

LASER

Light Amplification by
Stimulated emission of Radiation

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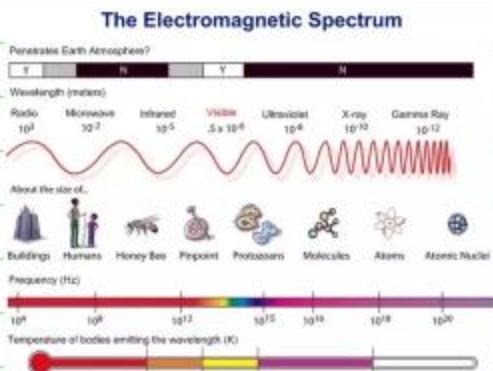
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Introduction:

The first two successful lasers developed during 1960, were the pulsed ruby laser ($\lambda = 6943\text{ \AA}$) and the He-Ne gas laser ($\lambda = 11,500\text{ \AA}$).

Laser action has been obtained with atoms, ions and molecules in gases, liquids, solids, glasses, flames, plastics and semiconductors at wavelength λ spanning from ultraviolet to radio frequency regions.

with power ranging from a few milliwatts to megawatts.



The distance of the moon from the earth was measured with considerable accuracy with the help of what is known as a laser ranging retro-reflector. This is a precise mirror which would reflect an intense beam of light shot up to the moon. By bouncing the laser beam off the reflector and back to earth, astronomers could measure the distance with an accuracy of 15 cm in 3,84,000 km [1].

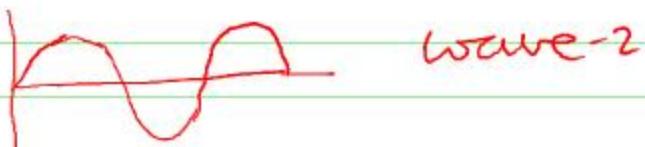
What is so special about lasers? What are the characteristics which distinguish them from other light sources?

The most striking features of lasers are:

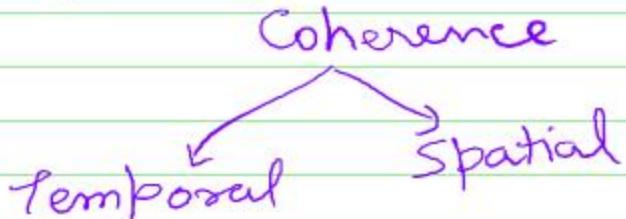
- (a) Its directionality
- (b) Its high intensity
- (c) Extraordinary monochromacity
- (d) High degree of coherence.

Coherence : light waves are said to be coherent

if they are in phase with each other for example

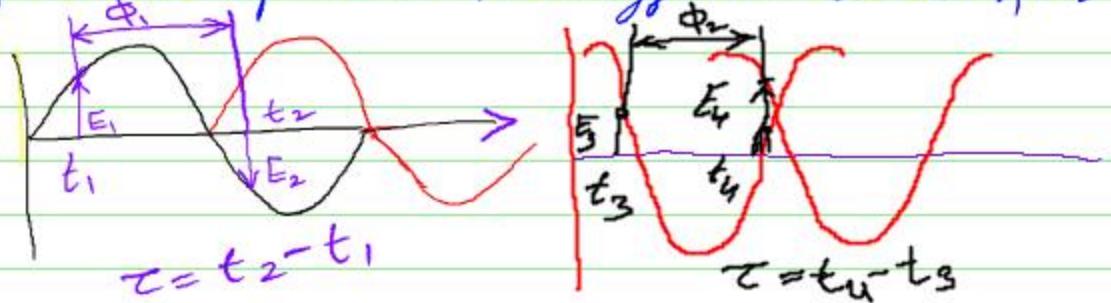


Both the waves must start with the same phase at the same position, second their wavelengths must be the same.



Temporal Coherence: apniphysics.com

Let us consider a single wave propagating along x -direction. Let us note the electric field at one point in space at two different times t_1, t_2



Let the phase difference between the field E_1 at t_1 and the field E_2 at t_2 be ϕ_1 .

Let us again note the electric fields at later times t_3 and t_4 , where $(t_4 - t_3) = (t_2 - t_1)$. Let the phase difference be now ϕ_2 .

If $\phi_1 = \phi_2$ and it is true for any time interval of same duration, then the wave is said to be temporally coherent.

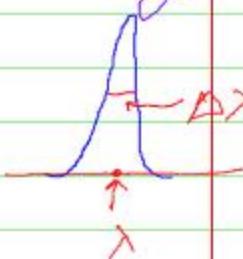
if $\phi_1 \neq \phi_2$ Then wave is said to be incoherent.

Spatial Coherence: If the phase difference between the two electric vectors remain zero for all times, then the two waves are said to have spatial coherence.

Monochromaticity:

If light Coming from a Source has only one frequency of oscillation, The light is said to be monochromatic and The source monochromatic.

Lasing Beams have a pure spectrum having a small spectral width $\Delta\lambda = 10^{-6}\text{ Å}$.



The spectral width is related to the coherence length of a given radiation ($L = c\tau$)

$$\Delta\lambda \sim \frac{\lambda^2}{L} = \frac{\lambda^2}{c^2\tau^2} = \frac{\Delta\theta}{\theta}$$

Angular divergence :

light from a laser diverges very little.

upto a certain distance, the beam shows a little spreading and remains in a bundle of parallel light rays.

The distance from the laser over which the light rays remain parallel is known as Rayleigh range. The laser beam diverges beyond the Rayleigh range.

The two parameters causes the divergence

- size of the beam waist
- and diffraction.

The divergence angle is measured from the centre of the beam to the edge of the beam.

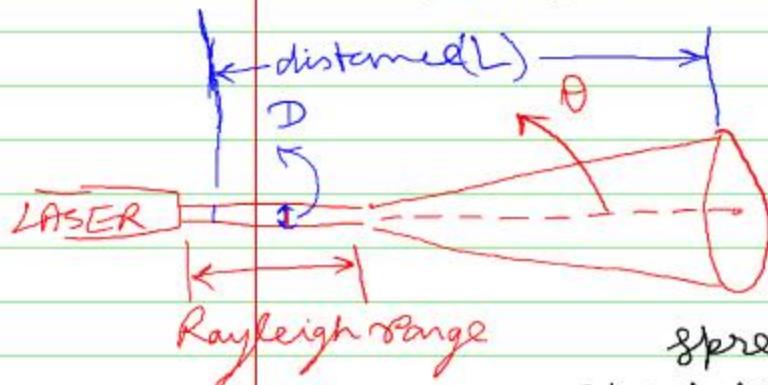
twice the angle of divergence is known as the full angle beam divergence.

$$2\theta = \frac{4\lambda}{\pi d_0}$$

$$\Delta\theta = \frac{\lambda}{D} \times 1.22 \frac{\lambda}{D}$$

$$d_0 = 2D$$

D - aperture of diameter



A laser beam of 5 cm diameter when focused from earth will have spread to a diameter only about 10 m on reaching the surface of the moon.

Focusing : The radius of the focused spot is given as follows

$$r = \frac{\lambda f}{a}$$

$$\Rightarrow A = \pi r^2 = \pi \left(\frac{\lambda f}{a} \right)^2$$

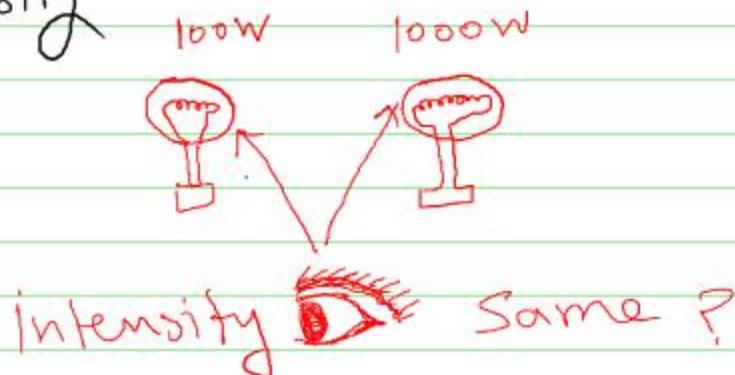
where λ is the wavelength of laser light

f is the focal length of the lens

a is the radius of the aperture

A is the area of the focused spot

Intensity :



The laser gives out light into a narrow beam and its energy is concentrated in a small region.

A one watt laser would appear many thousands time more intense than 100 W ordinary lamp.

The intensity of a laser beam is

$$\lambda = 6328 \times 10^{-10} \text{ m}$$

1 mw Laser

$$I = \left(\frac{10}{\lambda}\right)^2 P \quad \frac{\text{W}}{\text{m}^2}; P \text{ is the power radiated by the laser.}$$

$$I = \frac{100 \times 10^{-3} \text{ W}}{(6328 \times 10^{-10})^2 \text{ m}^2} = 2.5 \times 10^{11} \frac{\text{W}}{\text{m}^2}$$

Q: If the coherence length of sodium light is 2.9×10^2 m and its wavelength is 5890 Å. Then calculate the number of oscillations corresponding to coherence length and the corresponding coherence time.

