted by ruby, ordinary is $3A^0$ while the line width of the LASER with the same material is $5 \times 10^{-4} A^0$.

1.4 Coherence

LASER radiation is characterized by a high degree of ordering of the light field than the other sources. In other words, it has a high degree of coherence. The high coherence of LASER emission makes it possible to realize a tremendous spatial concentration of light power, such as 10^{13}W in a space with linear dimensions of only 1μm. Radiation of such intensity can cut metal, produce micro welding, drill microscopic holes through diamond crystals and so on.

The monochromacity, directionality and intensity of LASER light are making possible a wide range of scientific investigations that would have been unimaginable without them..... even so, we are still sometimes limited by the properties of available LASER's, and have to try to extend LASER technology. Perhaps someday we will have tunable γ-ray LASER's that we can use to excite coherent super positions of nuclear energy levels and to alter radioactive decay of nuclei. The existence of LASER's has not provided solutions to all our problems. But it has given us a pretty good hint as to where some interesting solutions might be found.

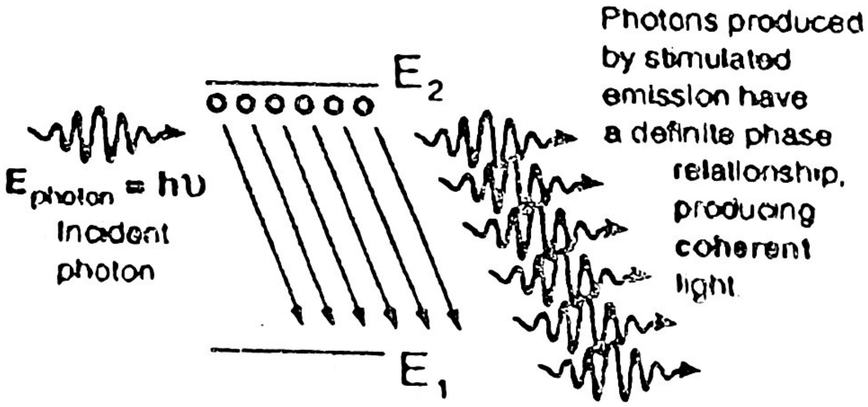


Fig.-1.5

Coherence is one of the unique properties of laser light. It arises from the stimulated emission process which provides the amplification. Since a common stimulus triggers the emission events which provide the amplified light, the emitted photons are "in step" and have a definite phase relation to each other. This coherence is described in terms of temporal coherence and spatial coherence, both of which Ordinary light is not coherent because it comes from independent atoms which emit on time scales of about 10^{-8} seconds. There is a degree of coherence in sources like the mercury green

These oscillations are considered coherent if the phase difference between the oscillations at C is constant. This coherence is said to be spatial coherence.

1.5 Generation of Coherent Radiation (Lasing)

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If the sun of energies of a signal, E_s and stimulated emission, E_c, is higher than the energy loss E_{loss} and energy E_l given up to the load,

$$E_s + E_c > E_{loss} + E_l \, , \tag{1.12}$$

The quantum system enters the mode of self excitation and begins to operate as a quantum oscillator (LASER), in which oscillation are also built up in the absence of an external signal under the action of random spontaneously emitted quanta.

The optical range within the spectrum interval extending from the ultraviolet to the sub-millimetric wave region: $\lambda = 0.1$ to $800\mu m$.

The energy levels between which optical transitions occur always have a finite width ΔE because the time of the settle life of electrons on these levels is finite, which, according to uncertainty relation, must cause broadening of the levels and their spreading into narrow bands. Consequently, the radiation emitted during optical transitions never happens to be trcitly monochromatic, and its frequencies cover a certain band Δv.

LASER excites oscillations only at resonant frequencies satisfying the condition

$$L = n\left(\frac{\lambda}{2}\right) \tag{1.13}$$

The LASER emits the waves of one or less frequencies, the wavelength of which satisfy the resonances condition eq^n(1.13) and lie within the band $\Delta \nu$. The bandwidth of each of these waves is a function of the Q-factor of an optical cavity and can be rather short (less than 100Hz). The frequency stability depends on the stability of the dimension L of the cavity.

1.7 Characteristics Properties of a LASER Light

(i) Coherent: Different parts of the laser beam are related to each other in phase. These phase relationships are maintained over long enough time so that interference effects may be seen or recorded photographically. This coherence property is what makes holograms possible. The light is coherent with the waves all exactly in phase with one another.

(ii) Monochromatic: The light is very nearly monochromatic. Laser light consists of essentially one wavelength, having its origin in stimulated emission from one set of atomic energy levels.

(iii) Collimated: Because of bouncing back between mirrored ends of a laser cavity, those paths which sustain amplification must pass between the mirrors many times and be very nearly perpendicular to the mirrors. As a result, laser beams are very narrow and do not spread very much.

(iv) The LASER light beam is extremely intense. A LASER beam diverges hardly at all.

Chapter II

2.0 Quantum Processes

Quantum properties dominate the fields of atomic and molecular physics. Radiation is quantized such that for a given frequency of radiation, there can be only one value of quantum energy for the photons of that radiation. The energy levels of atoms and molecules can have only certain quantized values. Transitions between these quantized states occur by the photon processes absorption, emission, and stimulated emission. All of these processes require that the photon energy given by the Planck relationship is equal to the energy separation of the participating pair of quantum energy states.

