LASER:
Understanding the Basics

Light :

In a conventional (incoherent) light source like a lightbulb, an LED, or a star, each atom excited by input pump energy randomly emits a single photon according to a given statistical probability. This produces radiation in all directions with a spread of wavelengths and no interrelationships among individual photons. This is called spontaneous emission.

Light having following Properties :

- Spontaneous emission.
- Polychromatic.
- Poorly energized.
- Highly divergence
- Not coherent
- Can not be sharply focussed.

Although lasers range from quantum-dot to football-field size and utilize materials from free electrons to solids, the underlying operating principles are always the same.

The laser would not have been possible without an understanding that light is a form of electromagnetic radiation.

To grasp the relevance of lasers in physics, it is enough to note that no other man-made sources can generate pulses (of any type) as short as laser pulses — now below to 10^{-16} s — or tools to measure absolute frequencies with an accuracy of $\sim 10^{-15}$!

Beginning of LASER :

In 1905, Einstein released his paper ***on the photoelectric effect*,**which proposed that ***light also delivers its energy in chunks, in this case discrete quantum particles now called photons*.**

In 1917, Einstein ***proposed the process that makes lasers possible***

Max Planck received the Nobel Prize in physics in 1918 for his discovery of elementary energy quanta.

"***energy could be emitted or absorbed only in discrete chunks — which he called quanta — even if the chunks were very small.***"

- Photon represents minimum energy unit of light. It is localized in small volume of space and remains localized as it moves away from the light source.

Energy of photon; $E = h\nu$

- Light energy „$\rho(\nu)$‟ emitted by a source must be integral multiple of photon energy $\Rightarrow$ **Quantization**

$$\rho(\nu) = n\,h\nu \quad ; \quad n = 1,2,3,\ldots$$

- **1954:** Herbert J. Zeiger and graduate student James P.Gordon, Townes ***demonstrates the first MASER*** at Columbia University. T*he first device based on Einstein's predictions, obtains the first amplification and generation of electromagnetic waves by stimulated emission.*
- **September 1957:** Charles Townes (awarded the **Nobel Prize in physics in 1964**) and Arthur Schawlow ***sketched on notebook showing his idea for "A maser at optical frequencies." The first theoretical concept of LASER.***
- **November 13, 1957:** Columbia University graduate student **Gordon Gould** jots his ideas for building a laser in his notebook and has it notarized at a candy store in the Bronx. ***It is considered the first use of the ellipsis LASER.***
- **May 16, 1960:** Theodore H. Maiman, a physicist at Hughes Research Laboratories in Malibu, Calif., ***constructs the first LASER using a cylinder of synthetic Ruby.***
- **October 2018:** Arthur Ashkin, Gérard Morou, and Donna Strickland, were awarded the **Nobel Prize in physics** for the inventions of short, intense laser pulses that have broad industrial and medical applications called **Chirped Pulse Amplification (CPA).**

LASER Physics :

- Interaction of radiation with matter is better explainedusing concept of photon rather than by the wave concept.

  - *Energy exchange can take place only at certain discrete values for which the photon energy is the minimum energy unit that light can give or accept.*

- Wave picture of light is **Classical** and Photon picture is **Quantum Mechanical**.

- **Laser- inherently a Quantum Mechanical device ⇒ its operation depends on the existence of photons.**

- **Light as electromagnetic waves, emitting radiant energy in tiny package called 'quanta'/photon. Each photon has a characteristic frequency and its energy is proportional to its frequency.**

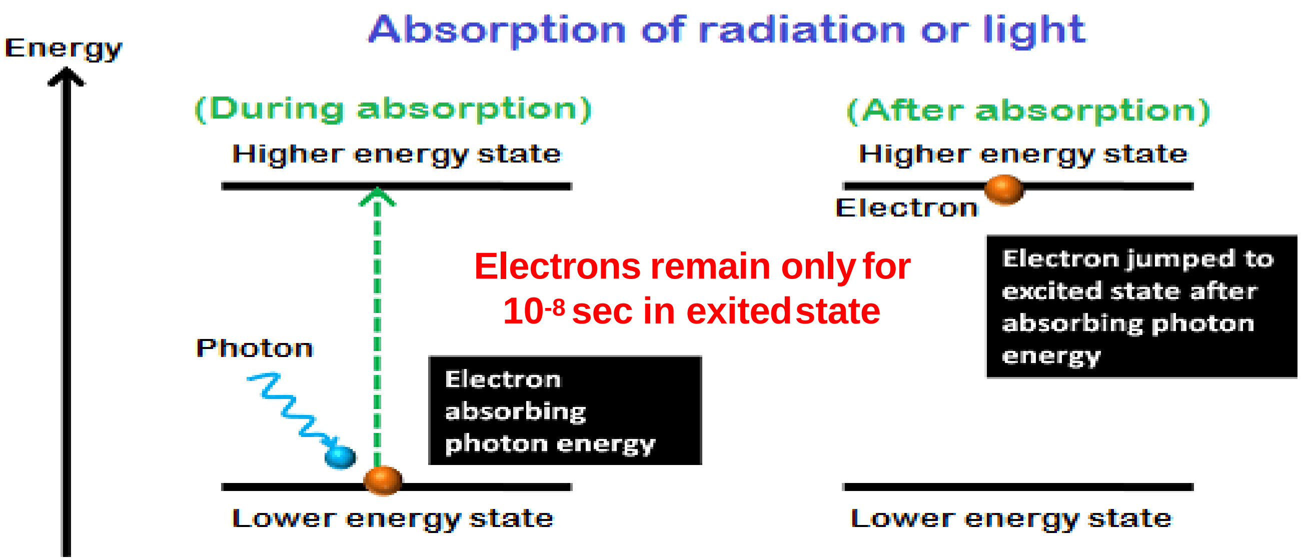
- **Three basic ways for photons and atoms to interact:**

  - ***Absorption***
  - ***Spontaneous Emission***
  - ***Stimulated Emission***

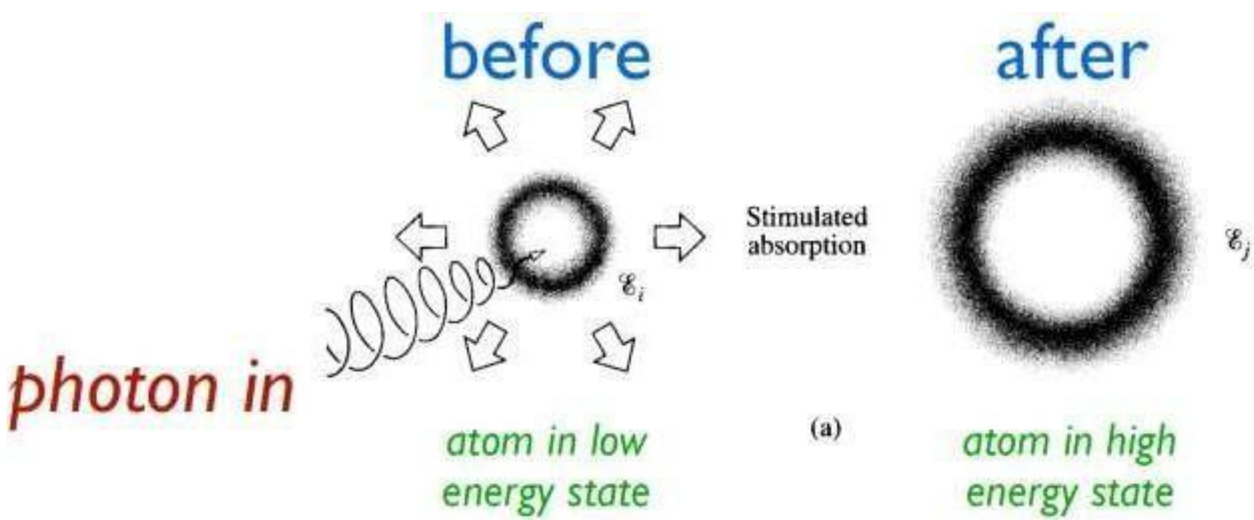
A medium consisting of identical atoms in thermal equilibrium having;