Given

$$\lambda = 5890 \text{ Å} = 5890 \times 10^{-10} \text{ m}$$

$$l = 2.9 \times 10^2 \text{ m}$$

$$\text{The no. of oscillations } n = \frac{l}{\lambda}$$

$$n = \frac{2.9 \times 10^2}{2.890 \times 10^7} = 4.92 \times 10^{-4}$$

$$\text{Coherence time } T_c = \frac{l}{c} = \frac{2.9 \times 10^2 \text{ m}}{3.0 \times 10^8 \frac{\text{m}}{\text{s}}} = 9.667 \times 10^{-11} \text{ sec.}$$

Q8: A laser beam has a wavelength of $9 \times 10^{-7} \text{ m}$ and aperture $5 \times 10^{-3} \text{ m}$. The laser beam sent to moon. The distance of the moon is $4 \times 10^5 \text{ km}$ from the earth. Calculate

(a) The angular spread of the beam

(b) The area spread when it reaches the moon

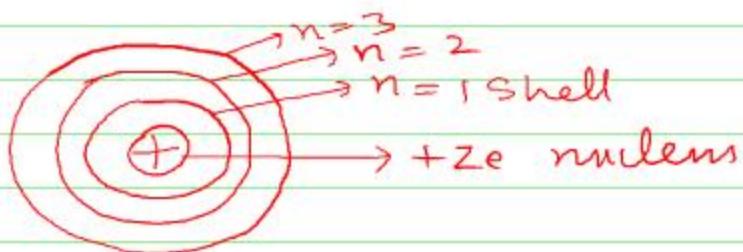
Given $\lambda = 9 \times 10^{-7} \text{ m}$; $a = 5 \times 10^{-3} \text{ m}$
and $d = 4 \times 10^5 \text{ km} = 4 \times 10^8 \text{ m}$

$$(a) \theta = \frac{\lambda}{a} = \frac{9 \times 10^{-7}}{5 \times 10^{-3}} = 1.8 \times 10^{-4} \text{ rad.}$$

(b) The area spread when it reaches the moon

$$\begin{aligned} &= (d \times \theta)^2 \\ &= (4 \times 10^8 \times 1.8 \times 10^{-4})^2 \\ &= 5.18 \times 10^9 \text{ m}^2 \end{aligned}$$

Atom
ajoniphysics.com



$$n=1$$

$$l=0$$

$$m_l=0$$

$$m_s=\pm \frac{1}{2}$$

$$l=0 \text{ to } n-1$$

\rightarrow s orbital \rightarrow no of electrons = 2

$l=1 \rightarrow p$ orbital \rightarrow no of e^- = 6

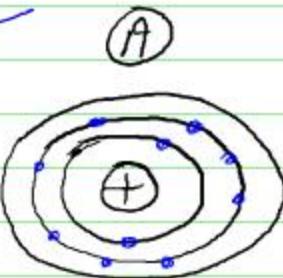
$l=2 \rightarrow d$ orbital \rightarrow no of e^- = 10

$l=3 \rightarrow f$ orbital \rightarrow no of e^- = 14

$Ne \rightarrow Z = 10 \rightarrow$ electronic configuration

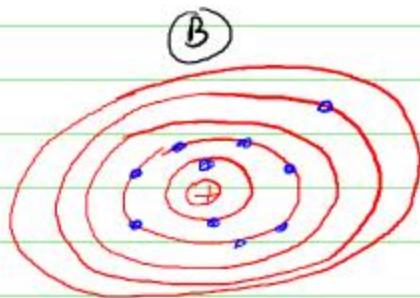
$$1s^2, 2s^2 2p^6$$

e^- are filled in all possible states as per the rule, first lower shell filled then higher



$\text{Ne} (Z=10)$

$1s^2, 2s^2 2p^6$



$1s^2, 2s^2 2p^5, 4d^1$



any difference?

yes!

Change in electronic
Configuration

(A) → Atom in ground state

(B) → Atom is in excited state

representation of Ground and excited states by lines

E_2 ←(Excited state)

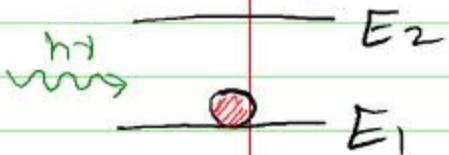
E_1 ←(Ground state)

E_2]
Atom is in ground
 E_1] state

E_2]
Atom is in excited
 E_1] state.

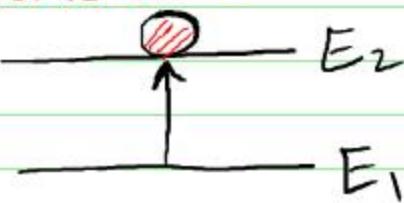
Absorption of Radiation

(aerophysics)



(before)

one photon
from external
source and
atom in ground
state



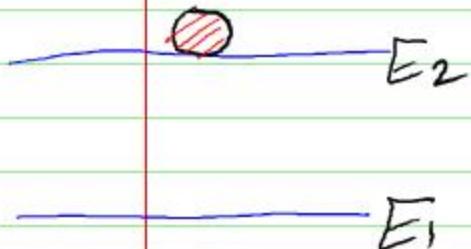
After absorbing the
photon, atom goes
into the excited state
and stay here upto
 10^{-8} sec.

$$E_1 + h\nu = E_2$$

$$E_2 - E_1 = h\nu$$

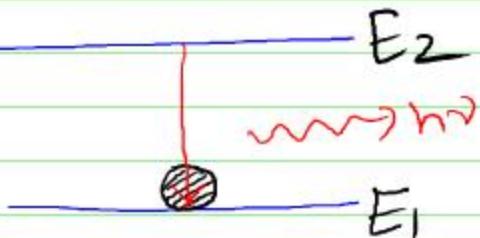
Note :
external source is
required for this
process.

Spontaneous emission:



(before)

atom is in excited state

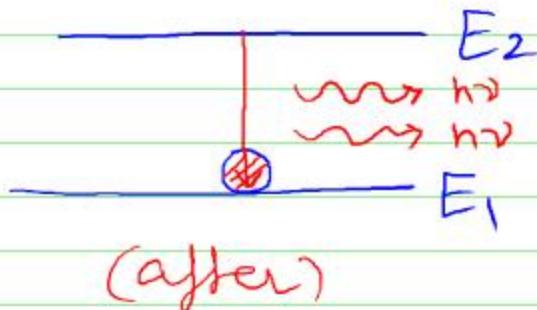
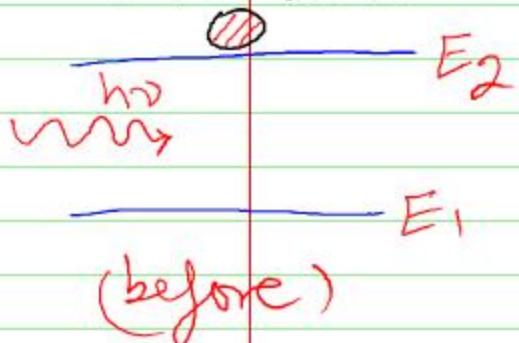
it stays here up to 10^{-8} secThen after jumps into
the ground state.(after 10^{-8} sec)emits a photon
Spontaneously in
random directions

$$E_2 - E_1 = h\nu$$

$$\nu = \frac{E_2 - E_1}{h}$$

h - Planck's Constant

Stimulated emission :-

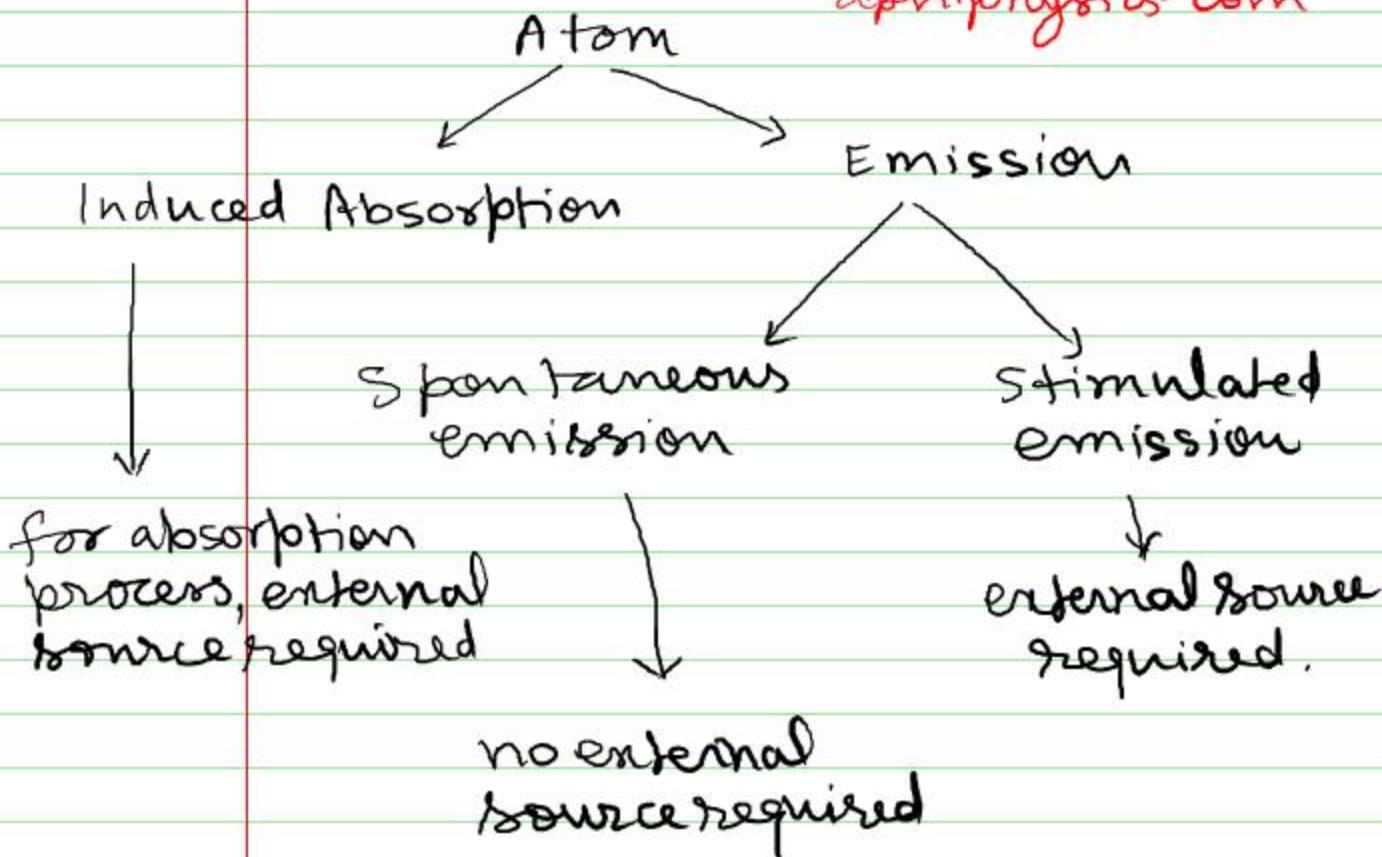


Atom is in excited state (lifetime of excited state = 10^{-8} sec)

during this period one photon interact with the atom, and as a result atom get induced and emits a photon of same frequency, in some direction

emission of 1 photon in same direction as of the incident photon, also in phase.

(external source required)



Transition probability :-

Absorption and Emission process explained by using only one atom practically it is not possible! we use bulk matter in which atoms are not countable by general methods. So we will apply our understanding to the assembly of atoms, where we use large no. of atoms.

So statistical concept will use.