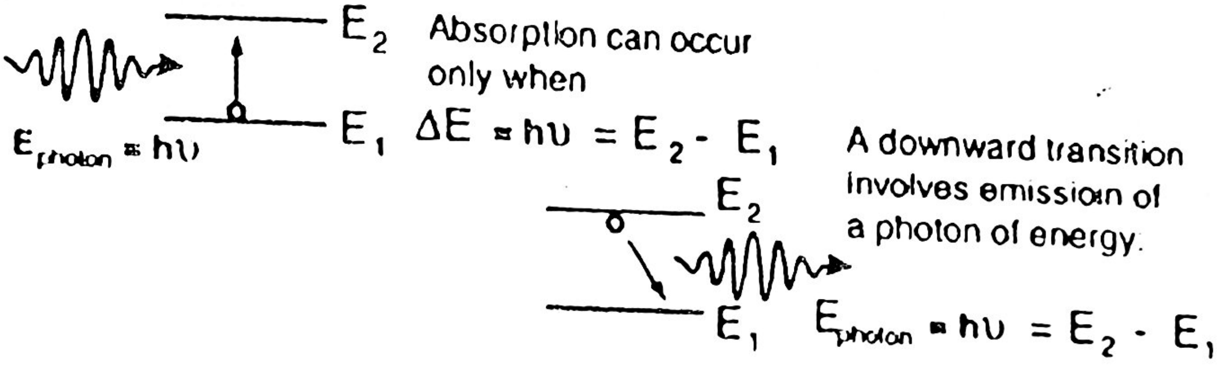


Fig.-2.1

Three Kinds of transition involving electromagnetic radiation are possible between two energy levels E_1 and E_2 in atom:

(i) Induced absorption
(ii) Spontaneous emission
(iii) Stimulated emission

2.1 Induced Absorption

Taking the electron transitions associated with visible and ultraviolet interactions with matter as an example, absorption of a photon will occur only when the quantum energy of the photon precisely matches the energy gap between the initial and final states. In the interaction of radiation with matter, if there is no pair of energy states such that the photon energy can elevate the system from the lower to the upper state, then the matter will be transparent to that radiation.

If the atom is initially in the lower state E_1, it can be raised to E_2 by absorbing a photon of energy

$$E_2 - E_1 = h\nu \tag{2.1}$$

This process is called induced absorption.

Einstein postulated that the induced absorption transition rate was proportional to the number of atoms with electron in the lower state and to the density of radiation energy incident on these atoms.

$$\frac{dN_{12}}{dt}\Big|_1 = B_{12}\,\rho_{21}\,N_1 \,. \tag{2.2}$$

where N_1 = Number of atoms with electrons in the n = 1 state., ρ_{21} = density of electromagnetic radiation with energy equal to the energy difference between the two states and B_{21} = Einstein coefficient for induced absorption.

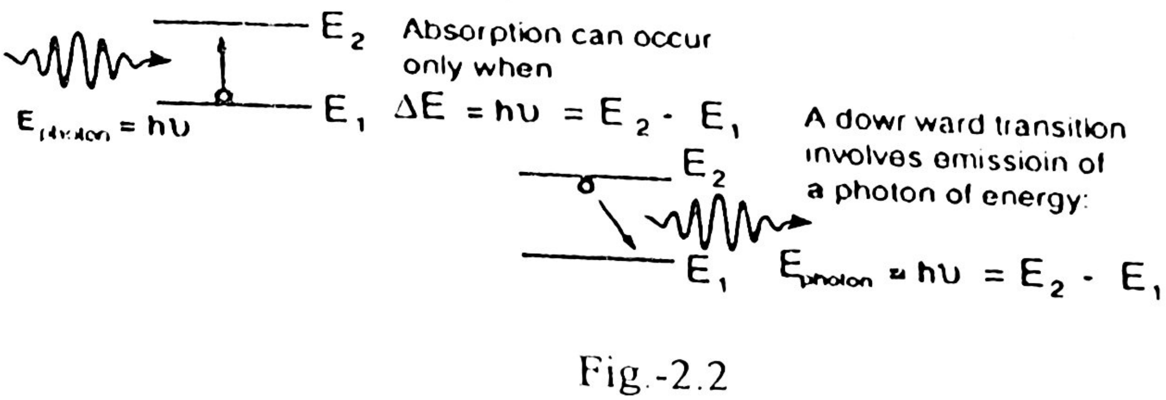


Fig.-2.2

2.2 Spontaneous Emission ✓MOU

Energy levels associated with molecules, atoms and nuclei are in general discrete, quantized energy levels and transitions between those levels typically involve the absorption or emission of photons. Electron energy levels have been used as the example here, but quantized energy levels for molecular vibration and rotation also exist. Transitions between vibrational quantum states typically occur in the infrared and transitions between rotational quantum states are typically in the microwave region of the electromagnetic spectrum.

f the atom is initially in the upper state E_2, it can drop to E_1 by emitting a photon of energy hv; this is spontaneous emission.

Einstein postulated that the spontaneous transition rates were proportional to the number of atoms with electrons in the upper state.

$$\frac{dN_{21}}{dt}\Big|_S = A_{21}N_2, \qquad (2.3)$$

where A_{21} = Einstein coefficient for spontaneous emission.

2.3 Stimulated Emission

If an electron is already in an excited state (an upper energy level, in contrast to its lowest possible level or "ground state"), then an incoming photon for which the quantum energy is equal to the energy difference between its present level and a lower level can "stimulate" a transition to that lower level, producing a second photon of the same energy.

