Mercury vapour lamp → white light
↓ coherent ⟨not monochromatic⟩

LASER

LASER → Light Amplification by Stimulated Emission of Radiation

Properties:

(i) Monochromatic (not necessarily)
(ii) Coherent → constant phase diff
(iii) Uni-Directionality
(iv) Brightness

Applications:

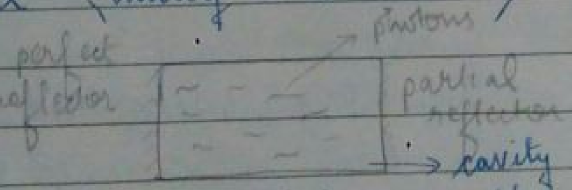
(i) Manufacturing
(ii) Communication (optical fibres)
(iii) Scanning machines
(iv) Eye operations
(v) Used in Sensors
(vi) Cutting, Welding

Sodium Vapour lamp → coherent
↳ shows interference
↳ transmission takes place due to ~~molecules~~ electronic transitions
↳ energy is supplied e^- get excited & jump to higher energy level

The lifetime of e^- in excited state is 10^{-8} sec. It emits photon & jumps back to initial state.

After every $\underbrace{10^{-8}\text{ sec}}_{\text{constant}}$, photons are emitted
constant → phase diff is constant

OPTICAL CAVITY: Atomic transitions to make laser light highly directional. ⟨lasing action occurs⟩



The photons keep colliding on the reflector & get reflected again & again. They gain inertia for axial direction.
Laser light is trained to move in a straight direction.
{Law of inertia}
Photons in random direction are chucked out.

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→ Temporal Coherence :
→ Coherence length
→ Coherence time
→ Spatial or lateral Coherence

SODIUM VAPOR LAMP :

When power source is switched on, e^- jumps from ground state to excited state. The lifetime of e^- in excited state is very small $\approx 10^{-8} - 10^{-12}$ sec. This process happens continuously & randomly. {Spontaneous absorbtion & emission}
⟨not triggered by us⟩ ★

So the process is uncontrolled ∴ Sodium Vapor lamp cannot be converted into laser.
Something that can't be controlled cannot be manipulated.
After every 10^{-8} sec, a set of photons keeps being emitted which makes it very difficult to impart them inertia for axial direction.

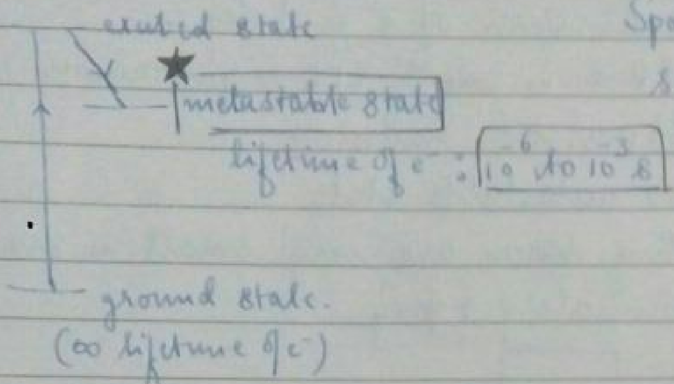
Stimulated Emission → forced
e^- lose energy only when they are made to.

★ Stimulated Emission is necessary for lasing action to take place.

Pumping : Forcing e^- from lower energy level to higher energy level

Methods of Pumping
- Optical Pumping: Light incident, excites the e^- from lower energy state to higher energy state.
- Gas discharge: High freq. & high voltage is supplied to excite e^- from ground state to high energy state.
- Chemical Reactions

STIMULATED EMISSION:



Spontaneous emission: only 2 states → ground & excited

∵ excited state is unstable, e⁻ come from excited state to metastable state & this transition is $\boxed{\text{radiationless}}$

∵ Time period of e⁻ in metastable state > excited state, e⁻ get enough time to populate the metastable state & a phenomenon known as $\boxed{\text{Population Inversion}}$ takes place

[No of e⁻ in higher energy state > no of e⁻ in ground state]

{possible only due to metastable state}

Stimulated emission

As the lifetime of e⁻ in metastable state is over, it falls back to ground state generating a photon which in turn hits another e⁻ in metastable state forcing it back ~~on~~ to the ground state & generating another photon. The 2 photons again strike e⁻ which release more photons before falling to the ground state.