We can approximate that This amount of no. of atoms are absorbing the energy, emitting spontaneously or by stimulated emission process. HOW?

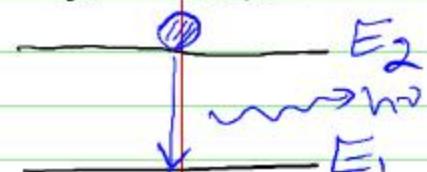
Absorption



$$P_{12} = u(\gamma) \beta_{12} \quad \text{--- (1)}$$

↑
Proportionality Constant

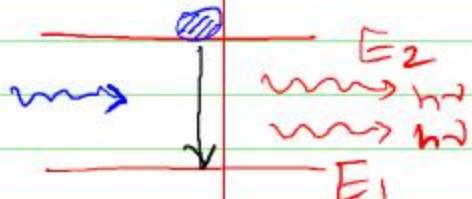
Spontaneous emission



$$P'_{21} = A_{21} \quad \text{--- (2)}$$

↓
Einstein's coefficient of
spontaneous emission of
radiation

Stimulated emission



$$P''_{21} = u(\gamma) \beta_{21} \quad \text{--- (3)}$$

$$P_{21} = P'_{21} + P''_{21} = A_{21} + u(\gamma) \beta_{21}$$

Relation Between Einstein's Coefficient:

Let N_1 and N_2 be the no. of atoms in ground and excited states respectively.

The Probability of transition for no. of atoms from state 1 to 2 per unit time is

$$N_1 P_{12} = N_1 U(\gamma) B_{12} \quad \text{--- (1)}$$

The total probability of transition for no. of atoms from state 2 to 1 is

$$N_2 P_{21} = N_2 [A_{21} + B_{21} U(\gamma)] \quad \text{--- (2)}$$

In Thermal equilibrium at temperature T, the absorption and emission probabilities are equal and thus

$$N_1 P_{12} = N_2 P_{21}$$

$$N_1 B_{12} u(\gamma) = N_2 A_{21} + N_2 B_{21} u(\gamma)$$

$$u(\gamma)(N_1 B_{12} - N_2 B_{21}) = N_2 A_{21}$$

or $u(\gamma) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$

$$u(\gamma) = \frac{\cancel{N_2} A_{21}}{\cancel{N_2} B_{21} \left(\frac{N_1}{N_2} \frac{B_{12}}{B_{21}} - 1 \right)}$$

$$u(\gamma) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{\left(\frac{N_1}{N_2} \cdot \frac{B_{12}}{B_{21}} - 1 \right)} \quad (3)$$

But $B_{12} = B_{21}$

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$$n(\gamma) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{\left(\frac{N_1}{N_2} - 1 \right)} \quad (4)$$

NOW, According to Boltzmann's law,
 The distribution of atoms among the energy
 states E_1 and E_2 at the Thermal equilibrium
 at temperature T is given by

$$N = N_0 e^{-E/kT}$$

$$\qquad \qquad \qquad - E_1/kT$$

for State-1

$$N_1 = N_0 e^{-E_1/kT}$$

for State-2

$$N_2 = N_0 e^{-E_2/kT}$$

Now

$$\frac{N_1}{N_2} = \frac{e^{-E_1/kT}}{e^{-E_2/kT}} = e^{E_2 - E_1 / kT}$$

$$\therefore E_2 - E_1 = h\nu \quad \therefore \frac{N_1}{N_2} = e^{h\nu/kT}$$

(5)

Here k is the Boltzmann constant.
so putting this value of N_1 in
above eqⁿ.

$$U(\gamma) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{e^{\frac{hv}{kT}} - 1} \quad \text{--- (6)}$$

Using Planck's radiation formula

$$U(\gamma) = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{\frac{hv}{kT}} - 1} \quad \text{--- (7)}$$

Comparing (6) & (7) we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

$\{ \theta, \pi, h, c \rightarrow \text{constant} \}$

$$\boxed{\frac{A_{21}}{B_{21}} \propto \nu^3} \quad \text{--- (8)}$$

$$\gamma = \frac{E_2 - E_1}{h} = \frac{\Delta E}{h}$$

$\nu \propto \Delta E$

Spontaneous emission $\leftarrow \frac{A_{21}}{B_{21}} \propto (\Delta E)^3$

Stimulated emission $\leftarrow \frac{B_{21}}{A_{21}}$

for LASER action stimulated emission dominates over the spontaneous emission.
it means $B_{21} > A_{21}$ and it will be

possible only when $(\Delta E)^3$ is small i.e. further it means $\Delta E = E_2 - E_1$ should be reasonably small.

(applied physics)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h^2 r^3}{c^3}$$

$$\text{or } A_{21} = \left(\frac{8\pi h^2 r^3}{c^3} \right) B_{21}$$

$$\underline{A_{21} > B_{21}} \quad \text{in general}$$

Population Inversion:

Usually the no of atoms in the lower energy states is more than that in the excited state. According to Boltzmann the ratio of atoms in the energy state 2 and 1 at Temperature T is

$$N = N_0 e^{-E/kT}$$

for E_1

$$N_1 = N_0 e^{-E_1/kT}$$

E_2

$$N_2 = N_0 e^{-E_2/kT}$$

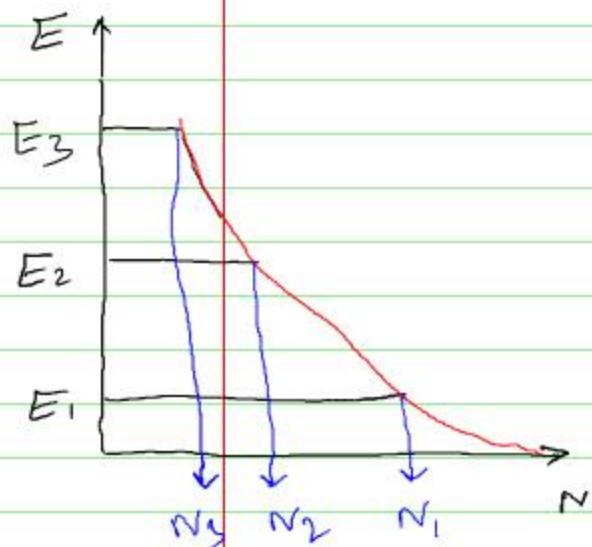
The ratio $\frac{N_2}{N_1} = \frac{N_0 e^{-E_2/kT}}{N_0 e^{-E_1/kT}} = e^{-(E_2 - E_1)/kT}$

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

$$E_2 - E_1 = h\nu$$

$$\gamma = \frac{E_2 - E_1}{h}$$

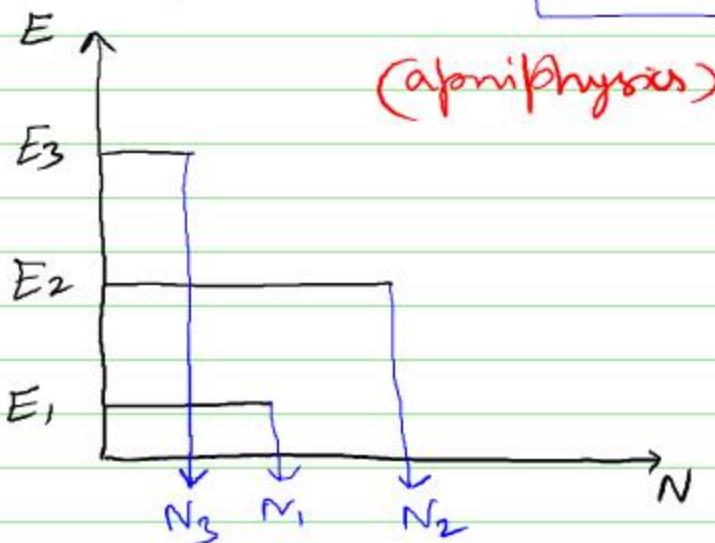
$$\frac{N_2}{N_1} = e^{-(E_2 - E_1)/kT} = \frac{1}{e^{(E_2 - E_1)/kT}} \Rightarrow \boxed{E_2 > E_1 \\ N_2 < N_1}$$



$E_3 > E_2 > E_1$;

$N_1 > N_2 > N_3$;

(In general)



(Population inversion)

$E_3 > E_2 > E_1$;

$N_2 > N_1$

for two states.

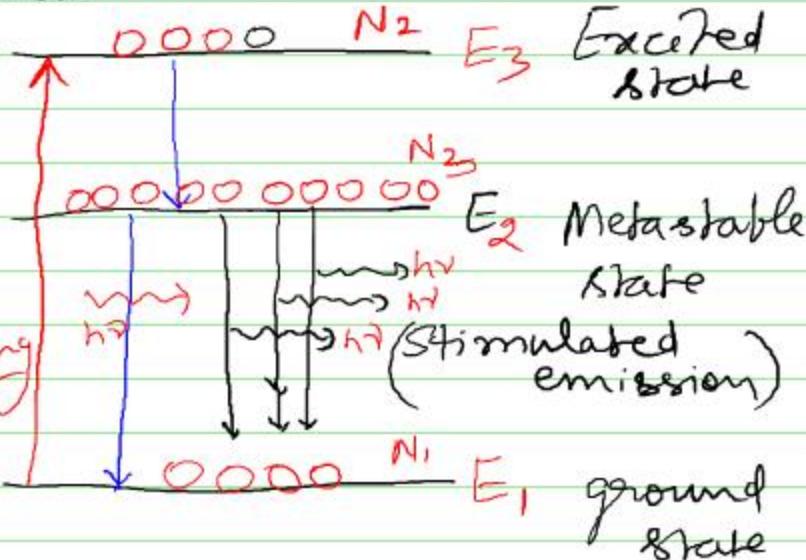
Three energy levels

(abnormal physics)

Life time 10^{-8} sec.

Life time 10^{-3} sec.
(metastable state)

pumping



Population inversion between $E_2 \leftrightarrow E_1$!

$$N_2 > N_1$$

Principle of Laser:

An atomic system having one or two meta-stable states is chosen.

Normally, the number of atoms in the lower energy state is greater than that in the meta-stable state.

This population is inverted by a technique known as optical pumping. It is made induced absorption of incident photons of suitable frequency.

The atoms are made to fall from meta-stable state to lower energy state and photons are emitted by stimulated emission.

The photons are reflected back and forth in the active medium to excite the other atoms.

Thus a large number of photons are emitted simultaneously which possess the same energy, phase and direction. This process is called 'amplification of light'.