Two photons instead of one move on. The excited atom emits light waves in step with the incoming wave and increases its intensity. This is known as stimulated emission of radiation. The radiated light waves are exactly in phase with the incident ones, so that the result is an enhanced beam of coherent light.

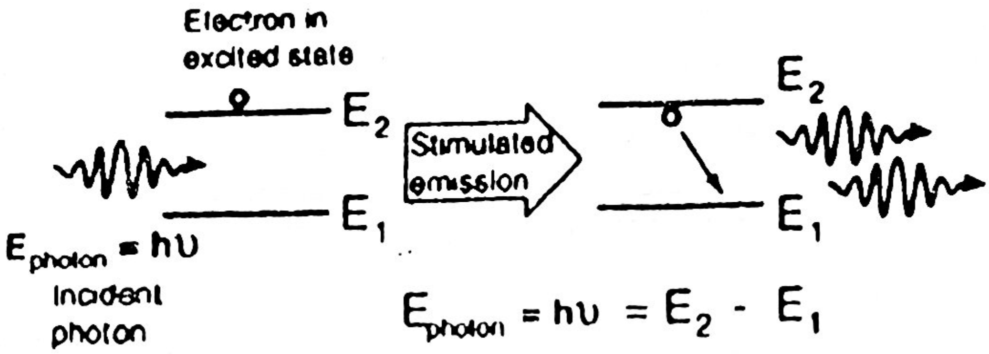


Fig.-2.3

The transition rate for stimulated emission is proportional to N_2 and to the density of radiation incident on the atoms with energy equal to the energy difference between the two states.

$$\frac{dN_{21}}{dt}\Big|_s = B_{21}\rho_{21}N_2, \tag{2.4}$$

where B_{21} = The Einstein coefficient for stimulated emission. After making the above assumptions, Einstein showed that for thermal equilibrium the coefficients of induced absorption and stimulated emission are equal.

$$B_{21} = B_{12} \tag{2.5}$$

He also showed that the relationship between the coefficient of spontaneous emission and the coefficient of stimulated emission is

$$\frac{A_{21}}{B_{21}} = \frac{8(E_2 - E_1)}{h^2 c^3}, \tag{2.6}$$

where $E_2 - E_1$ is the energy difference between the two states.

When a sizable population of electrons resides in upper levels, this condition is called a "population inversion", and it sets the stage for stimulated emission of multiple photons.

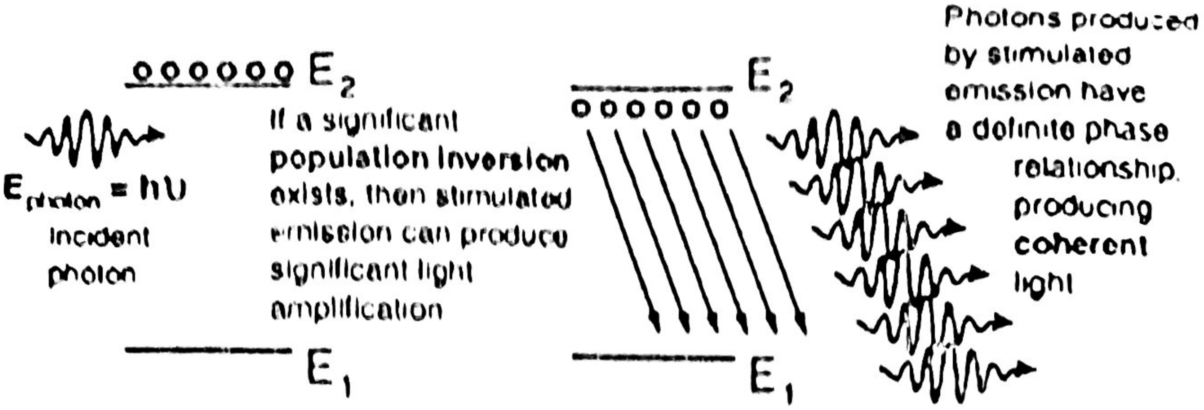


Fig.-2.4

This is the precondition for the light amplification which occurs in a laser, and since the emitted photons have a definite time and phase relation to each other, the light has a high degree of coherence.

Like absorption and emission, stimulated emission requires that the photon energy given by the Planck relationship be equal to the energy separation of the participating pair of quantum energy states.

2.4 Spontaneous and Stimulated (Induced) Emission and Einstein A and B Coefficients

In 1917, about 9 years before the development of the relevant quantum theory and this was predict purely from thermodynamical considerations. Consider an atom in two states. Let the number of atoms per unit volume per unit time in state 1 be N_1 and state 2, N_2. Let ψ represent the energy density for radiation for frequency v. The ψ dv represents the energy density for radiation between frequency range v and v + dv. Assuming that the rate of absorption of radiation of frequency v from state 1 to state 2 is proportional to the radiation energy density ψ, the number of absorptions per unit volume per unit time will be given by $N_1B_{12}\psi$. Here B_{12} is a constant of proportionality from state 1 to state 2.

Einstein argued that equilibrium would be possible, and the laws of thermodynamics obeyed, only if the ratio of the A_{21} and B_{12} coefficients had the value shown above. This ratio was calculated from quantum mechanics in the mid 1920's. In recognition of Einstein's insight, the coefficients have continued to be called the Einstein A_{21} and B_{12} coefficients.