- ***Energy levels E_1 and E_2***
- ***Population N_1 and N_2***

Absorption



Electrons remain only for 10^{-8} sec in exited state



According to Bohr's law -atomic system is characterized by discrete energy level

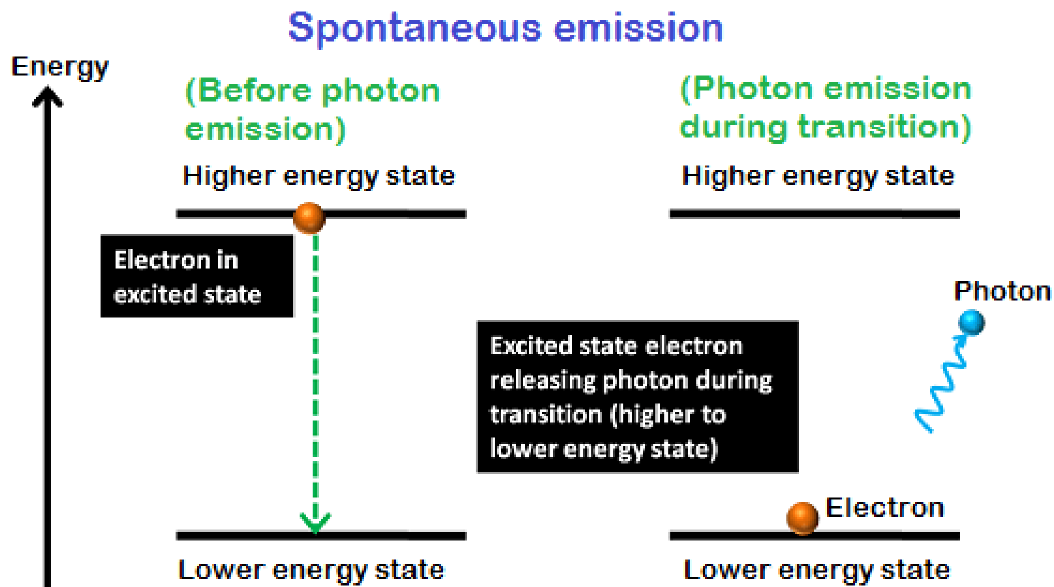
- When atoms absorb or release energy it transit upward or downward.
- Lower level E_1 & Excited level E_2
- So, $h\nu = E_2 - E_1$
- The rate of absorption depends on no. of atoms n_1 present in E_1 & spectral energy density $\rho(\nu)$ ofradiation

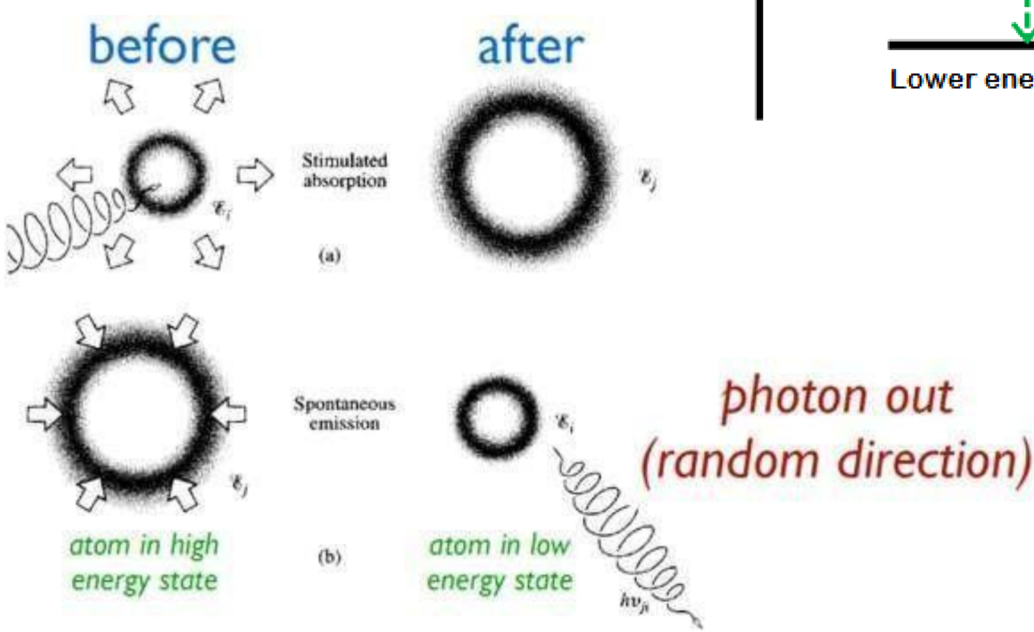
So, $P_{12} \alpha N_1 \rho(\nu)$

$$P_{12} = B_{12} N_1 \rho(\nu)$$

Where, B_{12} = Einstein coefficient for Stimulated Absorbtion.

Spontaneous Emission





Spontaneous Emission

- System having atoms in excited state.
- Goes to downward transition with emitting photons, $h\nu = E_1 - E_2$.
- Emission is random, so if not in same phase, it becomes incoherent.
- The transition depends on no. of atoms N_2 in excited state E_2.

Rate of Spontaneous transitions:

$$P_{12}(\text{spont}) \propto N_2 = A_{21} N_2$$

- Where,

A_{21} = Einstein coefficient for spontaneous Emission.
we get Incoherent radiation forms heat by light amplification of radiation by spontaneous emission.

Important Features:

- No outside control
- Probabilistic in nature
- Incoherent Light
- Not monochromatic
- Lack of directionality

Incoherent Radiation:

- Results from superposition of wave trains of random phases.

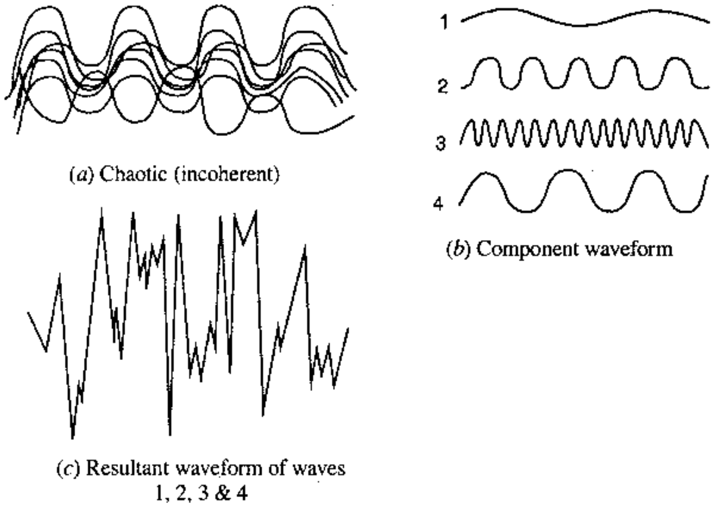


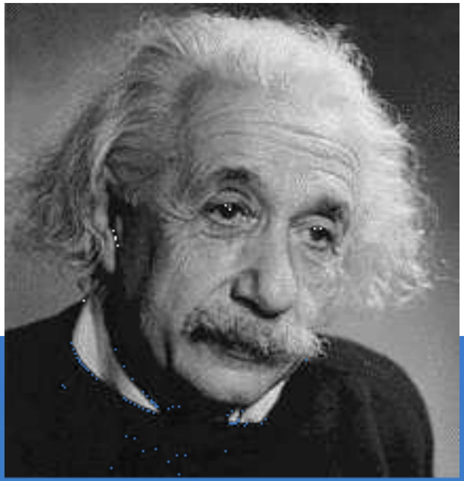
Fig. 1.9. Incoherent radiation (a) Incoherent waves (b) component wave form (c) Resultant wave.