To produce laser beam, the following two conditions must be fulfilled:

1. The meta-stable state should all the time have larger number of atoms than the number of atoms in lower energy state.
2. The photons emitted due to stimulated emission should stimulate other atoms to multiply the photons in the active medium.

We have seen $N_1 > N_2$; $E_2 > E_1$

$N_1 \rightarrow$ no of atoms in ground state

$N_2 \rightarrow$ no of atoms in excited state

E_2 & E_1 are the excited and ground states respectively.

② Also observe that spontaneous emission dominates over the stimulated emission

$$A_{21} = \frac{B_{21} h \nu^3}{c^3} B_{21}$$

here $A_{21} > B_{21}$

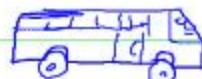
③ So what is the method from which one can obtain stimulated emission?

To explain it consider one example

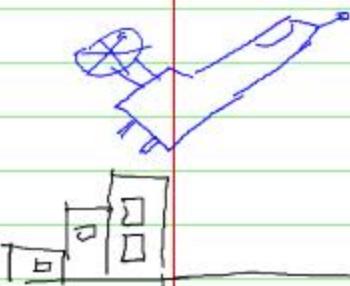
You have some work at New Delhi and from Chandigarh you take flight and reach there. You finished your work and ready to return but due to some reason flight missed now you approach to bus service and take tickets. You starts your travel for Chandigarh but after some time bus stops at Kamal bus stand for refreshment of passenger, and here you stay longer as compared to take the bus seat in New Delhi. After that your bus starts for Chandigarh and you reach safely at your place from where you start the journey.

algebraicphysics.com

New Delhi (5 min stay)



Bus



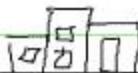
Airport

direct

Chandigarh

Bus stand

(30 min stay)
Karnal



You directly go New Delhi by airplane; Come back by bus
Stay 30 min at Karnal longer time compare to take beat (5 min)
at New Delhi. This is equivalent to

Airplane \rightarrow pumping process to pump atoms from G.s to E.S.

New Delhi Bus terminal \Rightarrow Excited state (10^{-8} sec life time)

Karnal bus stand \Rightarrow Metastable state (10^{-3} sec life time)
and Chandigarh \Rightarrow Ground state.

Three energy levels

(apniphysics.com)

①

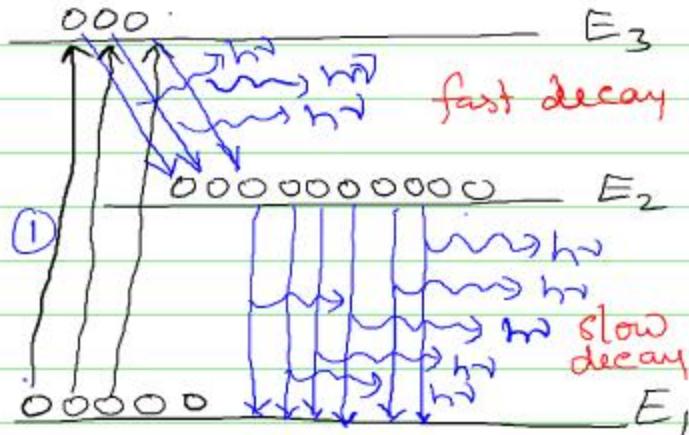
Transition by absorption
from E_1 to E_3

② Emission

→ Spontaneous emission from $E_3 - E_2$
→ Stimulated emission from $E_2 - E_1$

③ N_2 No. of atoms in E_2 are greater than N_1 , no. of atoms in ground state.

(Ruby laser is Three energy levels laser)



What is slow and fast transition?

You know in spontaneous emission

case life time of excited state is small

i.e. 10^{-8} sec. So atom immediately jumps to the ground state so this transition will be fast. While in stimulated emission the life time of excited state is large that is why transition will be slow.

[Transition rate depends upon the life time of higher energy states i.e. excited state and metastable state]

Three components of laser action

1. **The Pump:** It is an external source which supplies energy to obtain population inversion. The pump can be optical, electrical or thermal. In Ruby Laser, we use optical pumping and in He - Ne Laser, we use electric discharge pumping.
2. **The Laser Medium:** It is material in which the laser action is made to take place. It may be solid, liquid or gas. The very important characteristic requirement for the medium is that optical inversion should be possible in it.
3. **The Resonator:** It consists of a pair of plane or spherical mirrors having common principal axis. The reflection coefficient of one of the mirrors is very near to 1 and that of the other is kept less than 1. The resonator is basically a feed-back device, that directs the photons back and forth through the laser medium.

1. Optical Pumping: (apniphysics.com)

If luminous energy is supplied to medium for causing population inversion (light source in the form of short flashes of light; Ruby Laser)

2. Electric discharge

In discharge tube when a potential difference is applied between cathode and anode; accelerated electrons emits towards anode (gaseous-ion laser).

3. Inelastic atom-atom collision:

In electric discharge one type of atoms are raised to their excited states. These atoms collide in- elastically with another type of atoms (He-Ne Laser).

4. Direct Conversion:

A direct conversion of electrical energy into radiant energy occurs as in LED's. (Semiconductor Laser)

5. Chemical reaction

Energy comes from chemical reaction without any other external source.
(CO₂ laser)

Ruby Laser:

(apniphysics.com)

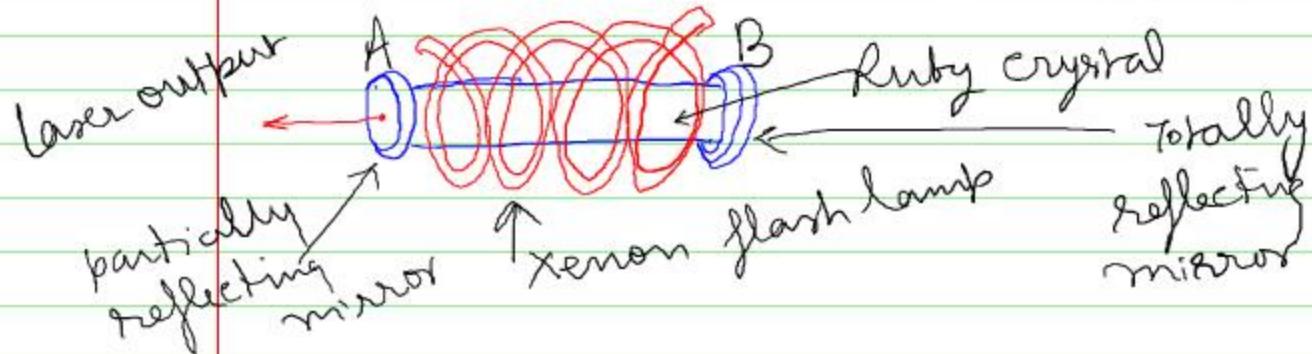
Introduction: Ruby laser is a solid laser in which bulk material is Al_2O_3 which does not participate in the laser action. The active material present in concentration less than one percent. for the laser action the ions of the active material are supposed to be excited at proper level, and this is possible only by optical pumping process.

The first laser action was achieved by Maiman in 1960 using a crystal of Ruby as a laser material.

Contd. Ruby is crystalline Al_2O_3

doped with chromium. The triply ionized Cr ions (Cr^{+++}) which replace some of the Al^{+++} ions, give the pink and red color depending upon its concentration. There are two main pump bands, $4F_1$ and $4F_2$ centred around $0.42 \mu\text{m}$ and $0.55 \mu\text{m}$ respectively.

Construction: The ruby was in the form of a cylinder 4 cm in length and 0.5 cm in diameter. Its end were ground and polished plane and parallel. One end was silvered to give a completely reflecting surface. A helical flash lamp filled with xenon gas for pumping purpose used from which white light in the form of pulse absorbed by ruby crystal.



Cavity

The space between the two faces A and B is known as the resonant cavity in which the light intensity can be built by the multiple reflections and through stimulated emission.

Working Principle :

In this laser Chromium ions are active centres which are responsible for the laser transition. The ruby laser fits in three-level scheme. When the ruby rod is irradiated with an intense burst of white light from the xenon lamp, then ground state Cr^{3+} ions absorb light in two pump bands one at 550Å (Green colour) and second 600Å (Blue colour) and as a result get excited into the upper band. The life times of the excited states are small (10^{-9} sec),

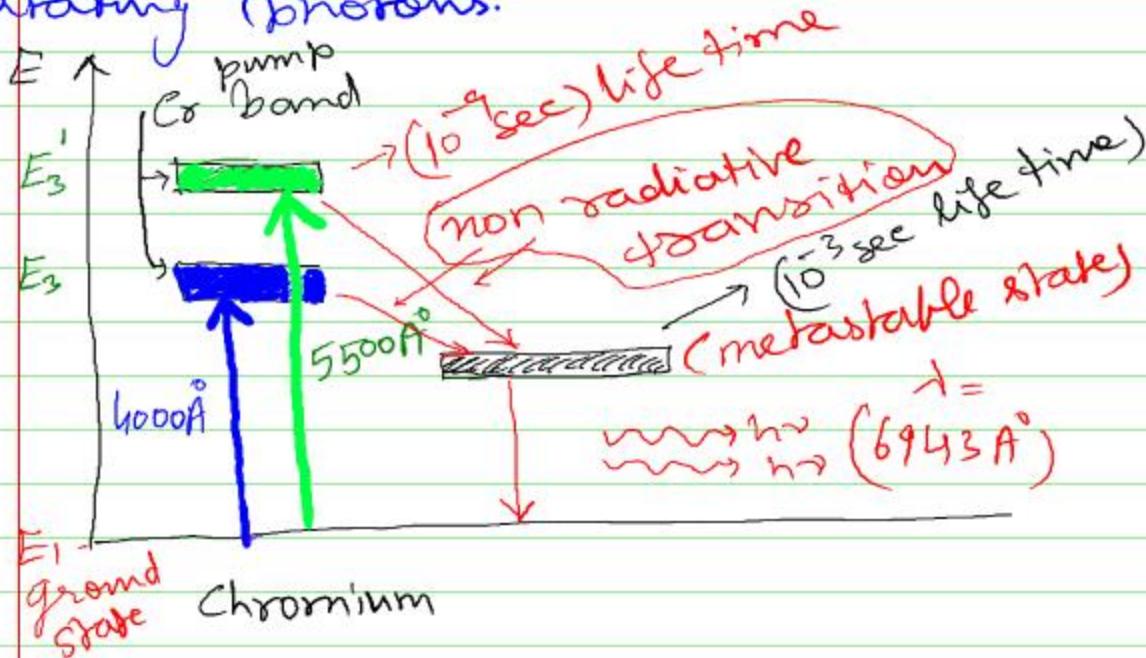
Hence the excited Cr^{+++} ions rapidly loose partially their energy to the crystal lattice and goes into the metastable states. The lifetime of these states are 3×10^{-3} sec. The transition from metastable states to the ground state are result of a red color light of 6943\AA .