While applicable in many situations, the A_{21} and B_{12} coefficients received particular attention in the period in which lasers were being developed. The nature of the coefficients is such that you cannot use the radiation in a cavity to elevate electrons preferentially into an upper state, producing the population inversion necessary for laser action. The particular ratio between the coefficients suggests that the presence of the light to "pump" electrons into upper states will have the same probability of stimulating an already elevated electron to make the downward transition, so that laser action cannot be achieved with a two-level system. The achievement of laser action was obtained by three-level systems like that in the helium-neon laser where the population of the upper neon level could be achieved by a non-radioactive transfer from the helium pumping gas to the neon atoms.

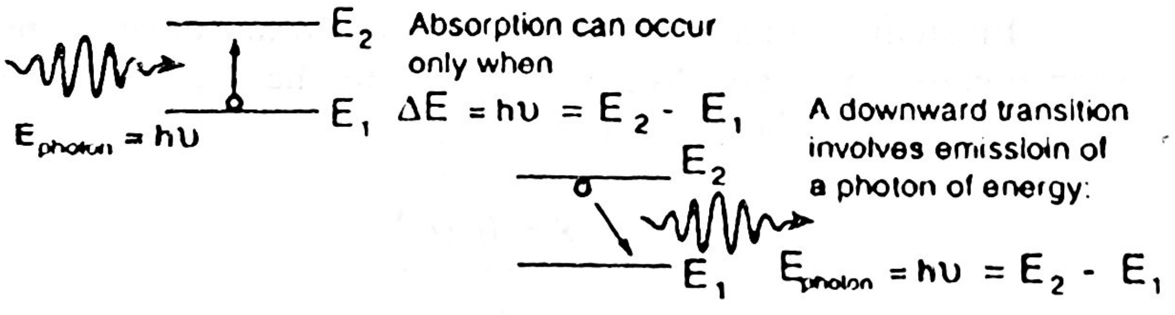


Fig.-2.5

The implication of the Einstein A_{21} and B_{12} coefficients is that these two processes will occur at equal rates, so that no population inversion can be attained in a two-level system like that depicted here.

2.5 Population Inversion

The achievement of a significant population inversion in atomic or molecular energy states is a precondition for LASER action. Electrons will normally reside in the lowest available energy state. They can be elevated to excited states by absorption, but no significant collection of electrons can be accumulated by absorption alone since both spontaneous emission and stimulated emission will bring them back down.

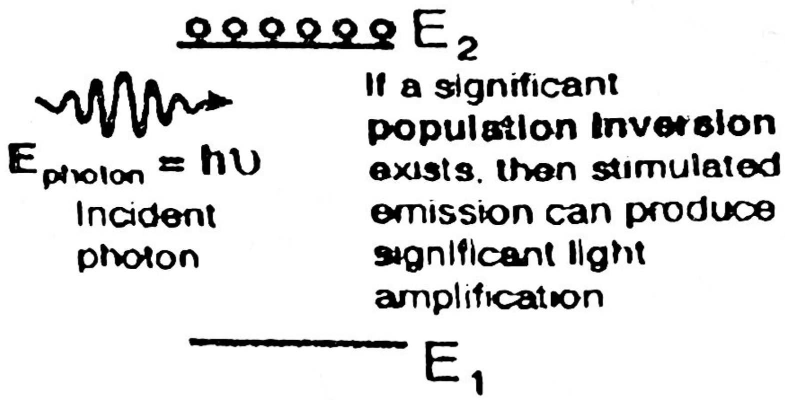


Fig.-2.6

A population inversion cannot be achieved with just two levels because the probability for absorption and for spontaneous emission is exactly the same, as shown by Einstein and expressed in the Einstein A_{21} and B_{12} coefficients. The lifetime of a typical excited state is about 10^{-8} seconds, so in practical terms, the electrons drop back down by photon emission about as fast as you can pump them up to the upper level. The case of the helium-neon laser illustrates one of the ways of achieving the necessary population inversion.

Under ordinary conditions of thermal equilibrium, the number of atoms in the higher energy state is considerably smaller than the number in the lower energy state. By Boltzmann low

$$\frac{N_2}{N_1} = e^{-(E_2 - E_1)/KT} \qquad (2.17)$$

i.e. $N_2 < N_1$. Hence there is very little stimulated emission compared with absorption. The atoms be initially excited so that there are more atoms in the higher energy state E_2 than in the lower energy state E_1. We then have $N_2 > N_1$. This is known as population inversion.

2.6 Pumping

The method of producing population inversion is called pumping. One type of pumping is optical pumping. Atoms in ground state are pumped to state E_3 by photon energy

$$h\nu' = E_3 - E_1 \tag{2.18}$$

The excited atoms then undergo non-radiative transitions with a transfer of energy to the lattice thermal motion, to the level E_2. There will be more atoms in the higher metastable energy state E_2 than in the ground state E_1, we have a "population inversion".