This process continues & within a fraction of a second, we have a large no of photons. So all the photons are present in the optical cavity together & they are reflected again & again, thus inc the intensity of light along axial direction.

Hence, LASER light is emitted from the cavity

directional ← → coherent

Energy bands are present in solids.

Semiconducting Lasers

Principle: recombination of e^- & holes

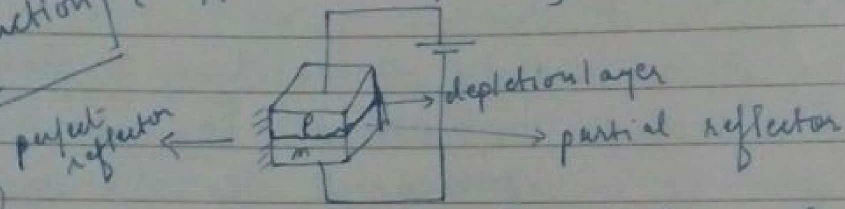
<similar to LED → in case of LED → spontaneous emission

Laser → Stimulated Emission>

in LED there is no metastable state.

→ Semiconducting lasers are very small in size {approximately 1 nm}

Homojunction Laser



Pumping is done with the help of forward bias battery. e^- & holes recombine ~~get excited~~ & release photons which get reflected again & again.

Semiconducting laser may melt if used for a long time due to the large amount of heat dissipated & its small size.

→ GaAs, GaAlAs

Direct band gap materials are used for making lasers. <which is why we can't use silicon & germanium>.

→ metastable state is present

→ loose photons - on collision

* In a Semiconducting laser, the entire lasing action occurs in depletion region.

→ population inversion

e^- & holes exist together → because of metastable state

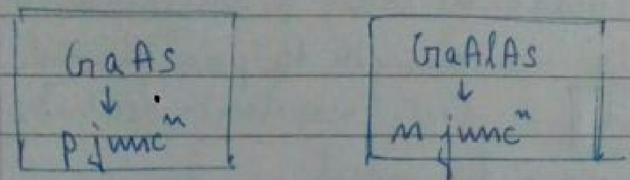
holes → valence band e^- → conduction band

* Refractive index of depletion region is diff from (greater than) refractive index of n side or p side → Total Internal Reflection ★

Limitation → Due to large depletion layer, movement of photons will be very large & the beam that emerges will not be very directional.

→ In the beginning, for very short time, laser will behave as LED.

Homojunction laser: Refractive index of material is constant.



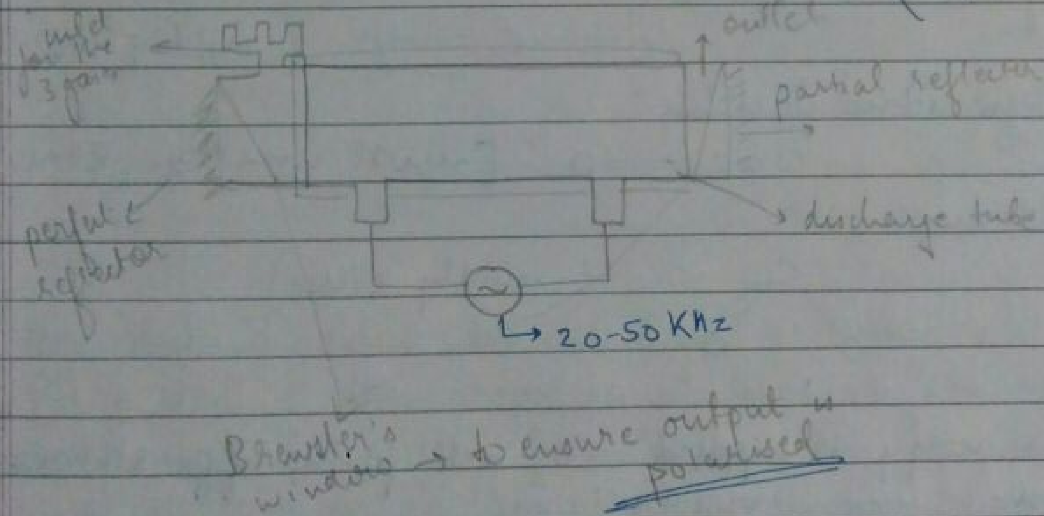
With change in doping, refractive index can be changed & also band gap.