As you know in metastable state ions goes on increasing while at the same time no of ions in the ground state goes on decreasing due to the optical pumping. Thus the population inversion is established between these two states (metastable and ground states).

first when an excited ion emits a photon spontaneously from the metastable state to the ground state. It travels parallel to the axis of ruby rod and stimulate the surrounding ions present in the metastable state.

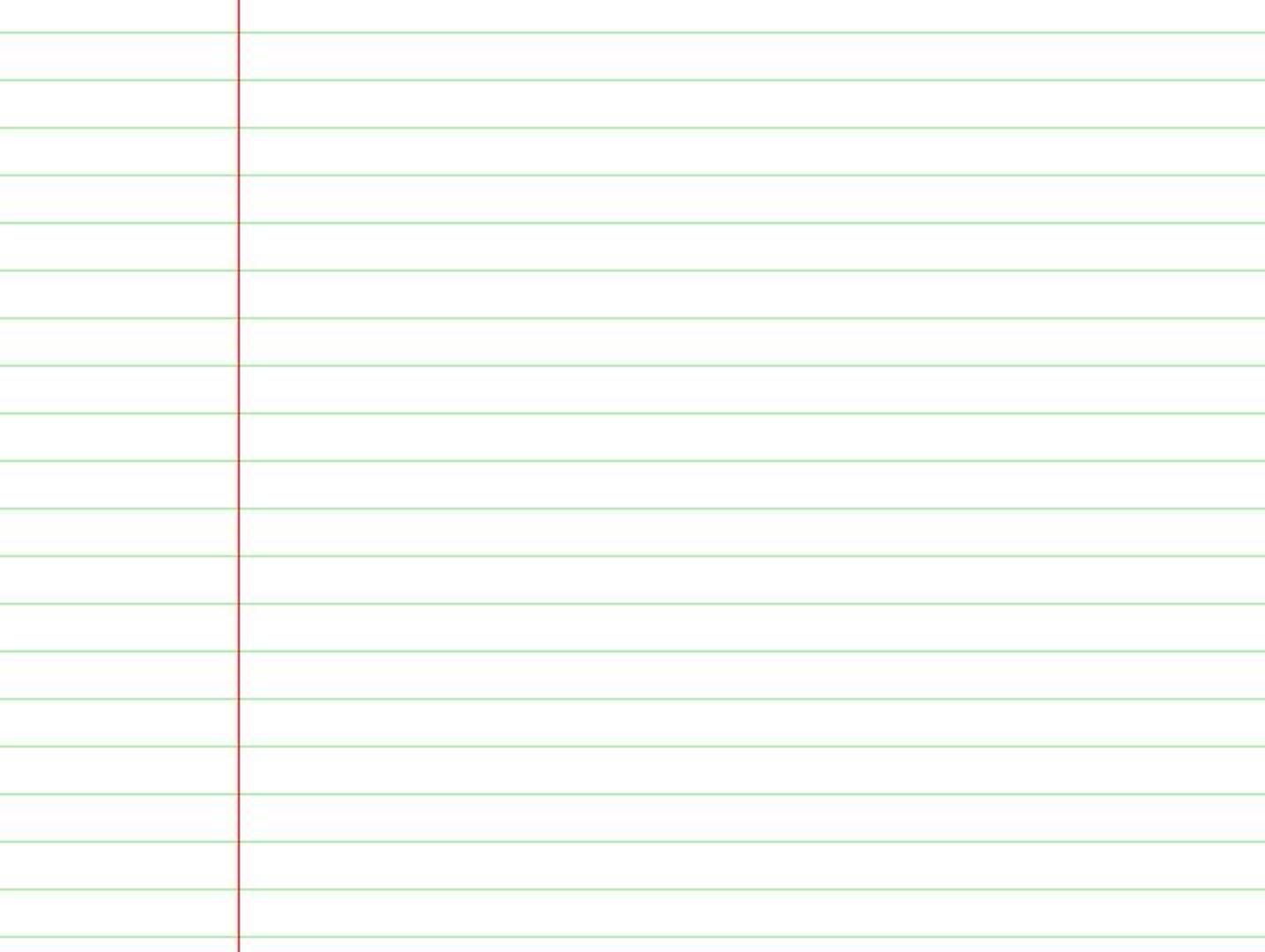
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further by stimulated emission other photons are emitted which remains in the phase with stimulating photons.



The ruby laser operates at about 1% efficiency. It may produce a laser beam of 1mm to 25 mm. in diameter.

In last — The Beam from ruby laser obtained is in the form of Pulse. on the other side the beam we can obtain as strong as 10,000W. the construction of this laser is simple and operation is easy. The most important use of this laser is in holography.



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He-Ne gas Laser

Introduction

The gas laser operates with rare gases as their active media and excited by an electric discharge. In gases, unlike in crystals, the energy levels of atoms involved in the lasing process are well defined and narrow. In order to excite atoms source with sharp wavelength are required. Optical pumping is not used in gases laser. The most common method of exciting gas laser medium is by passing an electric discharge through the gas. electrons are responsible for transferring the energy.

The first gas laser was He-Ne laser which was demonstrated in 1961 at Bell Telephone Laboratory USA by Javan, Bennett and Herriott.

In this laser system, a quartz tube is filled with a mixture of helium and neon gases in the ratio 10:1 respectively at a pressure of about 0.1 mm of mercury. The mixture acts as the active medium. Helium is pumped up to the excited state of 20.6 eV by the electric discharge.

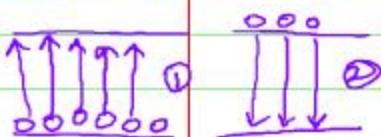
What principle used?

Suppose atoms of a kind A are excited in a discharge tube by this method, to a metastable state. If suppose discharge tube also contains atoms of other kind B, whose excited states lies very close to that of the metastable state of A,

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A resonant energy transfer to the atoms B and as a result they transit into excited state.

If the transfer of excitation rate is larger than the radiative decay of excited state, (see the picture) the population of

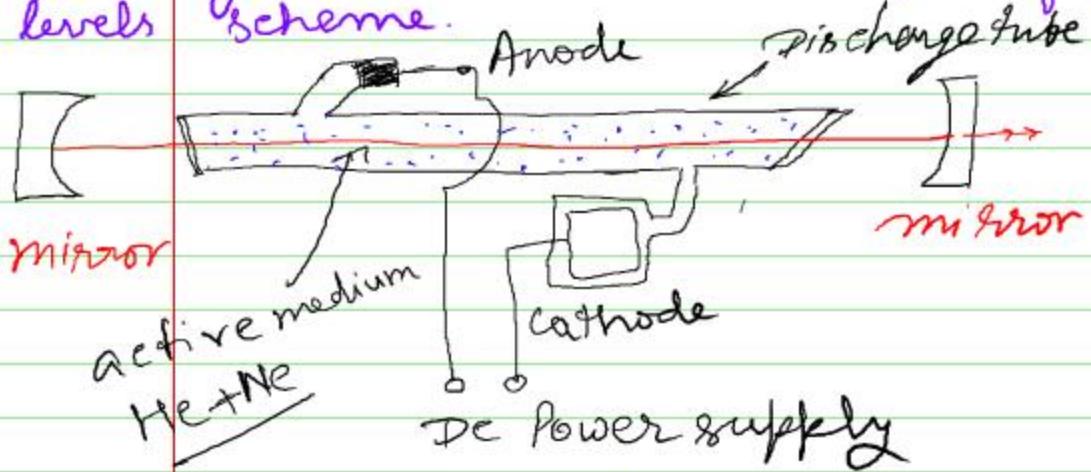


The excited state of the atom B will steadily increase and the state will be ∞ populated.

Hence an inversion of population achieved which is useful for laser action.

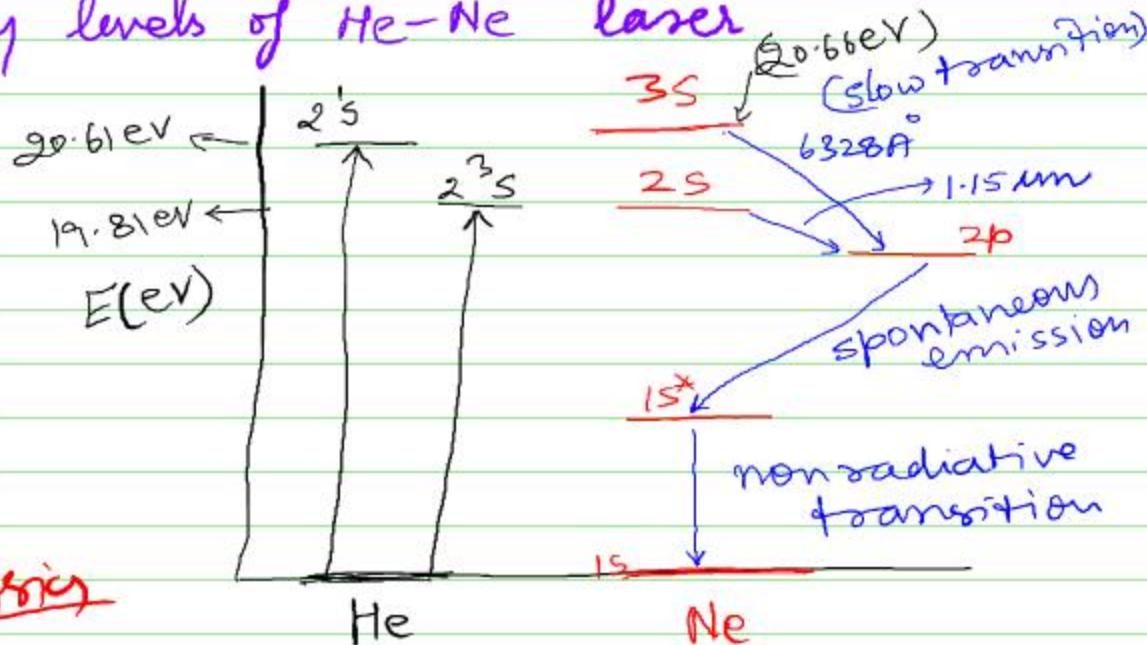
(apri physico)

(apni physics)
He-Ne gas laser is an example of four levels scheme.