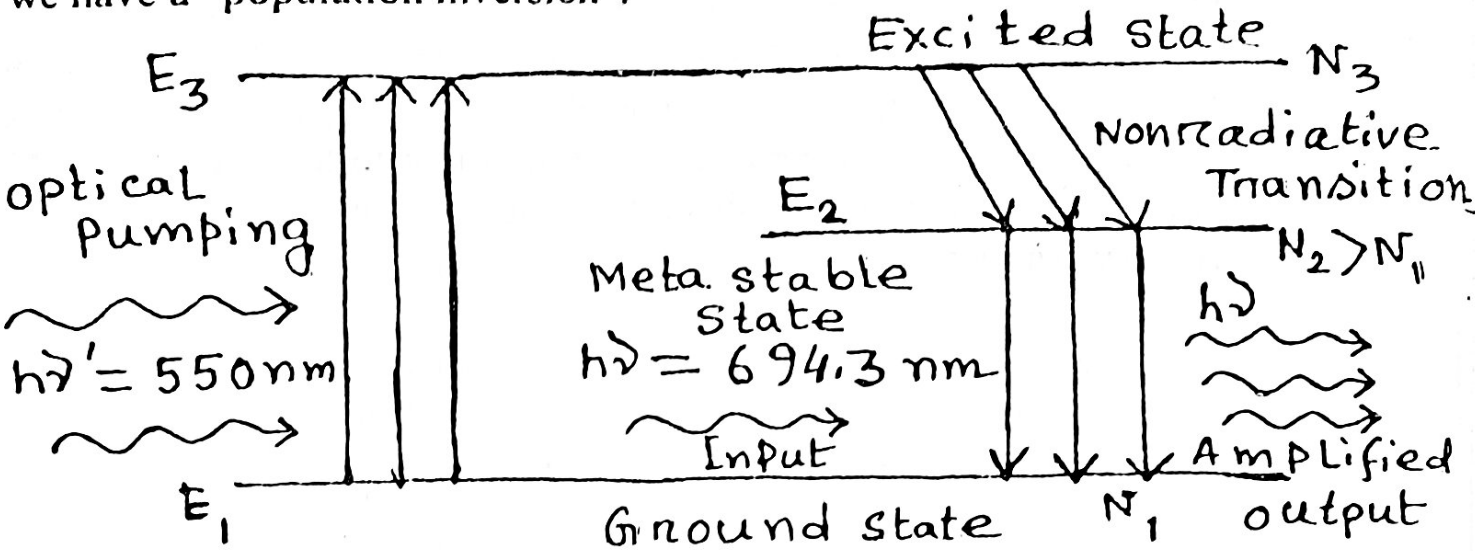


Fig.-2.7

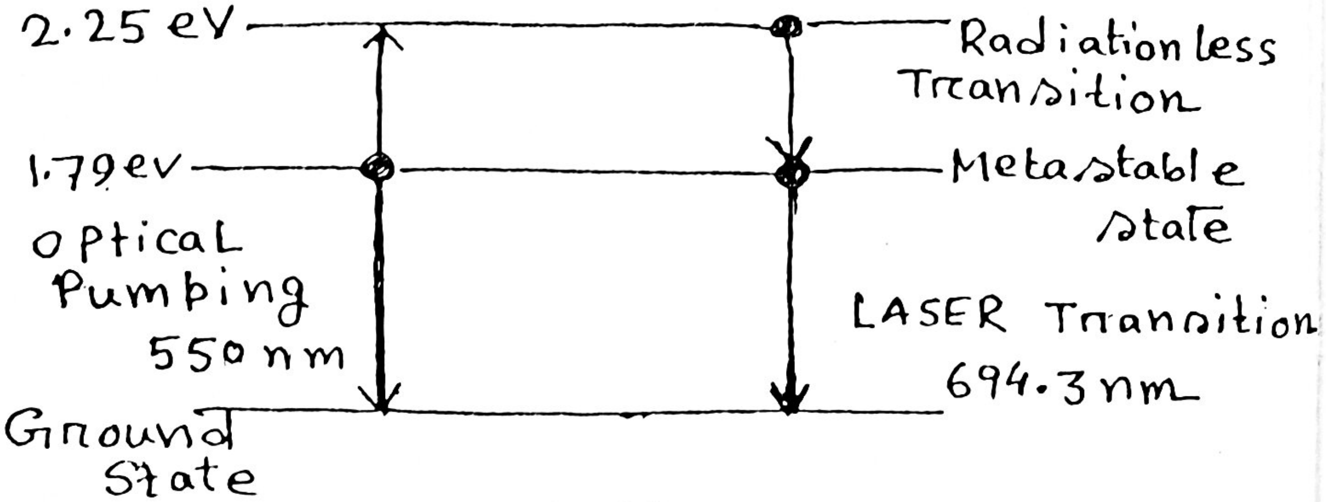


Fig.-2.8

Atoms in the metastable state E_2 are now bombarded by photons of energy $h\nu = \mathbf{E_2 - E_1}$, resulting in a stimulated emission giving an intense coherent beam in the direction of the incident photons.

2.7 Powering a LASER

If a LASER is continuously emitting light, then there must be power to replenish that lost energy in such a way that the laser action can continue. The power must maintain the necessary population inversion to keep the laser process going, and that implies a pumping mechanism to elevate electrons to that metastable state. The use of helium to "pump" electrons into a metastable state of neon in the helium-neon LASER is an example of such a mechanism.