- Net intensity is proportional to the number of radiating atoms

$$I_{Total} = N\,I$$

- **Dominates in conventional light sources.**

Stimulated Emission



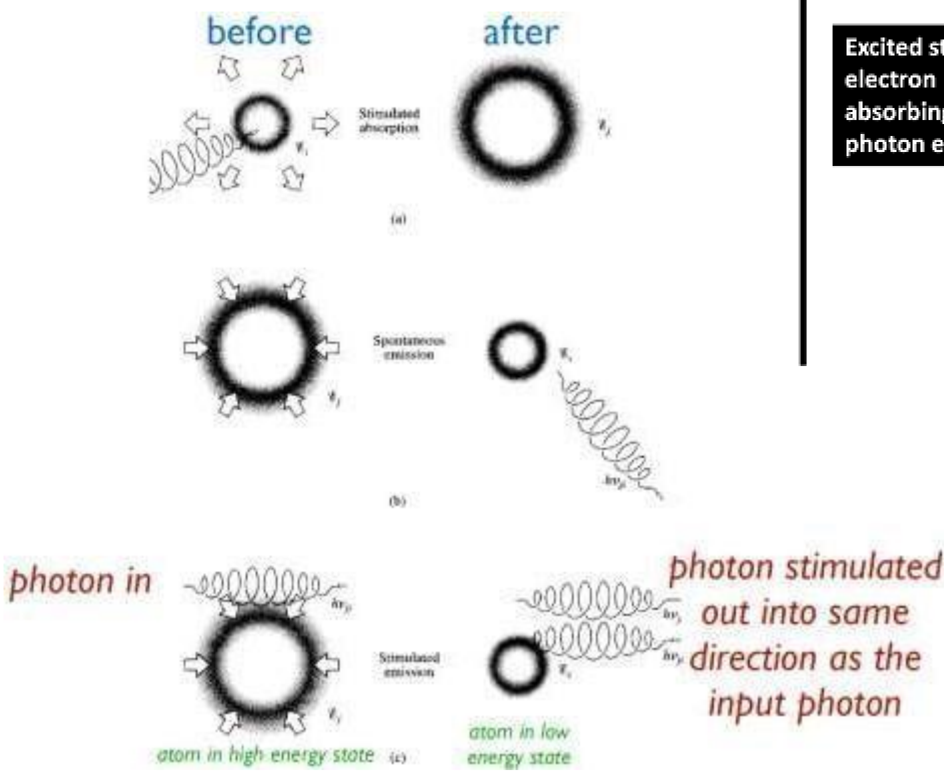
In 1917 **Einstein predicted** that

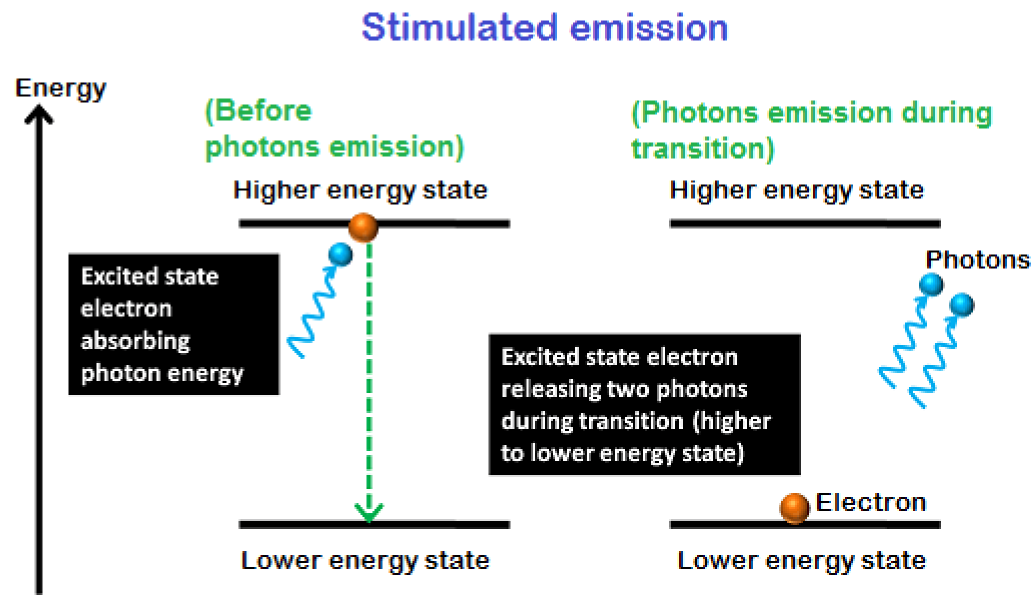
"Atoms in an excited state can be stimulated to jump to a lower energy level when they are struck by a photon of incident light whose energy is the same as the energy-level difference involved in the jump. The electron thus emits a photon of the same wavelength as the incident photon. The incident and emitted photons travel away from the atom in phase."

This process is called stimulated emission.

Violation of thermal equilibrium condition

Stimulated Emission





Stimulated Emission

- System having atoms in excited state.
- Goes to downward transition with emitting photons.
- $2h\nu = E_1 - E_2$. After applying photon energy $h\nu$.
- Emission is depends on energy density $\rho(\nu)$ & No. of atoms N_2 present in E_2

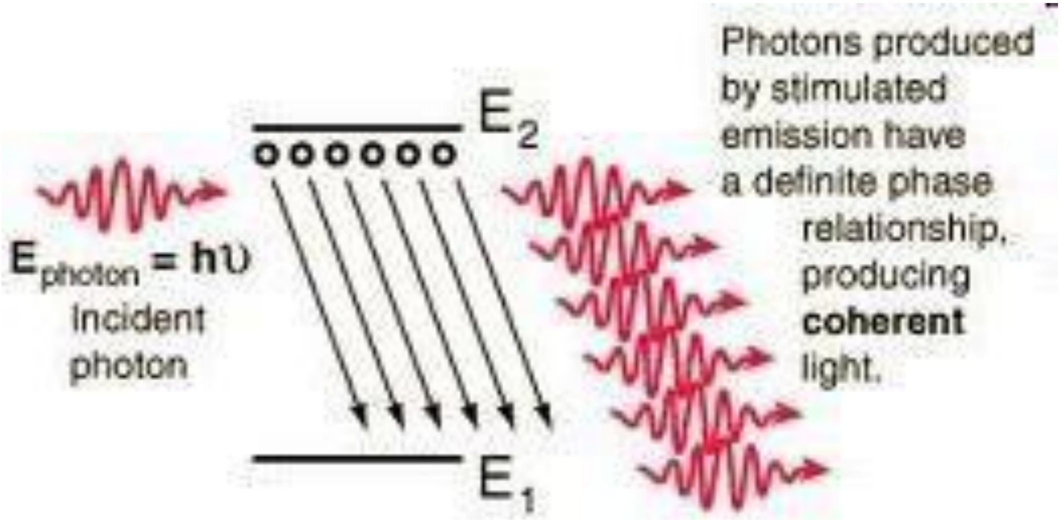
Rate of stimulated emission:

$$P_{12}(\text{stimul}) \, \alpha \, \rho(\nu) \, n_2 = B_{21} N_2 \rho(\nu)$$

- Where, B_{21} = Einstein coefficient for Stimulated Emission.
- Thus one photon of energy $h\nu$ stimulates two photons of energy $h\nu$ in same phase & directions. So, we get coherent light amplification of radiation by stimulated emission.

Important Features:

- Controllable from outside
- Emitted photon propagates in same direction as that of stimulating photon.
- Have exactly same frequency, phase and plane of polarization.
- Light produced is directional, coherent and monochromatic.



Light Amplification

- Multiplication of photons
- All in phase and travel in same direction
  - All the coherent waves interfere constructively.
  - Resultant amplitude is continuously growing.
  - Result is amplified light.

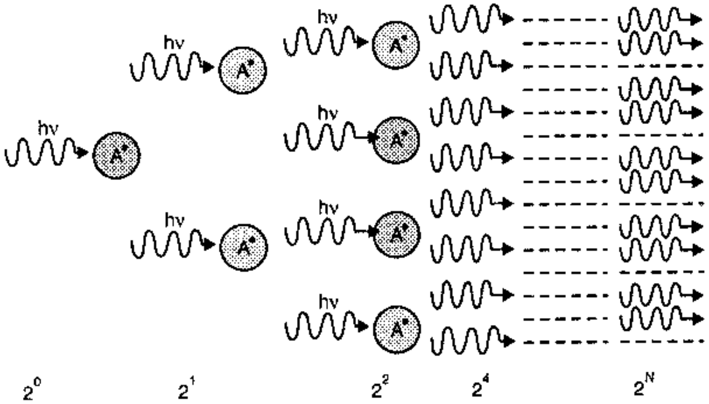


Fig. 1.11. Multiplication of stimulated photons into an avalanche

All the light waves generated in the medium are due to one initial wave and all of them are in phase. Therefore, the waves are *coherent* and

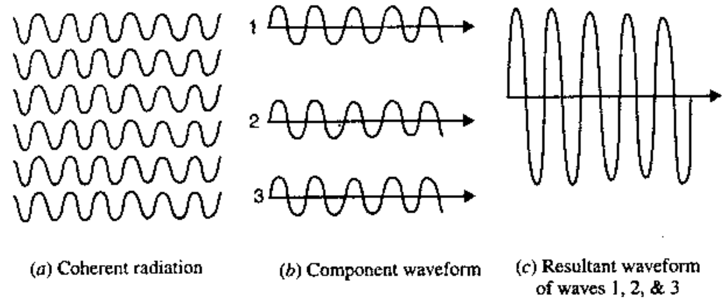


Fig. 1.12. Coherent radiation (*a*) coherent waves (*b*) component wave form (*c*) Resultant wave

High Intensity

- Because of constructive interference of waves, net intensity of the resultant light is proportional to square of the number of atoms emitting light

$$I_{Total} = N^2 I \quad \Rightarrow \quad \textbf{High intensity light}$$

Thermal Equilibrium

- **At temperature above 0K,**
  - Atoms alway have some thermal energy;
  - Distributed among available energy levels according to their energy.

❖ At Thermal Equilibrium;

- ➢ Population at each energy level decreases with increase of energy level,

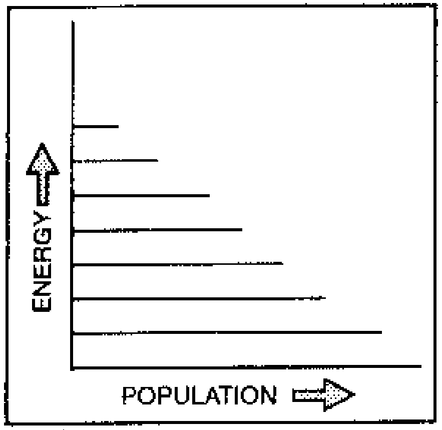


Fig. 1.4. Relative populations of energy levels as a function of energy above the ground state at thermal

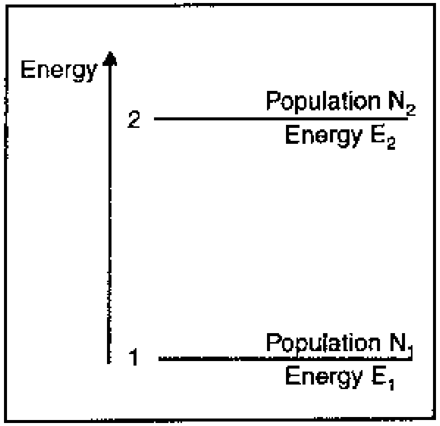


Fig. 1.5. Two energy level system.