As you know that He gas atoms are more as compared to Ne gas, which is required for the Ne atoms to be excited. He atoms get excited by the electric discharge method and further these atoms collide with the Ne atoms and transfer their energy to raising them in higher energy state.

Energy levels of He-Ne laser



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① $e^- + He \rightarrow He^*$ (singlet and triplet are (20.61 eV) two different states
 1^1S and 3^1S)

② $He^* + Ne \rightarrow Ne^*$ (20.66 eV)
 (E.S.) (G.S.) (E.S.)

Working : The energy level schemes of

helium and neon are shown. When the power is switched on, a high voltage of about 10 KV is applied across the gas. It is sufficient to ionize the gas. The electrons and ions produced in the process of discharge are accelerated towards the anode and cathode respectively.

applied physics

Since the electrons have smaller mass, they acquire a higher velocity. They transfer their kinetic energy to the He atoms through inelastic collisions. He atoms are much more readily excited by electron impact because of they are light. As a result He atoms goes in two different state either in singlet (19.81 eV) or triplet (20.61 eV) excited states.

These two levels (states) are metastable levels and the excited Helium atoms can not return to the ground state through spontaneous emission. The only way they have ⁱⁿ transfer of their energy to ground state Ne atoms.

by Collision. Such an energy transfer can take place when the two colliding atoms have identical energy states. It is called resonant transfer of energy.

(autophysics)

The two energy levels of Neon one at 20.66 eV and second at 18.70 eV nearly coincide with the He atoms triplet and singlet states respectively.

NOTE: The Ne atoms require an energy of 20.66 eV for excitation while the excited He atoms have only 20.61 eV; the diff of energy i.e. 0.05 eV is being provided by the kinetic energy of He atoms.

When a helium atom in the metastable state collides with a Ne atom in the ground state, the neon atom as a result gets excited and the helium atom drops back to the ground state. This process takes place due to electric discharge method and known as pumping mechanism in He-Ne laser.

The sole of He atoms is to excite neon atoms and cause population inversion. The probability of energy transfer from helium atoms to neon atoms is more as there are 10 atoms of helium per 1 neon atom in the gas mixture.

atomic physics

In the energy level diagram $3s$ and $2s$ states are metastable states. The Ne atoms will stay here longer and population inversion takes place between $3s \rightarrow 2p$ and $2s \rightarrow 2p$. Lasing action takes place now and light produced corresponding to the following transitions

$3s \rightarrow 2p$ transition \rightarrow Laser beam red
Colour, $\lambda = 6328 \text{ Å}^\circ$

$2s \rightarrow 2p$ transition \rightarrow Infra red light
 $\lambda = 11500 \text{ Å}^\circ$

$2p \rightarrow 1s^*$ ($1s^*$ is not ground state, this is just above ground state)
transition \rightarrow Spontaneous emission ($\sim 6000 \text{ Å}^\circ$)

$1s^*$ \rightarrow $1s$ transition \rightarrow radiationless
transition \rightarrow deexcitation
of Ne atoms by collision with walls.

both $1s^*$ and $1s$ are ground state but
 $1s^*$ is just above the ground state.

Application: less expensive, highly collimated
Coherent and monochromatic in nature.
Widely used in laboratories as a mono
chromatic source, in interferometry, laser
printing, bar code reading etc.

Semi Conductor Laser

A semi conductor laser is a specially fabricated p-n junction device that emits coherent light when it is forward biased.

Semiconductor laser have almost the same features as found in the solid state lasers, except one major difference that in the solid state lasers only 1% of the active material participants in the process of laser action while in semiconductor lasers, the whole material is active.

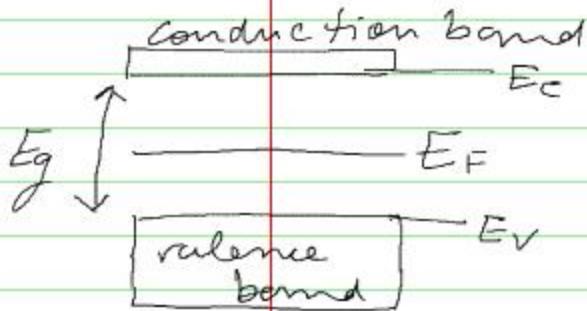
following conditions are essential for the semi conductor laser :-

- 1) The semi conductor must have a very high transition probability between the conduction and the valence band.

2) The excess population can be maintained across the laser transition.

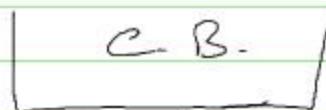
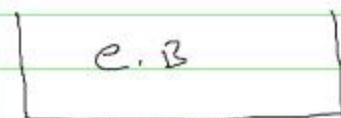
The first semiconductor laser was made by R. N. Hall and co-workers in USA, yr 1962. In this laser gallium arsenide (GraAs) is used, which is usually operated at low temperature and emits laser light close to IR. Diode lasers are remarkable due to their small size (0.1 mm long) and high efficiency of the order of 10%. Due to the rapid advances in the semiconductor technology, semiconductor lasers have a variety of applications in optical fibre communications, in CD audio players, CD-Rom drives, optical reading and high speed laser printing, etc.

apniphys



Fermi energy E_F
energy gap between
valence and Conduction
band $E_g = h\nu = E_c - E_v$

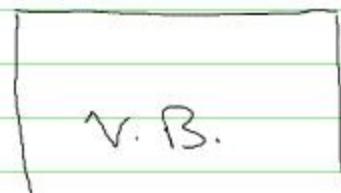
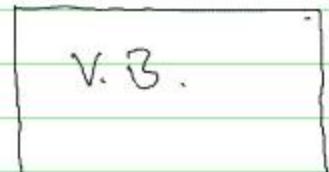
donor impurity



E_{Fn}

Fermi-energy
level

E_{Fp}



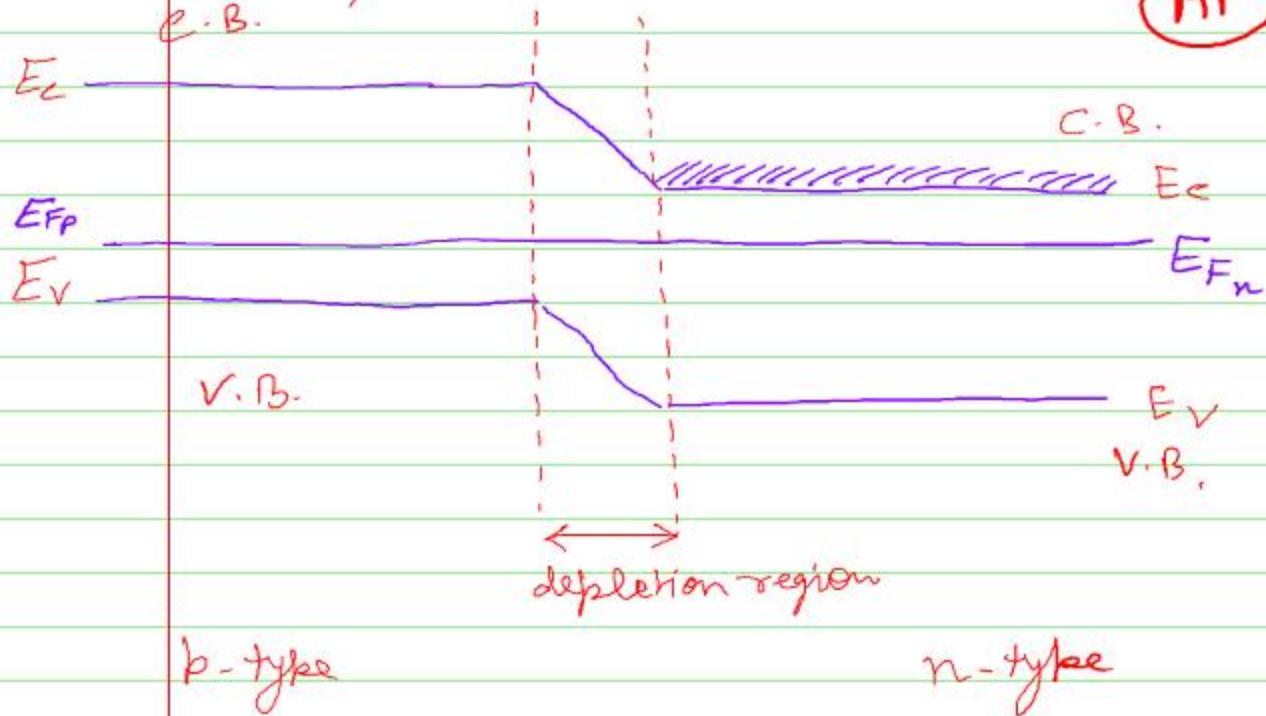
p-type

n-type

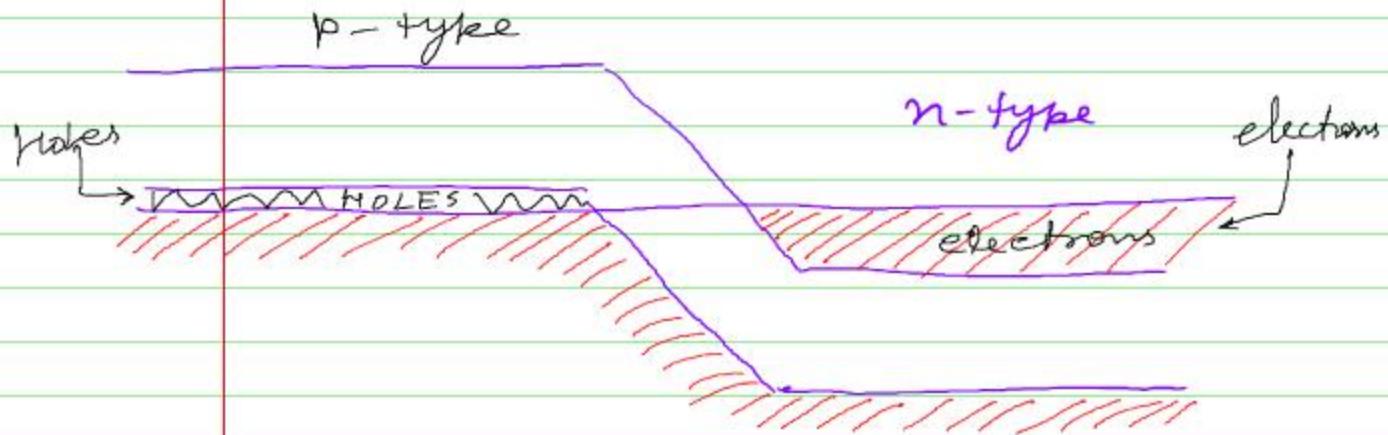
(fig. 1)

Energy Band diagram of a pn junction in equilibrium:-

(AP)



(fig 2.)



energy band diagram of a heavily doped p-n junction in equilibrium.