The minimum pumping power would occur if the pumping process were 100% efficient and you just had to replenish the energy lost in radiation. Lasers will have a finite bandwidth and a number of modes N_m within that bandwidth. The energy in a given mode can be characterized by an average lifetime t_c. Using the Planck relationship for the energy of a given photon, the minimum pumping power can be expressed by

$$P = \frac{N_m hc}{\lambda t_c} \tag{2.19}$$

The rate of stimulated emission is proportional to the difference in the number of atoms in the excited state and the ground state, $N_2 - N_1$, which is in turn affected by the average lifetime of the excited state and the average lifetime of the emission in the laser cavity.

$$N_2 - N_1 = \frac{N_m \tau}{t_c} \tag{2.20}$$

Chapter III

3.0 Different Types of LASER's

In this chapter, we will describe some specific LASER systems whose characteristics can be considered as representative of the entire category of LASER's. Four types of LASER:

(i) Solid State LASER's
(ii) Gas LASER's
(iii) Semiconductor LASER's
(iv) Liquid-, Dye- and Chemical LASER's

3.1 Solid State LASER's

In the solid substance used in LASER devices, the active material is present in concentration less than one percent. The bulk of the material does not participate in the LASER action. It only acts as the host. For LASER action to be possible, the ions of the active material will have to be excited to the proper upper level which is usually accomplished by optical pumping. The first successful LASER action was achieved in 1960 by Maiman using a crystal of ruby as a LASER material. The successful use of ruby was particularly interesting because theoretically it is a poor LASER material and was not considered a promising candidate for this purpose. Maiman, however, had earlier carefully analyzed ruby, to determine whether or not the required criteria for LASER oscillations could be satisfied. In one of his papers he had reported his observations on the florescence relaxation processes in this crystal.

3.1.1 Crystalline Solids

The first LASER $Cr^{3+}.Al_2O_3$ possessed all the general properties of this large class of LASER's. They are characterized by impurities in low concentrations ($\sim 10^{-3} \rightarrow 10^{-2}$) and fluorescent emissions between $0.6 \rightarrow 2\mu m$. Excitation of the fluorescent levels is through absorption bands lying at higher photon energies. At this time the two most commonly encountered are the $Cr^{3+}:Al_2O_3$ and Nd^{3+}:YAG.

3.1.2 Ruby LASER

The ruby LASER is the first type of LASER actually constructed, first demonstrated in 1960 by T. H. Maiman. The ruby mineral (corundum) is aluminum oxide with a small amount (about 0.05%) of chromium which gives it its characteristic pink or red color by absorbing green and blue light.

The ruby LASER is used as a pulsed LASER, producing red light at 694.3 nm. After receiving a pumping flash from the flash tube, the LASER light emerges for as long as the excited atoms persist in the ruby rod, which is typically about a millisecond.

A pulsed ruby LASER was used for the famous LASER ranging experiment which was conducted with a corner reflector placed on the Moon by the Apollo astronauts. This determined the distance to the Moon with an accuracy of about 15 cm.

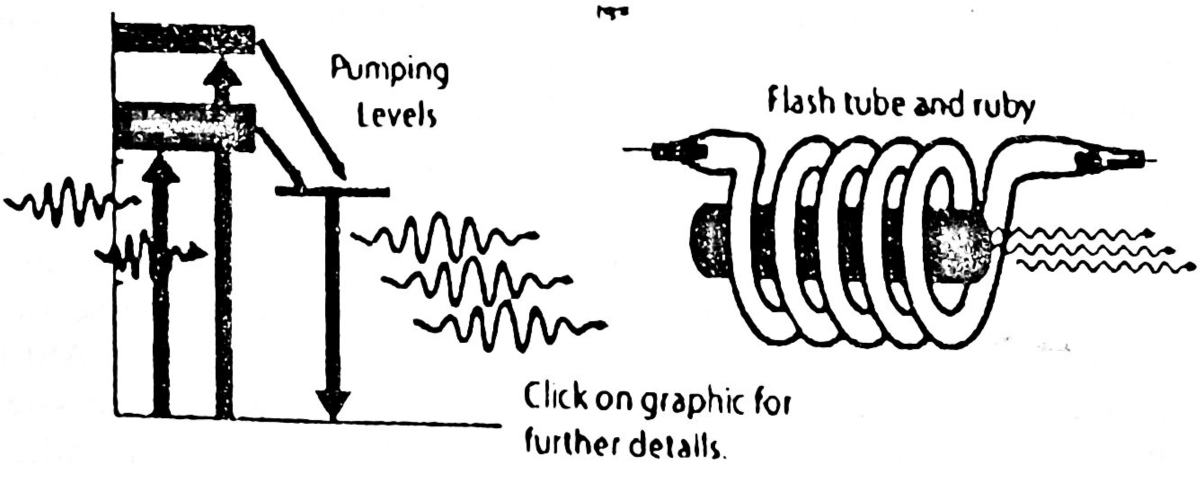
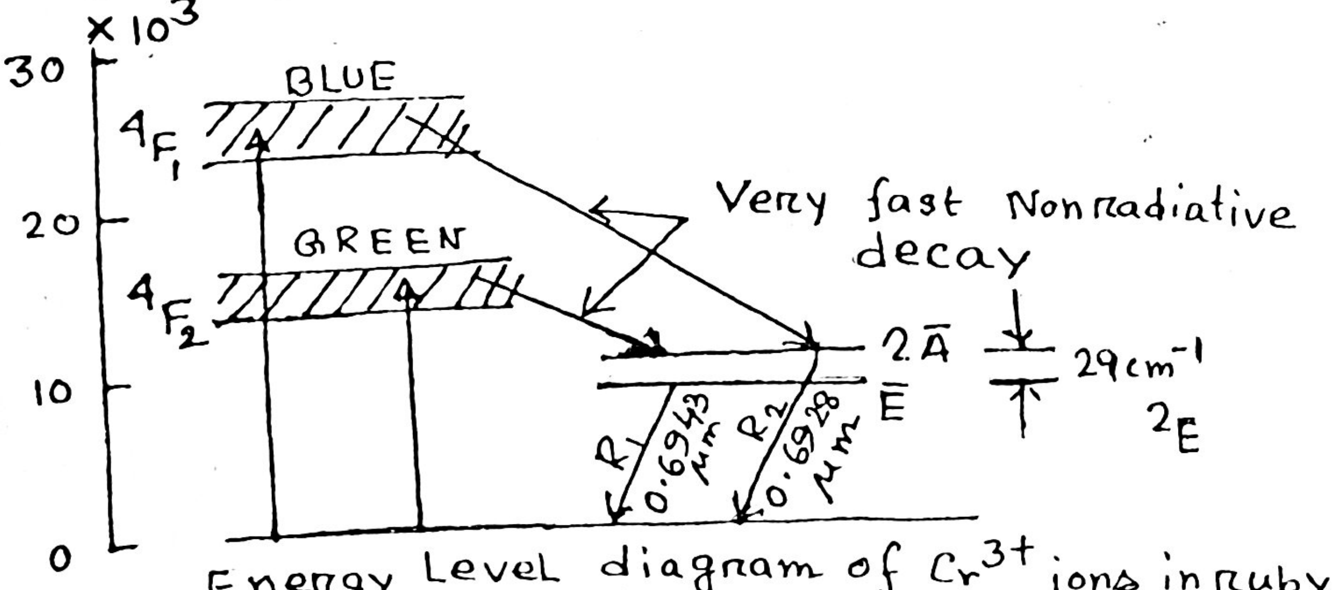