Carbon dioxide Laser

very efficient

With respect to its size, its diameter is very small.

Consists of N_2, CO_2 & He ⟨may have traces of H_2O vapour⟩
2 : 1 : 1 → ratio is not fixed
(keeps changing depending on output



2 types of lasers: Air cooled & Water cooled
water surrounds the tube
⟨used when output is very high

inflow lasers have inlets for all the 3 gases.
Inflow system ensures there is no heating & water cooling is not req.

For high output, Gold silvering is used.

Brewster's windows — Lens system is made of Zinc ~~[illegible]~~ selenide

★ To make laser monochromatic, prism is used
or ★ length of tube is made in such a way that it only allows a particular wavelength to pass through.

$\boxed{l = n\lambda}$ (only 1 wavelength oscillates)

★ or diffraction grating can be used.

• Prism is not used because output is very high (glass will melt)

WORKING:

Modes of Vibration:

O = C = O [Ground state]

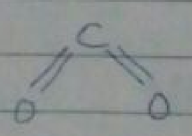
Symmetric Stretching:

O ═══ C ═══ O (mildly stable)

Assymmetric Stretching:

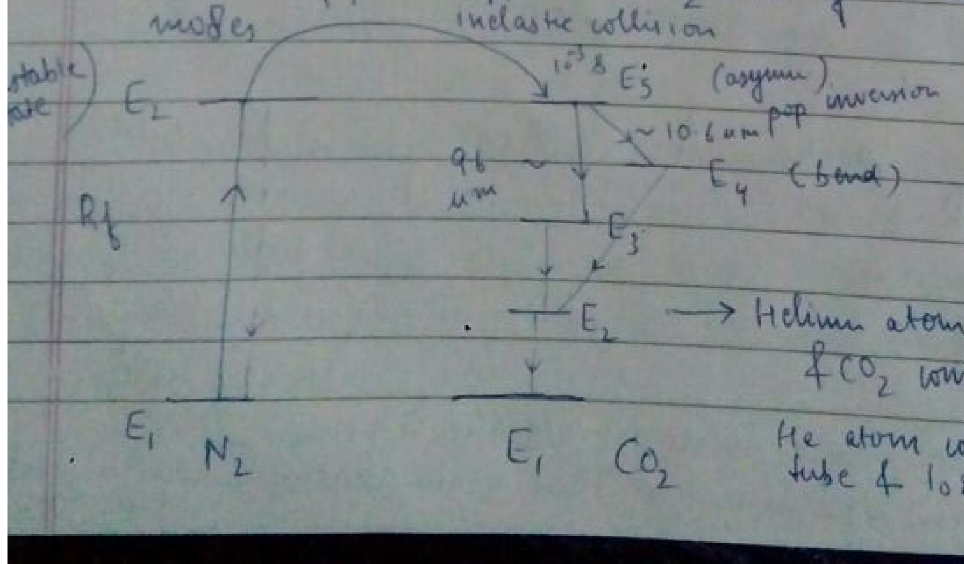
O = C ═══ O [most unstable state]

Bending:



(mildly stable)

When energy is supplied, CO_2 will go in diff. vibration modes



$E_{2\,(N_2)} \equiv E_{5\,(CO_2)}$

E_2 → Helium atom collides with CO_2 & CO_2 comes to ground state

He atom collides with walls of tube & loses energy.

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$N_2 > CO_2$. There is very high probability that one CO_2 will collide with N_2 & gain energy.

Though in E_5 of CO_2, asymmetric stretching takes place, e^- can still stay there for sufficient time to allow $\boxed{\text{population inversion}}$ to take place & from there they fall back to E_4 & E_3.