(fig. 3)

AP

Let us see how Fermi Energy level displace from one position to the other in -p and n-type semiconductor material.

You have considered here highly doped pn-junction. The following events occur in the course of the equalization of Fermi-levels, which is different in n and p type semiconductors.

position

(See the figure one in semiconductor laser)

AP

1. The electrons are larger in number (majority charge carriers) on n-side and smaller (minority) on p-side. Similarly holes are larger in number on p-side and smaller on n-side.

Thus, There is a concentration gradient for majority carriers across the junction. Hence they tend to diffuse across the junction.

2. The electrons and holes diffuse in opposite directions and recombine in the vicinity of junction. Therefore, a narrow region around the junction is left with only immobile impurity atoms and neutral host atoms.
3. The immobile ions are negative on the p-side and positive on n-side. These layers of opposite charges create a potential barrier for the diffusion of majority charge carriers

The mutual displacement of the energy levels on both sides of the junction causes a bending of the energy bands around the junction region.

When the doping levels are very high, the Fermi level in p-type region will be below the valence band edge and will be above the conduction band.

(See fig. 3)

aniphotysis

The probability of stimulated emission event occurring is low because there must be a region of the device where a large number of conduction electrons and a large number of holes would be simultaneously present. In thermal equilibrium there is no scope of it.

However, when the junction is forward biased with a large enough voltage, electrons and holes injected into the junction region. In other words carriers are pumped by the DC source. As a result the depletion region contains a large concentration of electrons with in the conduction band and a large concentration of holes in the valence band. This is the condition of population inversion. The electrons and holes recombine in the active region emitting photons.

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Working :— A pn-junction formed from very heavily doped p- and n-type materials provide the active medium. When forward bias is applied to the junction diode, the bias current performs the role of pumping agent.

As a result of forward bias, electrons and holes are injected into the junction region. At low forward current level, electron-hole recombination causes spontaneous emission of photons and the junction acts as a light-emitting diode.

When the current reaches a threshold value, the carrier concentrations reaches very high values within the depletion region and the state of population inversion is established.

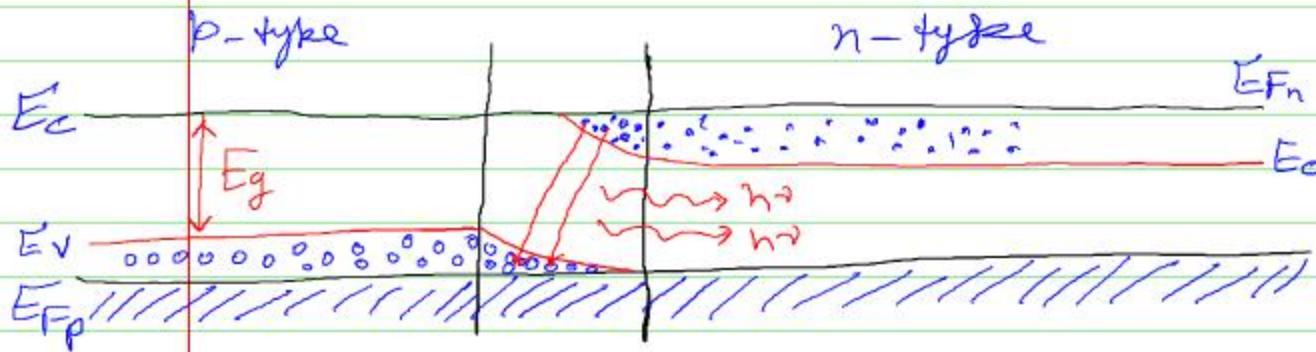
There is simultaneously a large concentration of electrons within the conduction band and a large concentration of holes within the valence band of the active region.

optipraxis

The spontaneous photons propagating in the junction plane induce the conduction electrons to jump into the holes of valence band. These stimulated electron-hole recombinations cause emission of coherent radiation.

applied physics

The stimulated emission is confined to a particular direction by the reflective surfaces formed perpendicular to the junction.



The Grafts laser emits a light of wavelength 9000 \AA° in Infra Red region while a Graftsp laser radiates at 6500 \AA° in the visible red region. Diode lasers are less monochromatic and highly temperature sensitive.

amorphous

Applications of He-Ne laser

~~apniphysics~~

- He-Ne lasers have many **industrial** and **scientific** uses.
- He Ne lasers are often used in laboratory **demonstrations of optics**.
- The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.
- Measuring distances



Applications

- A consumer application of the red He-Ne laser is the Laser Disc player, made by Pioneer. The laser is used in the device to read the optical disk.
- guided “smart” weapons
- The He- Ne Laser is used in Holography in producing the 3D images of objects.



APPLICATIONS OF LASERS

- In Communication
- Industrial Applications
- Medical Applications
- Military Applications
- In Computers
- In thermonuclear fusion
- In Scientific Research
- Entertainment
- Holography

applied physics

Applications of Laser Light:

1. The smallest lasers used for telephone communication over optical fibres have as their active medium a semiconducting gallium arsenide crystal about the size of the pin-head.
2. The lasers are used for laser fusion research. They can generate pulses of laser light of 10^{-10} s duration which have a power level of 10^{14} W.
3. It is used for drilling tiny holes in diamonds for drawing fine wires.
4. It is used in precision surveying.
5. It is used for cutting cloth (50 layers at a time, with no frayed edges).
6. It is used in precise fluid-flow velocity measurements using the Doppler effect.
7. It is used for precise length measurements by interferometry.
8. It is used in the generation of holograms.
9. It is used to measure the x, y and z co-ordinates of a point by laser interference techniques with a precision of $\pm 2 \times 10^{-8}$ m. It is used in measuring the dimensions of special three-dimensional gauges which, in turn are used to check the dimensional accuracy of machine parts.
10. Medical applications: It has been used successfully in the treatment of detached retinas and cancer. A single pulse of laser beam of duration of a thousandth of a second only is needed for welding the retina.

Holography

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- The method of producing the 3-dimensional image of an object due to the interference phenomena of coherent light waves on a photographic plate is known as holography.
- The idea of holography was first developed by Dennis Gabor in 1948. The invention of laser during 1960 enhanced research in this field. abniphysics.com
- When an object is photographed by a camera, a 2-dimensional image of 3-dimensional object is obtained. Here only the amplitude of the light wave is recorded on the photographic film. In holography, both the phase and the amplitude of the light waves are recorded in the film. The resulting photograph is called hologram. In Greek, 'holo' means whole and 'graphy' means writing. So holography stands for whole writing.
- The recorded hologram has no resemblance to the original object. It has in it a coded form of information of the object. The image is reproduced by a process called reconstruction

Comparison

Photography

- A conventional photography is a 2-D image of a 3-D scene
- A conventional photograph lacks the perception of the depth or the parallax with which we view a real life scene. Since a conventional photograph only records the intensity pattern, 3-D character of the object scene is lost.

Holography

- Holography represents a photographic process in a broad sense, but essentially it differs from a usual photo, as the phase of light wave scattered by the object carries the complete information about 3-D structure of the object.
- Hologram contains depth and parallax, which provides the ability to see around the object placed behind.

~~amplification~~

Photography

Comparison

Holography

- The intensity variations are recorded on the photographic plate while the phase distribution prevailing at the plane of the photographic plate is completely lost.
- In conventional photography, there is one to one relationship between object and image point as the light originating from a particular point of scene is collected by a lens focused on that particular point.
- It gives information about amplitude as well as the phase of an object. So hologram preserve information about the object for later observation.
- Hologram received light from every point of a scene and hence there is no one to one relationship. This is a record of entire signal wave.