Fig.-3.1

It consists of ruby cylindrical rod whose ends are optically flat and accurately parallel. One end is fully silvered and the other is only partially silvered. The rod is surrounded by a glass tube. The glass tube is surrounded by a helical Xenon flash tube which acts as the optical pumping system.

3.1.2.1 Pumping Levels for Ruby LASER

Ruby is crystalline Al_2O_3 doped with chromium. The triply ionized Cr ions, which replace some of the Al^{3+} ions, give the otherwise transparent crystal, a pink or red colour depending upon its concentration. The energy levels in fig.-3.2 are those of Cr^{3+} ions in the Al_2O_3 lattice. There are two main pump bands, $^4F_1$ and $^4F_2$ centered around 420nm and 550nm respectively. $^4A_2$- is the ground level. The absorption spectrum of chromium ion is given in fig.-3.3.



Energy Level diagram of Cr^{3+} ions in ruby

Fig.-3.2

Maiman used a one centimeter cube of pink ruby with a concentration of about 0.05% of Cr corresponding to the Cr ion density n_0 = $1.62\times10^{19}/cm^3$, and irradiated it with 5500 radiation causing absorption into the lower band $^4F_1$. Two components of radiation re-emitted were observed in a direction at right angles to the exciting beam. The luminescence spectrum of Cr ions in ruby is given in fig.-3.3(b)

]

Type	Peak Power	Wavelength	Application
GaAs	5 mW	840 nm	CD Players
AlGaAs	50 mW	760 nm	Laser printers
GaInAsP	20 mW	1300 nm	Fiber communications

3.3.1 Free-Electron Laser

The radiation from a free-electron laser is produced from free electrons which are forced to oscillate in a regular fashion by an applied field. They are therefore more like synchrotron light sources or microwave tubes than like other lasers. They are able to produce highly coherent, collimated radiation over a wide range of frequencies. The magnetic field arrangement which produces the alternating field is commonly called a "wiggler" magnet.