For energy levels E_1 and E_2,

- Populations can be computed with Boltzmann"s equation

$$\boxed{N_1 = e^{-E_1/KT}} \quad \& \quad \boxed{N_2 = e^{-E_2/KT}}$$

- Ratio of populations, N_2/N_1 is called ***Relative Population.***

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

or $$N_2 = N_1 e^{-\Delta E/KT}$$; $\Delta E = E_2 - E_1$

- **Relative Population** (N_2/N_1); dependent on two factors
  - Energy difference (E_2-E_1)
  - Temperature, T

- **At Lower Temperature;** All atoms are in the ground states.
- **At higher Temperature;** Atoms move to higher states

- **In a material at thermal equilibrium, more atoms are in the lower energy state than in the higher energy state.**
  - The fraction of excited atoms would be large, if the energy levels are close or temperature is very high.

In limiting case,

- When, $E_2 - E_1 \rightarrow 0$; $N_2 = N_1$
- When, $T \rightarrow \infty$; $N_2 = N_1$

<u>Important Conclusion</u>:

As long as the material is in thermal equilibrium, the population of the higher state cannot exceed the population of lower states.

Population Inversion

- A state in which a substance has been energized, or excited to specific energy levels.
- More atoms or molecules are in a higher excited state.
- The process of producing a population inversion is called pumping.
- Examples:

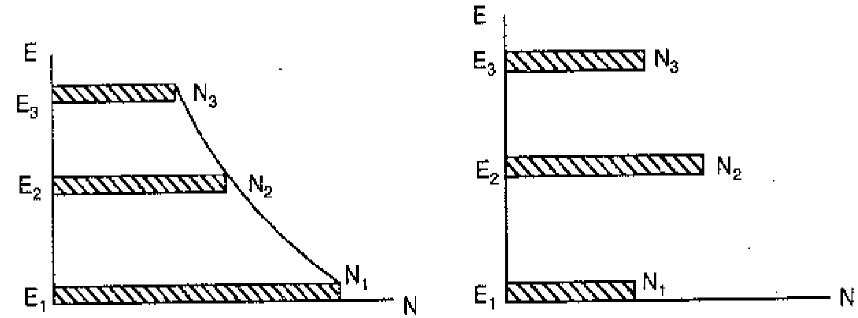
→by lamps of appropriate intensity

→by electrical discharge

❖ For a system with three energy states E_1, E_2 and E_3 in equilibrium, the uppermost level E_3 is populated least and the lowest level E_1 is populated most

- *Since the population in the three states is such that $N_3<N_2<N_1$, the system absorbs photons rather than emit photons.*

- If the system is supplied with external energy such that N_2 exceeds N_1 $\Rightarrow$ **System reached Population Inversion**
- P.I. taken place between the levels E_2 and E_1,



(*a*) Population in equilibrium.

(*b*) Population inversion of E_2 with respect to E_1.

Fig. 1.16. Three level system.

❖ **Under P.I. condition, stimulated emission can produce a cascade of light.**

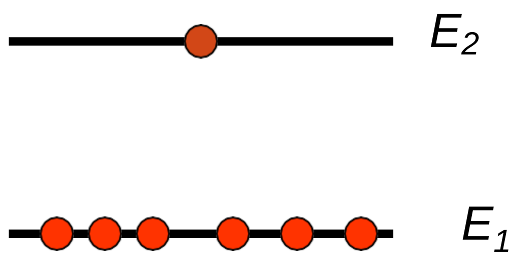
- The first few randomly emitted spontaneous photons trigger stimulated emission of more photons and those stimulated photons induce still more stimulated emissions and so on.
- As long as $N_2 > N_1$, stimulated emissions are more likely than absorption $\Rightarrow$ **light gets amplified**.

Necessary condition:
Population Inversion

If $n_1 > n_2$

- radiation is mostly absorbed
- spontaneous radiation dominates.

if $n_2 >> n_1$ - *population inversion*



Thermal excitation:

$$\boxed{\frac{N_2}{N_1} = \exp\left(\frac{-\Delta E}{kT}\right)}$$

impossible.

- **The system has to be "pumped"**
- most atoms occupy level E_2, weak absorption
- stimulated emission prevails
- light is amplified

Pumping:

- **Optical:** flashlamps and high-energy light sources
- **Electrical:** application of a potential difference across the laser medium
- **Semiconductor:** movement of electrons in "junctions," between "holes"

Pumping Methods

- **To create the state of P.I.** $\Rightarrow$ *selectively excite the atoms in the material to particular energy levels.*
- Most common methods of pumping make use of **Light** and **Electrons.**

Optical Pumping

- Use of photons to excite the atoms
  - A light source used to illuminate the laser medium
  - Photons of appropriate frequency excite the atoms to upper levels.
  - Atoms drop to the metastable level to create the state of P.I.

❖ **Optical pump sources** : Flash discharge tubes, Continuously operation lamps, Spark gaps or an auxiliary laser.

❖ Optical pumping is suitable for laser medium- <u>transparent to pump light</u>.

❖ Mostly used for solid state crystalline and liquid tunable dye lasers.

Electrical Pumping

- Can be used only in case of laser materials that can conduct electricity without destroying lasing activity.

  - **Limited to gases**.

  - In case of a gas laser, a high voltage pulse initially ionizes the gas so that it conducts electricity.
  - An electric current flowing through the gas excites atoms to the excited level from where they drop to the metastable upper laser level leading to **P.I**.

Direct Conversion

- In semiconductor lasers also electrical pumping is used, but here it is not the atoms that are excited. It is the current carriers; {e- h} pairs which are excited and a population inversion is achieved in the junction region.
- Electrons recombine with holes in the junction regions producing laser light.

  - **A direct conversion of electrical energy into light energy**

Metastable States

- An atom can be excited to a higher level by supplying energy to it. Normally, excited states have ***short lifetimes ≈ nanoseconds (10^{-8} s)*** and release their excess energy by spontaneous emission.
- Atoms do not stay at such excited states long enough to be stimulated to emit their energy. Though, the pumping agent continuously raises the atoms to the excited level, many of them rapidly undergo spontaneous transitions to the lower energy level $\Rightarrow$ ***Population inversion cannot be established***.
- For establishing population inversion, the excited atoms are required to **"wait"** at the upper lasing level till a large number of atoms accumulate at that level.

- **What is needed is an excited state with a longer lifetime?**

  ☞ *Such longer-lived upper levels from where an excited atom does not return to lower level at once, but remains excited for an appreciable time, are known as **Metastable States.***

- Atoms stay in metastable states for about **10^{-6} to 10^{-3}s**. This is **10^3 to 10^6 times longer** than the time of stay at excited levels.
  - Possible for a large number of atoms to accumulate at a metastable level. The metastable state population can exceed the population of a lower level and lead to the state of population inversion.

- **If the metastable states do not exist, there could be no population inversion, no stimulated emission and hence no laser operation.**

❖ **Foundation to the laser operation is the existence of metastable states.**

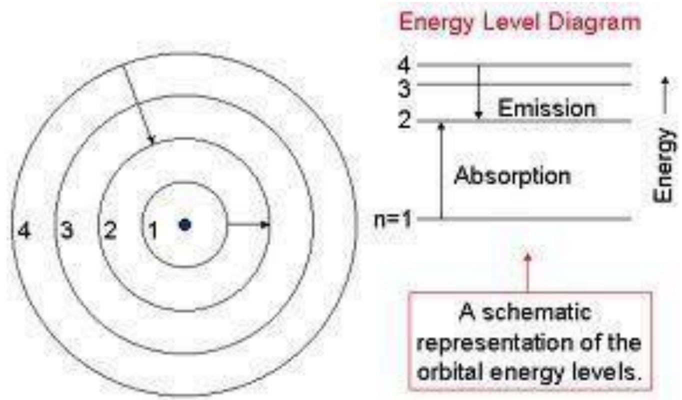
Pumping Schemes

❖ **Atoms characterized by a large number of energy levels.**

➢ Only two, three or four levels are significant to the pumping process.

❑ **Classified as**

- Two-level,
- Three-level and
- Four –level schemes.



❖ Two-level scheme will not lead to laser action.

❖ Three-level and four-level schemes are important and are widely employed.

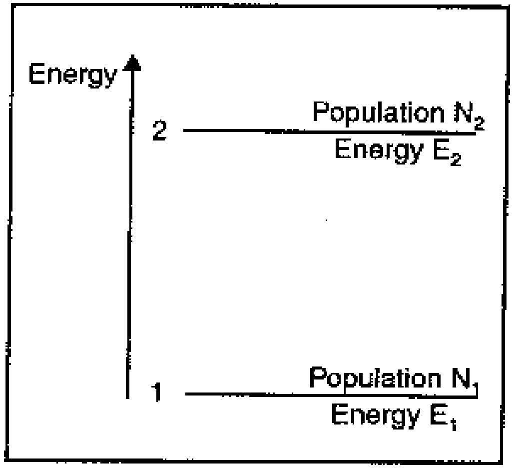
Two Level Pumping Scheme

- Appears to be most simple and straight-forward method to establish population inversion;
  - Pumping an excess of atoms into the higher energy state by applying intense radiation.
- A two-level pumping scheme is not suitable for attaining P.I.