$\therefore$ Only 9.6 µm & 10.6 µm wavelengths are allowed to oscillate in the tube.

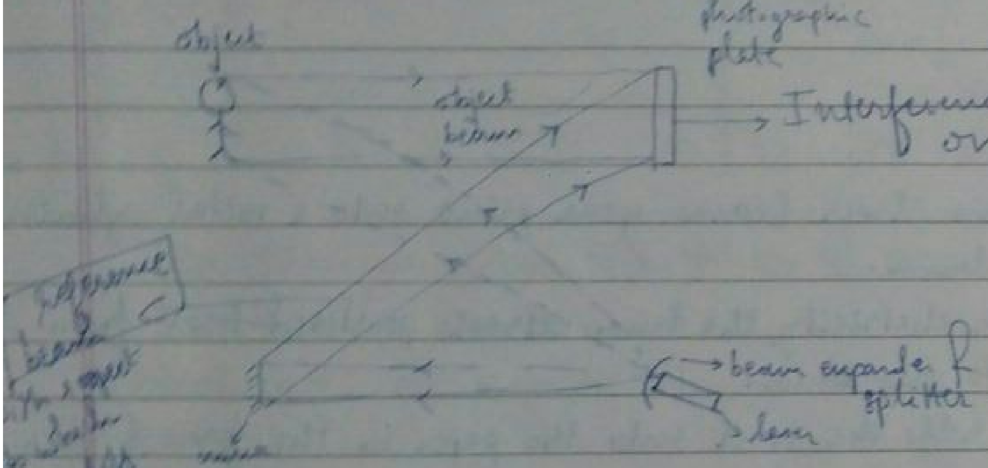
Holography:

Hologram is a 3D picture → amplitude, phase difference

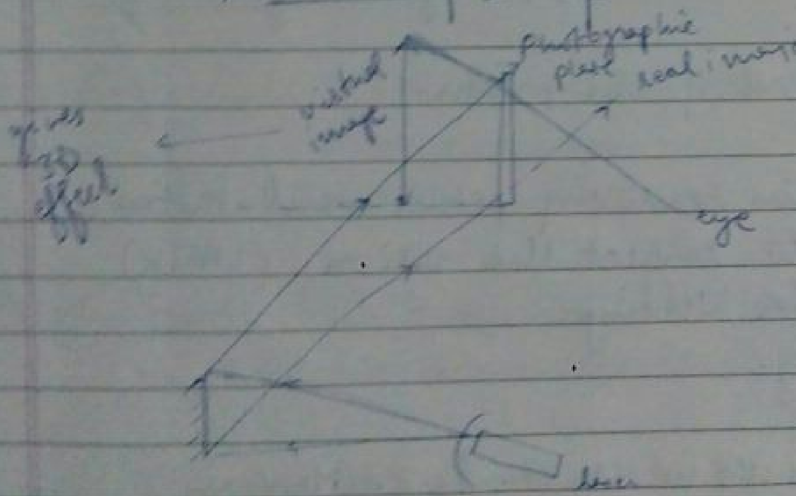
2 D picture: camera records amplitude

Interference pattern is being recorded in Hologram

Highly coherent source of light is used.



Retrieval of Image:



Photographic plate is illuminated by reference beam.

★ Hologram is formed by the interference of object beam & reference beam on the photographic plate.

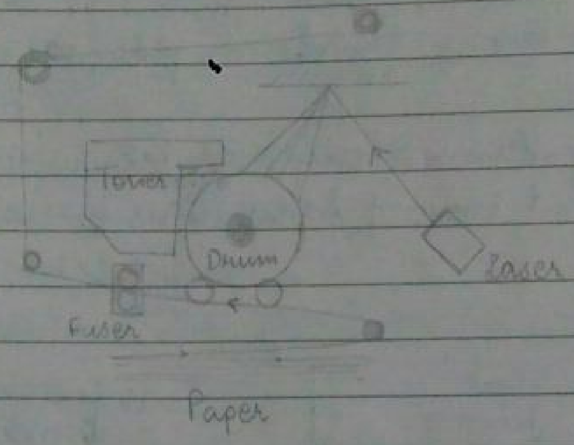
★ Light reflected by object → object beam

★ Light reflected by mirror → reference beam.