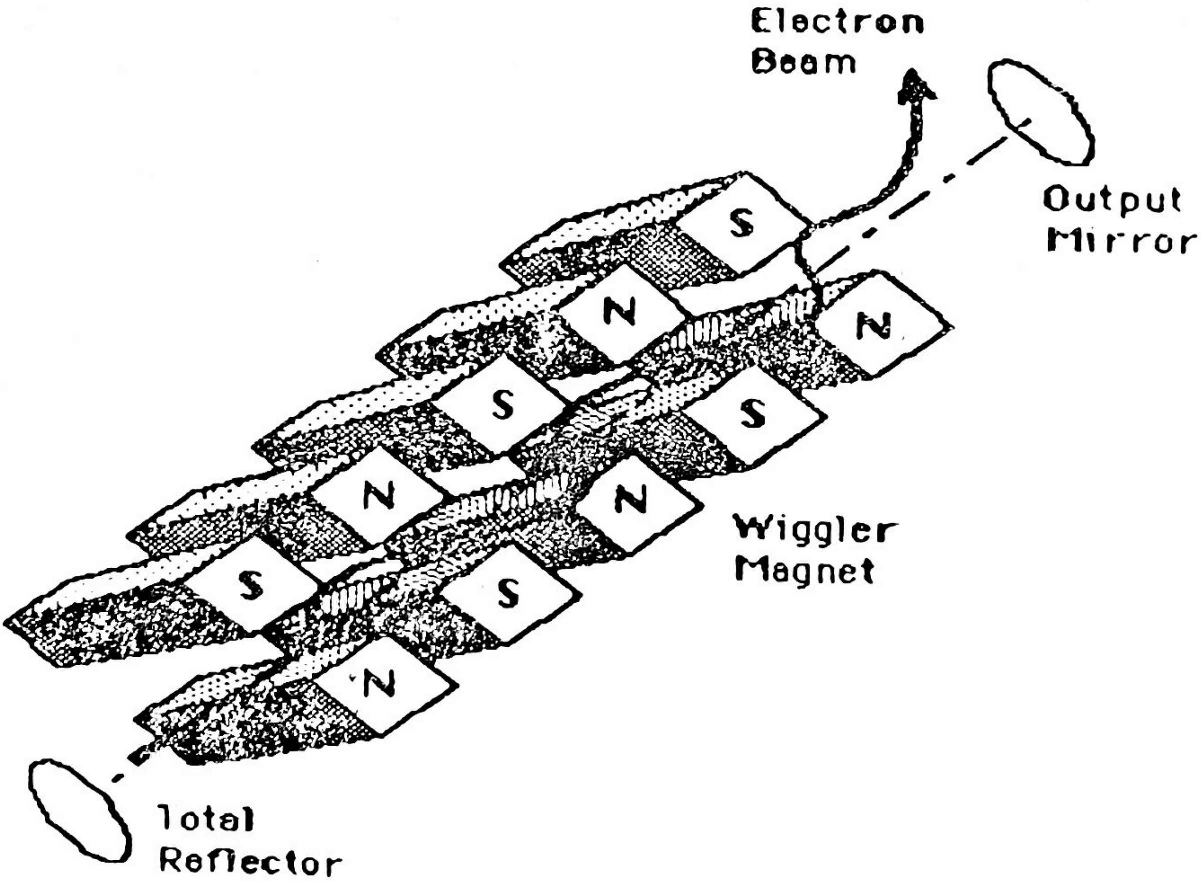


Fig.-3.12

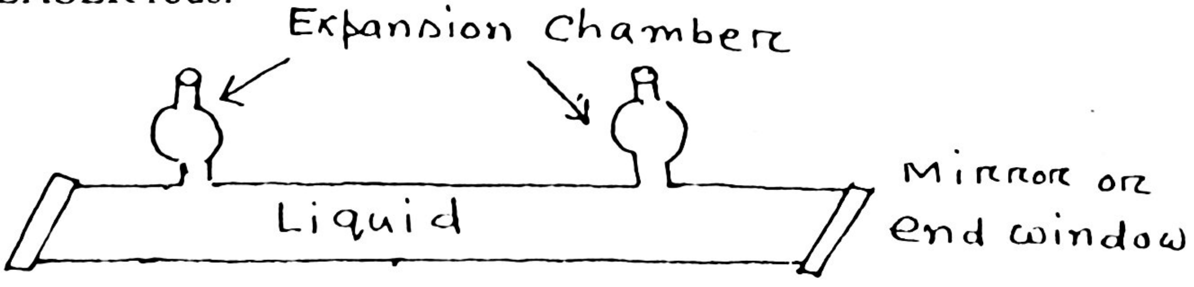
. The free-electron laser is a highly tunable device which has been used to generate coherent radiation from 10^-5 to 1 cm in wavelength. In some parts of this range, they are the highest power source. Particularly in the mm wave range, the FELs exceed all other sources in coherent power. FELs involve relativistic electron beams propagating in a vacuum and can be tuned continuously, filling in frequency ranges which are not reachable by other coherent sources

Applications of free-electron lasers are envisioned in isotope separation, plasma heating for nuclear fusion, long-range, high resolution radar, and particle acceleration in accelerators.

3.4 Liquid-, Dye- and Chemical LASER's

3.4.1 Liquid LASER's

In general, good LASER crystals are difficult to grow and are very expensive. Besides, optical strain, defects, imperfections and internal damage, which result at high power levels in crystals and which are mainly responsible for mode distortion, are difficult to eliminate. By contrast, the homogeneous liquids can have a very high optical cavity and would not crack or shatter if the output power becomes high. Of course, we cannot ignore the large thermal expansion coefficients and the change in the refractive index that will result as the temperature rises. These could be controlled by cooling and recirculating the LASER solution through the active region. One can, therefore, use tubes filled with liquid in fig.-3.13 instead of LASER rods.



Schematic of a typical Liquid LASER rod

Fig.-3.13

Problems

1. A 6Kw LASER emits light of 655nm wavelength. Calculate the number of photons emitted by the laser every second.

2. A LASER beam has a wavelength of 8×10^{-7}m and aperture 5×10^{-3}m. The LASER beam is sent to moon is 4×10^{5}Km from the earth. Calculate (i) the angular spread of the beam & (ii) the axial spread when it reaches the moon. [Angular spread, $d\theta = \frac{\lambda}{d}$ Areal Spread = $(D\times d\theta)^2$]

3. The coherence length for sodium light is 2.945×10^{-2}m. The wavelength of sodium light is $5890A^0$. Calculate (i) the number of oscillation corresponding to the coherence length and (ii) the coherence time. [Hints Number of oscillation in length L, $n = \frac{L}{\lambda}$ and Coherence time $= \frac{L}{c}$]

4. A LASER beam $\lambda = 6000A^0$ on earth is focused by a lens (or mirror) of diameter 2m on the crater on the moon. The distance of the moon is 4×10^{8}m. How big is the spot on the moon? Neglect the effect of earth's atmospheres. [Hint. Angular spread , $d\theta = \frac{\lambda}{d}$ and Areal spread i.e. area of the spot on the moon = $(D\times d\theta)^2$]

5. A LASER beam has a power of 50mW. It has an aperture of 5.2×10^{-3}m and it emits light of wavelength $7200A^0$. The beam is focused with a lens of focal length 0.1m. Calculate the area and the intensity of the image. [Hint Areal spread = $(f\times d\theta)^2$ and $I = \frac{P}{[f\times d\theta]^2}$]