- P.I. requires the lifetime Δt of upper level E_2 must be longer.
- **Heisenberg"s Uncertainty principle,**

$$\Delta E_2 \,.\, \Delta t \geq h/2\pi$$

$\Rightarrow$ Smaller ΔE_2 ; the upper energy level must be narrow



Two Energy level system

- **For such system, to excite atoms, pump source should be highly monochromatic.**
  - In practice, monochromatic source of required frequency may not exist.
  - Even if it exists, the pumping efficiency would be very low $\Rightarrow$ enough population cannot be excited to level E_2.

- Further, pumping radiation on one hand excites the ground state atoms and on the other hand induces transitions from the upper level to the lower level.
  - **means that pumping operation simultaneously populates and depopulates the upper level.**

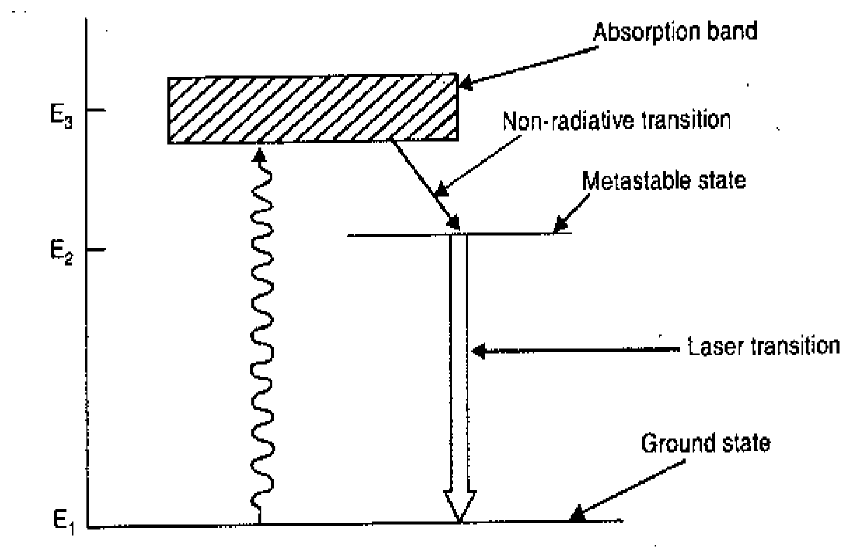
☞ **Hence, P.I. cannot be attained in a two-level scheme. All that it may achieve at best is a system of equally populated levels.**

Three Level Pumping Scheme

- **Athree level scheme**; Lower level is either the ground state or a level whose separation from the ground state is small compared to kT.

E_2 – A metastablelevel

- Atoms accumulate at level E_2
- Build-up of atoms at E_2 continues because of pumping process.
- Population N_2 at E_2 exceeds the population N_1 at E_1 and
  - **P.I. is attained**.



Three level Energy diagram

❖ **A photon of hν(=E_2-E_1) can induce stimulated emission and laser action.**

- **Major disadvantage of a three level scheme ⇒ it requires very high pump powers.**

  - Terminal level of the laser transition is the ground state.

- As the ground state is heavily populated, large pumping power is to be used to depopulate the ground level to the required extent ($N_2 > N_1$)

- **Three level scheme can produce light only in Pulses.**

  - Once stimulated emission commences, the metastable state E_2 gets depopulated very rapidly and the population of the ground state increases quickly. As a result the population inversion ends. One has to wait till the population inversion is again established.

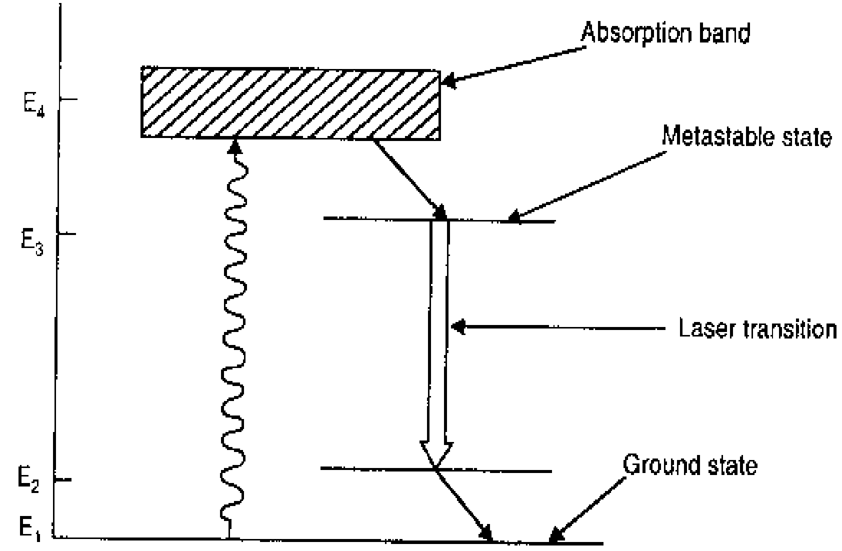
  - **Three level lasers operate in Pulsed Mode.**

Four Level Pumping Scheme

- **In Four level scheme, the terminal laser level E_2 is well above the ground level such that $(E_2-E_1) >> kT$.**
  - It guarantees that the thermal equilibrium population of E_2 level is negligible.

E_3 - a metastable level

- Laser transition takes the atoms to the level E_2
- Atoms lose the rest of their excess energy & finally reach the ground state E_1.
- Atoms are once again available for excitation.



Four level Energy diagram

- ***In contrast to three level scheme, the lower laser transition level in four level scheme is not the ground state and is virtually vacant.***
  - It requires less pumping energy than does a three level laser. This is the major advantage of this scheme.

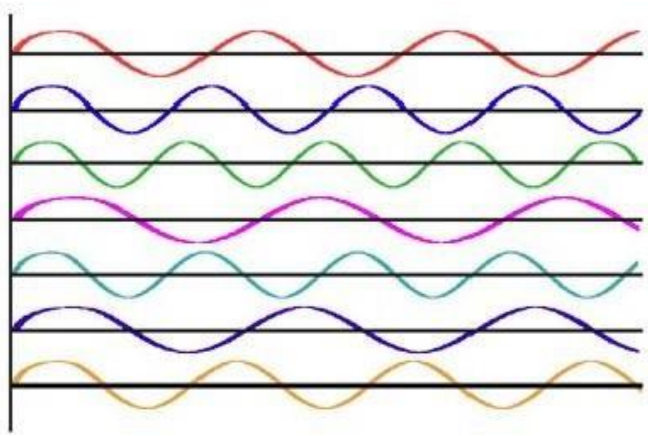
- ***Further, the lifetime of the lower laser transition level E_2 is much shorter, hence atoms in level E_2 quickly drop to the ground state.***
  - This steady depletion of E_2 level helps sustain the population inversion by avoiding an accumulation of atoms in the lower lasing level.

- Four level lasers can operate in **Continuous Wave mode.**

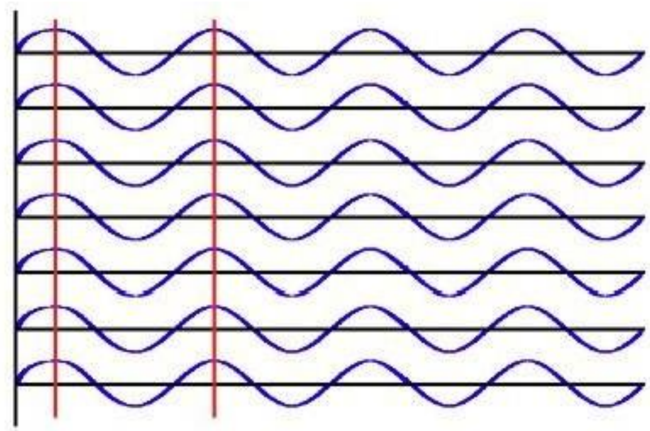
❑ **Most of the working lasers are based on Four Level Scheme**

Properties of Laser Light

Coherence:



Incoherent light waves

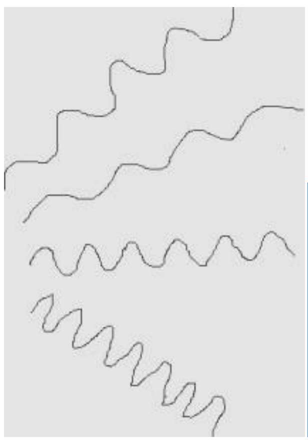


Coherent light waves

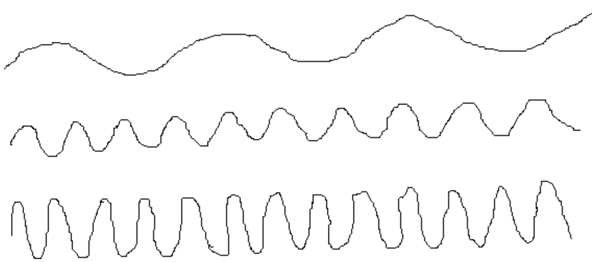
Laser light Cannot be perfectly monochromatic be perfectly directional perfect coherent

Coherence:

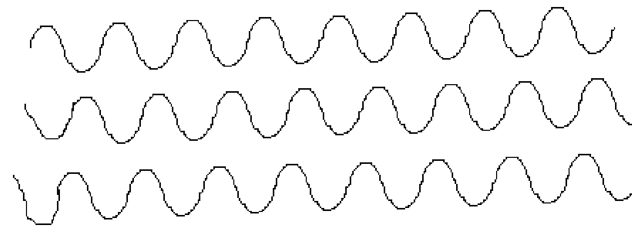
As it can be noted from Figures (5.1 to 5.4), an ordinary light is neither coherent, nor directional and nor monochromatic. A directional light may not be coherent and monochromatic, a directional and monochromatic light may not be coherent, and however, a coherent light is necessarily monochromatic, directional as well as sharply focusable



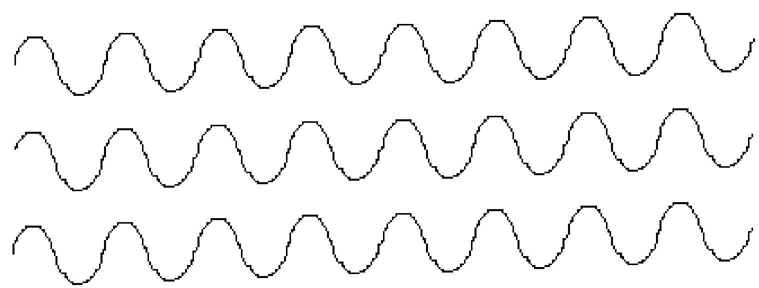
Ordinary light (such as that from tungsten) is neither coherent, nor directional and nor monochromatic



A directional but polychromatic and incoherent light



Monochromatic, directional but incoherent light



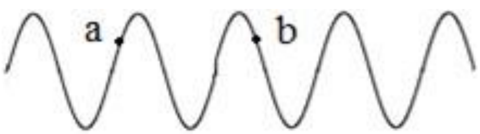
Coherent (and hence directional, monochromatic and sharply focusable) light

Coherence

Laser beam is highly coherent

Two waves are said to be coherent, if they have zero or constant phase difference between them. Laser has two types of coherence which are discussed below:

Temporal coherence : If the phase difference between any two points on a wave in a direction along with the wave remains constant with respect to time, the coherence is called as temporal coherence.



Temperoal coherence

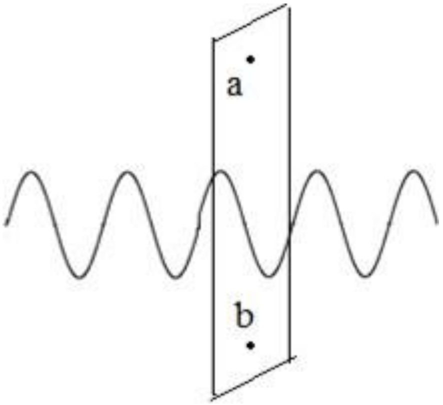
The length over which the phase difference remains constant is called as coherence length.

Sodium light - 0.3 mm approx.

LASER – 100 m approx.

The corresponding time is called as coherence time.

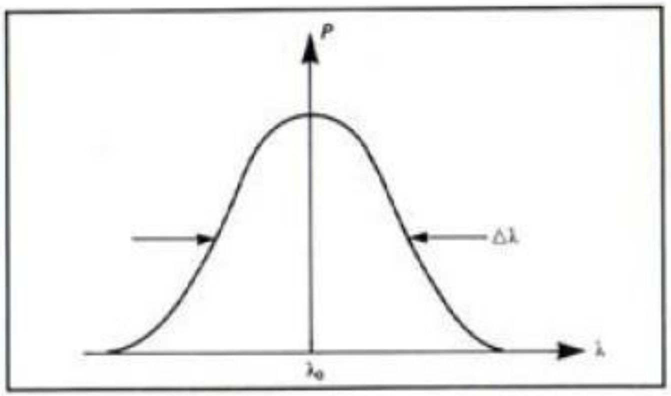
Spatial coherence : If the phase difference between the points (mentioned as a and b in Fig) laying in a plane perpendicular to the propagation of the waveremains constant with time, then it is called as spatialcoherence.



Spatial coherence

Properties of Laser

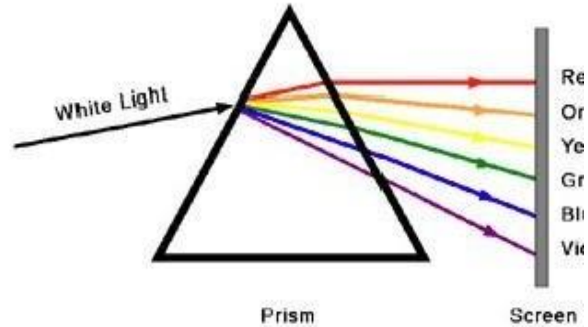
Monochromaticity:

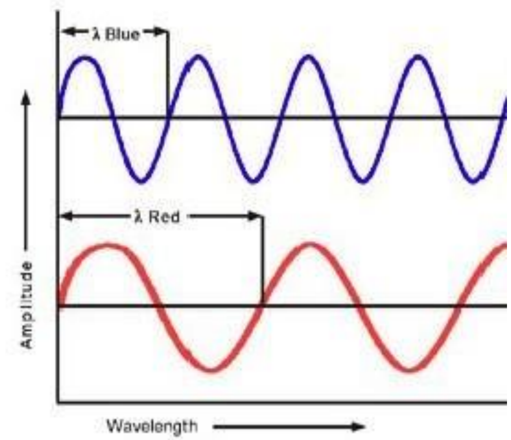


Nearly monochromatic light

Example:

He-Ne Laser	Diode Laser
$\lambda_0 = 632.5$ nm	$\lambda_0 = 900$ nm
$\Delta\lambda = 0.2$ nm	$\Delta\lambda = 10$ nm

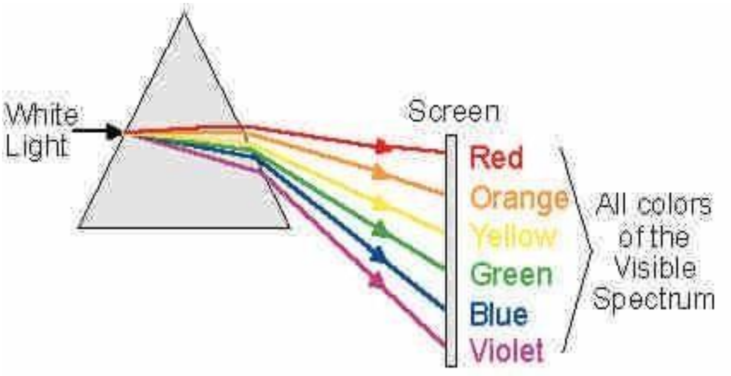




Comparison of the wavelengths of red

Monochromaticity

Monochromaticity means "One color".
When "white light" is transmitted through a prism, it is divided into the different colors which are in it.



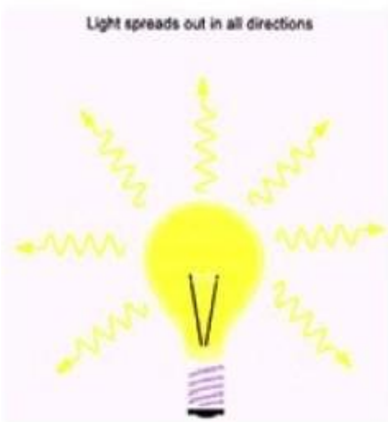
In the theoretical sense "**One Color**", which is called "**spectral line**", means **one wavelength**.

The monochromaticity of laser is considerably high as compared to the conventional monochromatic sources

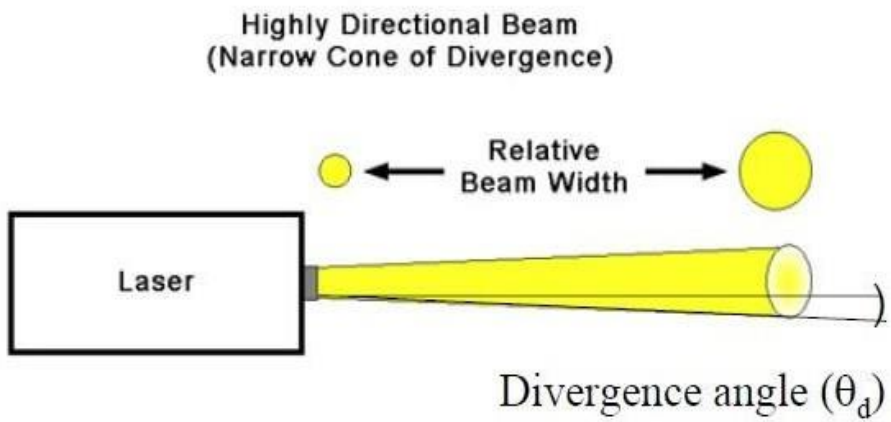
In conventional monochromatic sources the precision is up to 1 part in 10^6, while for LASER it is 1 part in 10^{15}.