Photography

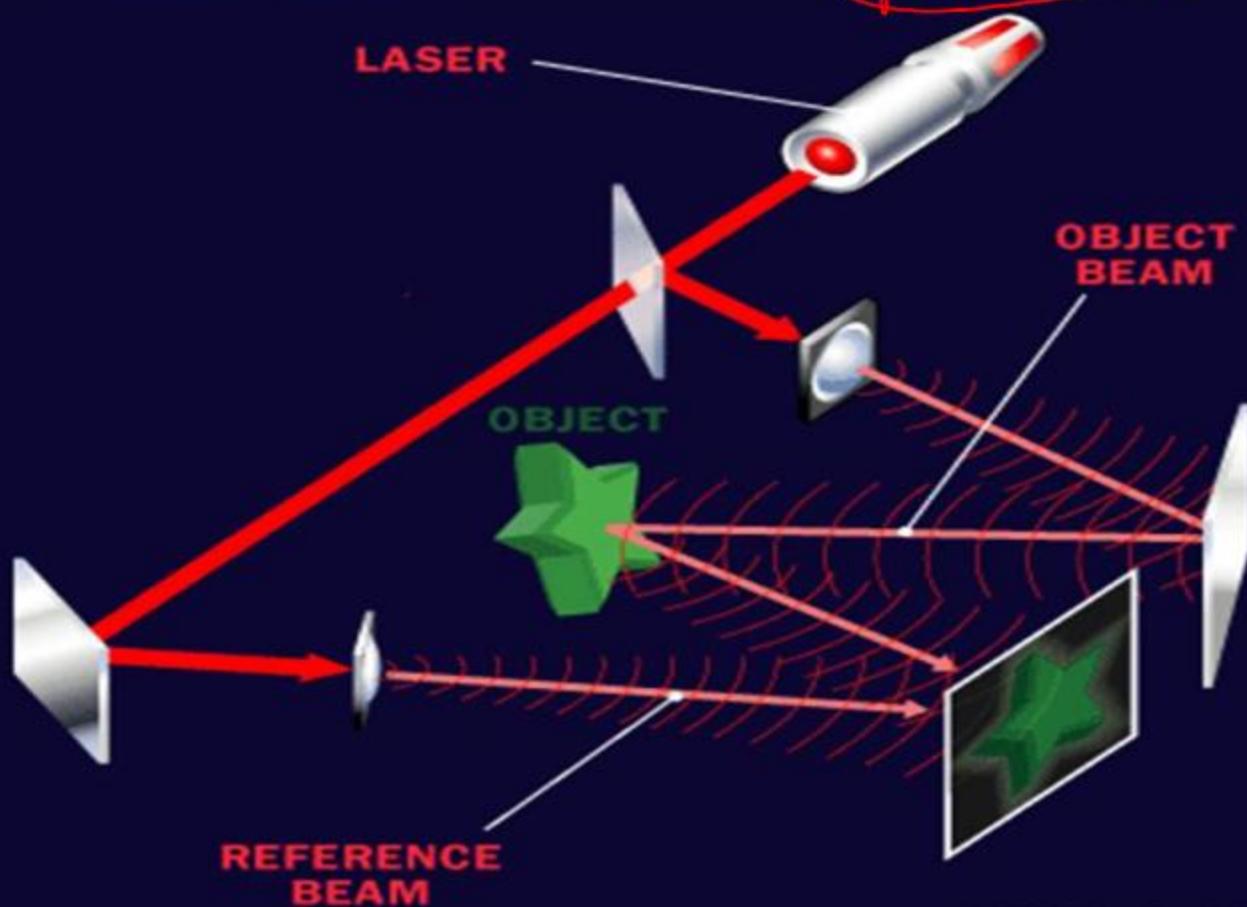
Holography

- Two dimensional (2-D) image of a three dimensional (3-D) object
- The quality of depth is missing
- Each region contains separate and individual part of the original object.
- In conventional photography, radiated energy is recorded and phase relationship of wave arriving from different distances and direction is lost.
- Ordinary light can be used for recording
- It is based on lens systems
- A 6×9 mm photograph can hold one printed page only

- Three dimensional (3-D) image of an object
- It provides depth perception also
- Each part contain information about the entire object.
- In holography phase relationship is recorded by using technique of interference of light waves.
- Only laser beam should be used for recording (or) constructing a hologram
- It is a lensless systems
- A 6×9 mm hologram can store up to 300 such pages.

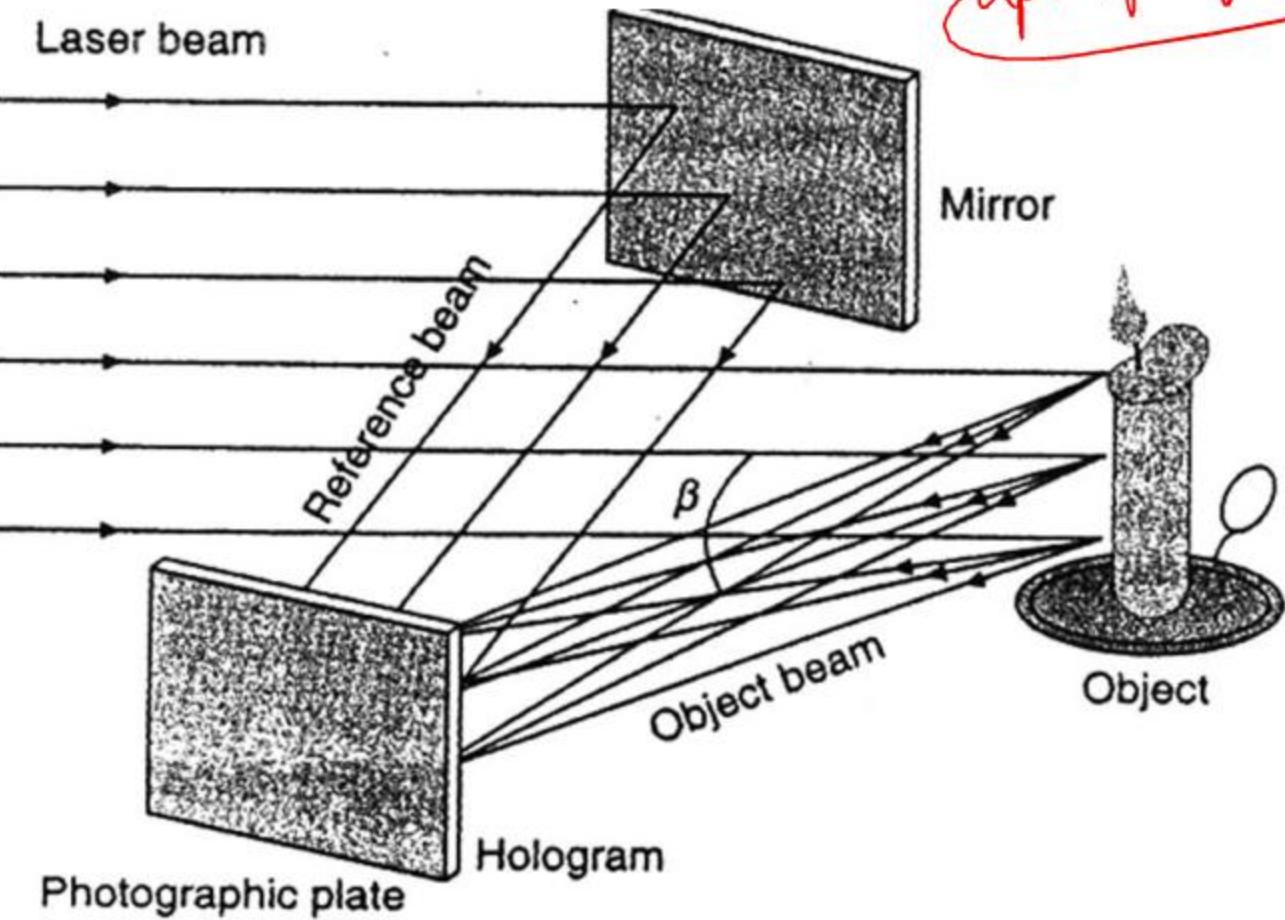
How Holograms Work Basic Setup

atmphy87120

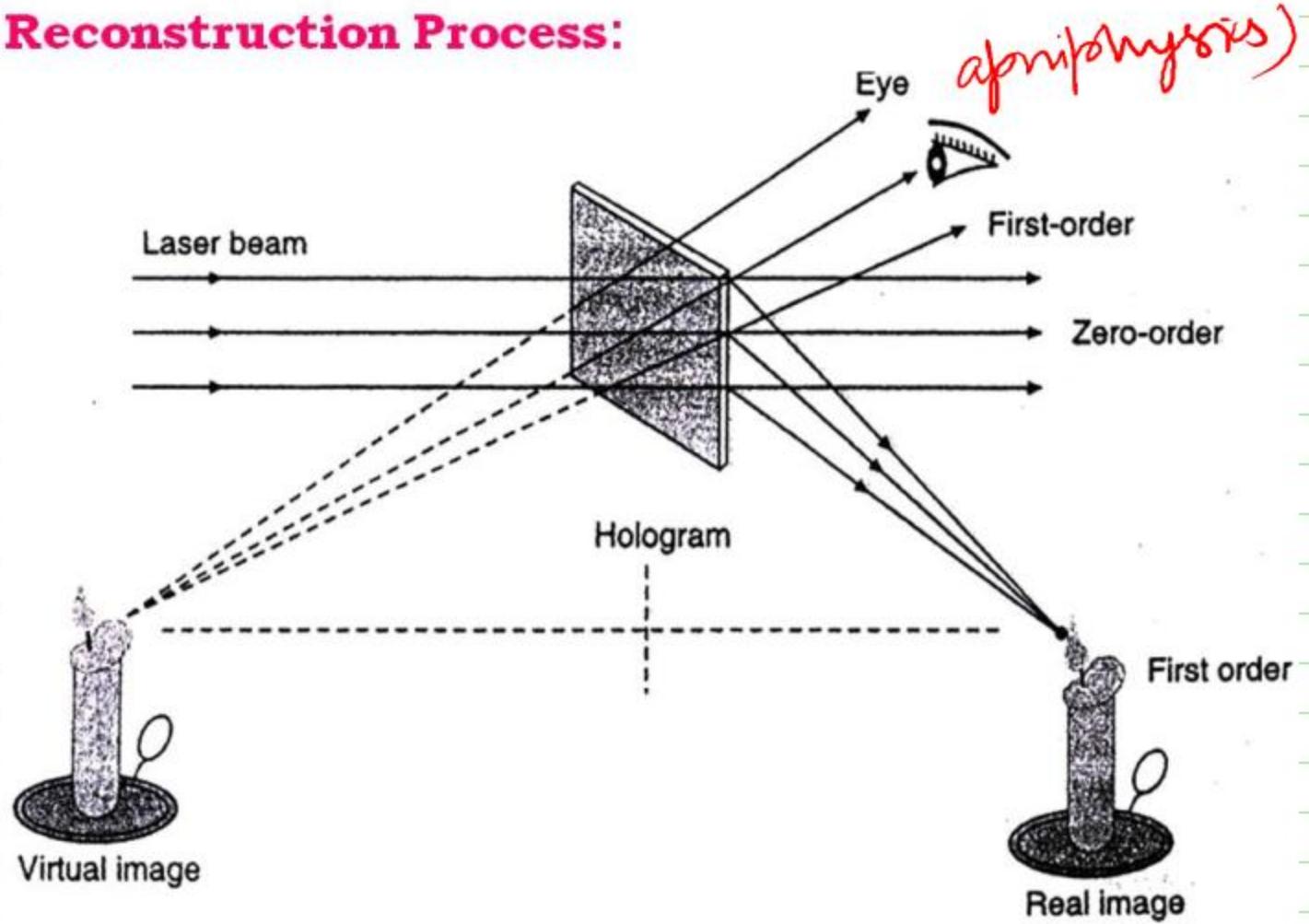


Construction of Hologram: Recording Process

apni jonyoos



Reconstruction Process:



Applications of Holography

- 1) In information storage in computers.
- 2) In holographic cinema.
- 3) In data processing.
- 4) Hologram can be used as an optical grating.
- 5) In information coding.
- 6) In pattern recognition.
and many more.....

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{ Suggest topics
ask problems?

Dr. Sandeep Kumar