Laser Printer

light source used for optical pumping → Xenon

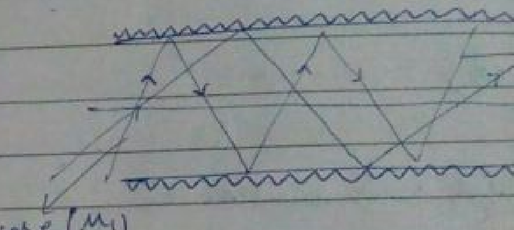
Helium : Neon
10 : 1



The printer's laser beams your print onto a metal cylinder called a drum.
Using static electricity, the drum attracts powdered toner from its cartridge to the drum.
The drum rolls the toner onto the paper in the form of your print.
The toner is melted onto the paper by heat from a fuser as it passes underneath.
The print comes out of the printer.

→ Laser is used in removing permanent tattoo.
→ Laser is used to correct the vision. (LASIK)
→ Laser is used for Welding.

Fiber Optic



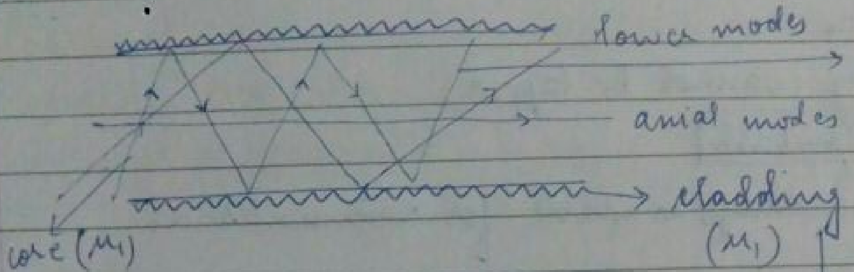
for TIR, $\mu_1 >$

Pulse Broadening leads to
↳ due to higher modes
lower mode light is tra
mode.

Types of fiber:

1. Single Mode Fiber →
   diameter →
   Pulse distortion is
2. Multimode Fiber → can

Fiber Optics Communication



→ higher modes (light is incident at steeper angles)

for TIR, $\boxed{\mu_1 > \mu_2}$

① To ensure TIR takes place
② Protection

Pulse Broadening leads to distortion of signal. & $\boxed{\text{noise}}$
↳ due to higher modes
lower mode light is travelling less distance compared to higher mode.

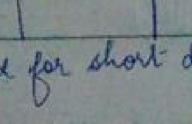
Types of fiber:

① Single Mode Fiber → can transmit only 1 signal at a time
diameter → 5 um
Pulse distortion is less

② Multimode Fiber → can transmit more than 1 signal.
50 – 200 um → diameter of core

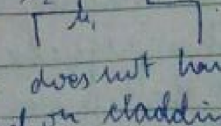
↳ Step Index Fiber & Graded Index Fiber

Step Index Fiber
→ TIR takes place at cladding.
→ Pulse broadening is higher.



→ Used for short dist

Graded Index Fiber
→ core has variable refractive index



→ Light does not have to depend on cladding for TIR
→ Pulse broadening is less
→ Used for long dist comm^n

Attenuation

The power loss of optical signals when they travel through optical fibres is known as attenuation

Power loss P_L in decibel (dB) is given as:

$$\boxed{P_L = -10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right)}$$

The attenuation constant (α) for optic fibres is defined as the power loss per unit length (expressed in dB/Km)

$$\boxed{\alpha = \frac{-10}{L} \log_{10}\left(\frac{P_{out}}{P_{in}}\right)}$$

L = length of the cable in Km

REASONS:

higher λ is preferred to reduce attenuation.

(i) Bending Loss: As long as the curve is ~~shaped or~~ has a large (of core) radius, signal will continue to pass. But when the radius reduces or curve becomes V-shaped, signal will be lost & TIR does not take place.