Properties of Laser

Directionality:



Conventional light source



Beam divergence: $\theta_d = \beta \lambda / D$

$\beta \sim 1$ = f(type of light amplitude distribution, definition of beam diameter)
λ = wavelenght
D = beam diameter

Directionality

This is perhaps the most obvious aspect of a laser beam: the light comes out as a highly directional beam. This contrasts with light bulbs and discharge lamps, in which the light is emitted in all directions. The directionality is a consequence of the cavity. But the LASER beam is not perfectly directional.

The directionality of the laser is because of the fact that in the laser in Cavity system the off axis photons are absorbed while only axial photons are transmitted.

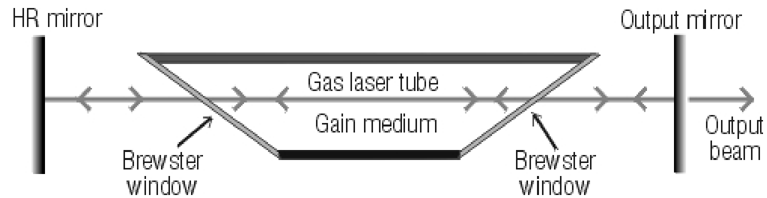
The divergence of laser is just small fraction of a degree but not zero. This is due to laser is diffracted from the exit aperture of the laser cavity.

The directionality of laser is so high that it has been used to measure the earth-moon distance.

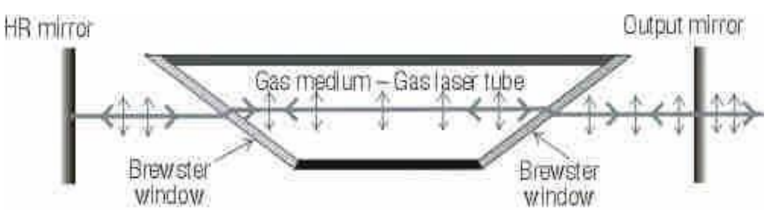
Polarization

Figure shown below is concerned with the operation of **Brewster windows** in a gas laser to produce a polarized laser beam.

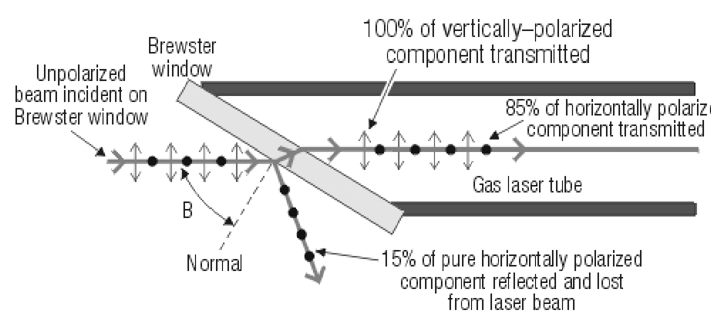
Figure (a) shows the overall cavity geometry, Figure (b) shows the initial action of a Brewster window on an unpolarized laser beam incident on window at Brewster's angle (56° for an air-to-glass interface).



(a) Overall cavity geometry



(c) Beam polarized in vertical direction after a short time, essentially no horizontal component remains



(b) Effect of Brewster window on incident unpolarized light beam

Laser light is highly powerful

Laser light is produced by amplification of the light and also highly monochromatic and directional. Therefore it is powerful than ordinary light.

Being highly directional,the power of the laser beam can be maintained over the large distances.

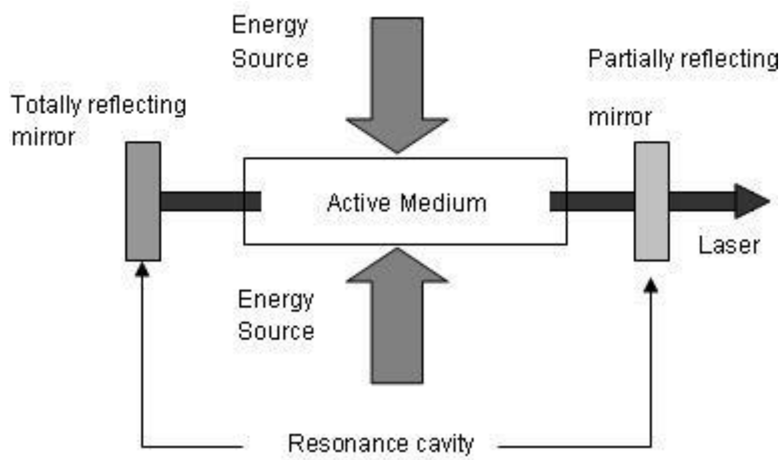
Components of laser

Components of Lasers

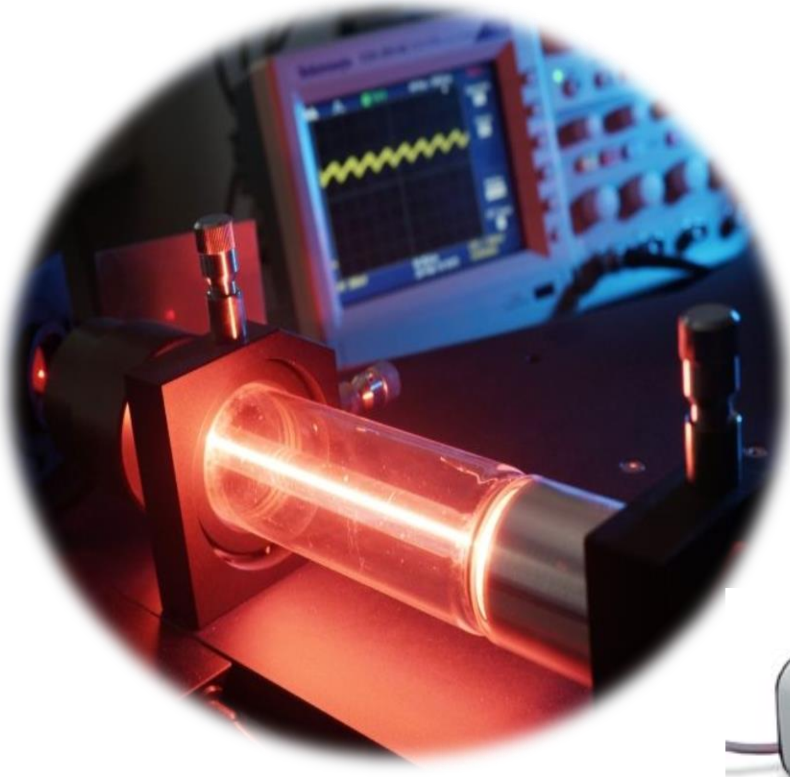
1.Active Medium : It is the material in which the laser action takes place. The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO_2 or Helium / Neon, or semiconductors such as GaAs. This medium decides the wavelength of laser radiation. Active mediums contain atoms which can produce more stimulated emission than spontaneous emission and cause amplification they are called "***Active Centers***".

2.Energy Source (Excitation Mechanism): Energy Source (Excitation mechanisms) pumps the active centers from ground state to excited state to achieve population inversion. The pumping by energy source can be optical, electrical or chemical depending on the active medium.

3.Resonance Cavity: Resonance cavity consists of active medium enclosed between two mirrors one is ***highly reflective mirror*** (100% reflective) and the other is ***partially transmissive mirror*** (99% reflective).