(ii) $\boxed{\text{Scattering Loss}} \propto \boxed{\frac{1}{\lambda^4}}$ {Lower wavelength gets scattered more}

is a signal
...rents of
...dwidth)
depends on
...al components
...ounts as the

(VI) **Wave Guide Dispersion**: diff refractive index of wave guide leads to WGD. Graded Index confines light signal to a narrow region so broadening of pulse is lesser
or Single ~~Index Fib~~ Mode Fibre whose diameter is less

** Improper core & cladding boundary leads to losses → GRIN is used to solve this

(iii) **Absorption Loss**: due to impurity that absorbs light or due to core material. If the core is pure, absorption loss will be reduced. {Optical fibres have the tendency to absorb lower wavelengths & let higher wavelength pass through}

(iv) **Dispersion Loss**: due to dispersion loss, pulse broadening takes place. Intermodal dispersion: due to diff modes travelled by light in cable

(colour)
(v) **Chromatic Dispersion Loss**: diff. colours travel with different velocity due to which pulse broadening takes place. (Monochromatic light should be used)

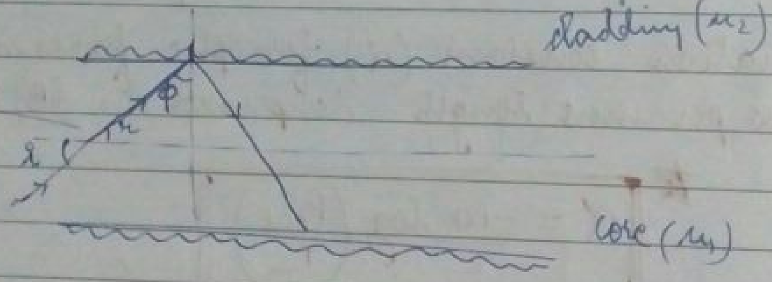
Fibre Optic Communication

Modulator → Transmitter $\xrightarrow{\text{fibre}}$ [Receiver] → [Demodulator] → [Amplifier]

Acceptance Angle

Max angle of incidence on the core for which Total Internal Reflec^n takes place inside the core

refrac^n takes place here light is coming from rarer med to denser med (core)



$$\mu_1 = \frac{\sin i}{\sin r}$$

TIR $\sin\phi \geq \frac{\mu_2}{\mu_1}$

$$\sin\phi = \sin(90-r)$$

$$\rightarrow \sin\phi = \cos r$$

$$\sin r = (1-\cos^2 r)^{\frac{1}{2}}$$

$$= (1-\sin^2\phi)^{\frac{1}{2}}$$

$$\sin r = \sqrt{1-\frac{\mu_2^2}{\mu_1^2}}$$

$\sin i = \mu_1 \sqrt{1 - \frac{\mu_2^2}{\mu_1^2}}$

★ $\boxed{i_m = \sin^{-1} \sqrt{\mu_1^2 - \mu_2^2}}$

★ ACCEPTANCE CONE = $\boxed{2 i_m}$

★ Acceptance cone of an optical fibre decides its light gathering power.

Acceptance Angle, $\boxed{\theta_0 = \sin^{-1} \sqrt{\mu_1^2 - \mu_2^2}}$

Numerical Aperture, $\boxed{\sin\theta_0 = \sqrt{\mu_1^2 - \mu_2^2} = NA.}$

Fractional Index Change, $\boxed{\Delta = \frac{\mu_1 - \mu_2}{\mu_1}}$

& $\boxed{NA = \mu_1 \sqrt{2\Delta}}$ (when μ_1 & μ_2 are approx equ

★ Multimode step index fibre : can transmit large no. of modes.

core diameter → 50mm to 200μm

cladding thickness → 20 to 25 μm

★ Single Mode Step Index fibre : usually transmit only AXIAL MODE

core diameter → 2μm to 10μm

cladding thickness → 25μm to 30μm

★ Graded Index fibre :

core diameter → 20μm to 100μm

cladding thickness → about 25μm

★ Rayleigh scattering varies as $\underline{\lambda^{-4}}$