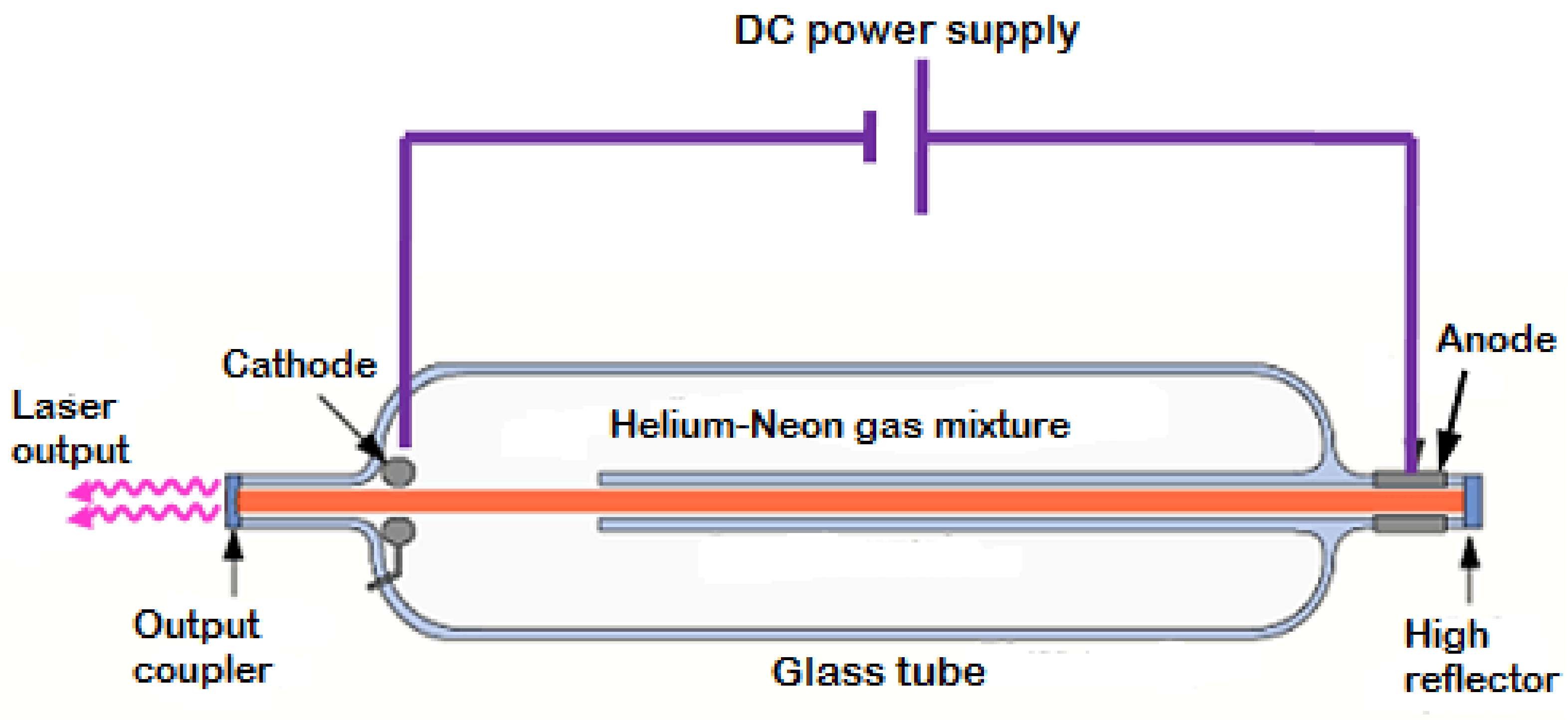
Helium-Neon (He-Ne) LASER



He-Ne laser

- It is a four level laser. Therefore population inversion can be easily obtained.
- It works in continuous mode(CW mode)
- The power output of He-Ne laser lies in the range 1-50mW with input electrical power of 10 watt.
- The laser is capable of supplying continuous laser beam without need of elaborate cooling arrangement.
- The light from He-Ne Laser is more directional and much more monochromatic as compared to that from solid state Laser.
- The He-Ne laser employs electrical pumping.

He-Ne laser

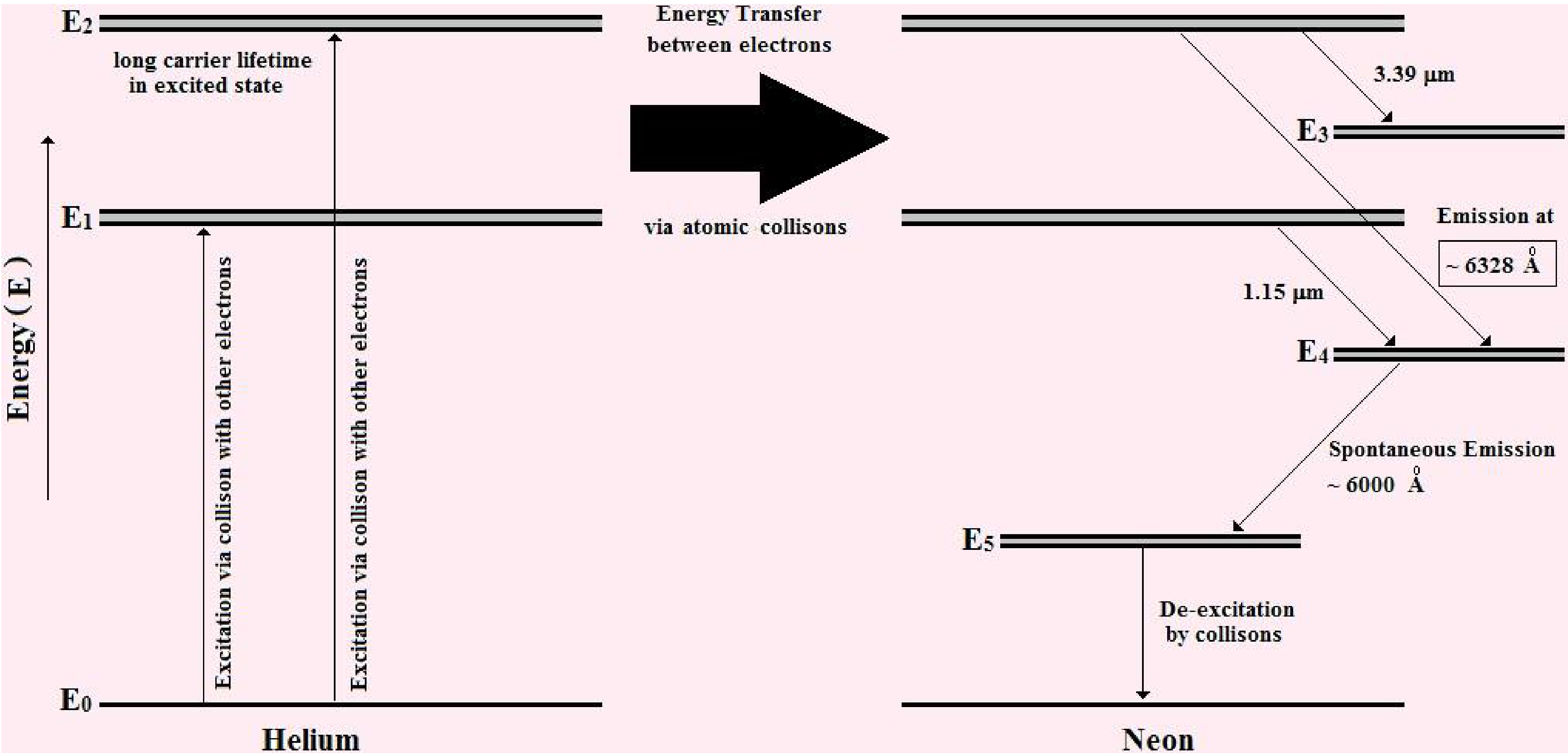


DC power supply
Cathode
Laser output
Helium-Neon gas mixture
Anode
Output coupler
Glass tube
High reflector

He-Ne laser- Construction

- The He-Ne laser consists of a long and narrow discharge tube of length=25 cm to 100 cm and diameter=1cm. It is filled with He and Ne gases at a pressure of about 1mm of Hg(for He)and 0.1 mm of Hg(for Ne).
- The gas mixture of He & Ne (85% : 15%) forms the lasing medium and is enclosed between a set of mirrors forming a resonant cavity.
- A stationary glow discharge is excited in the gas by applying a few kilovolt d.c supply.

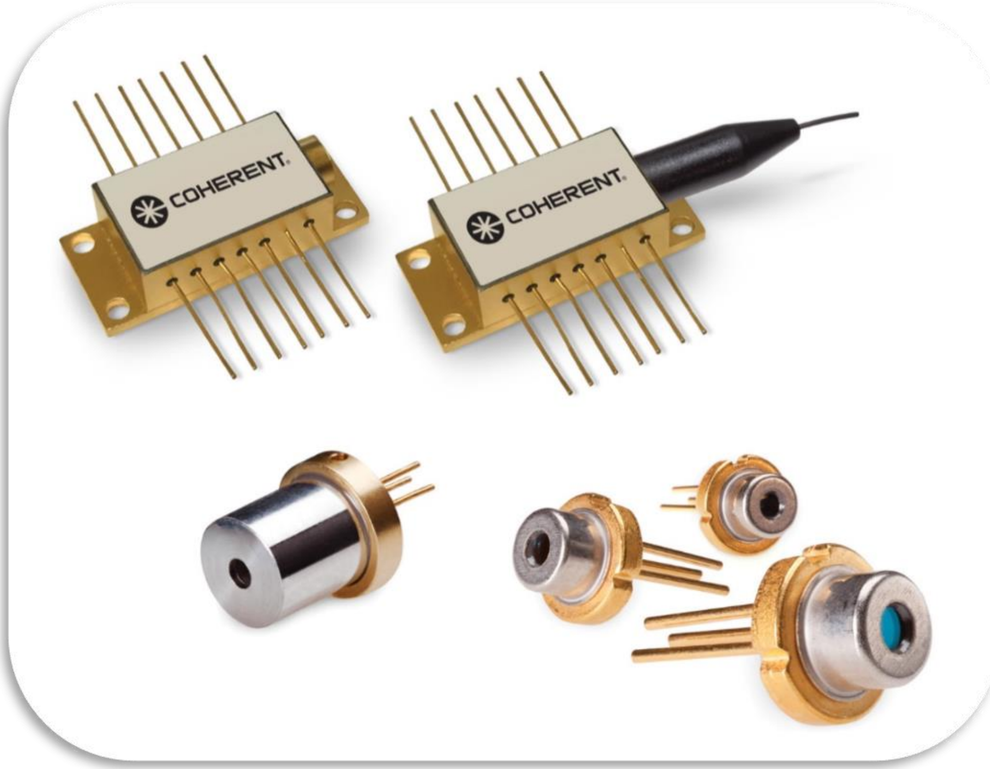
He-Ne laser- Working Principle



He-Ne laser- Applications

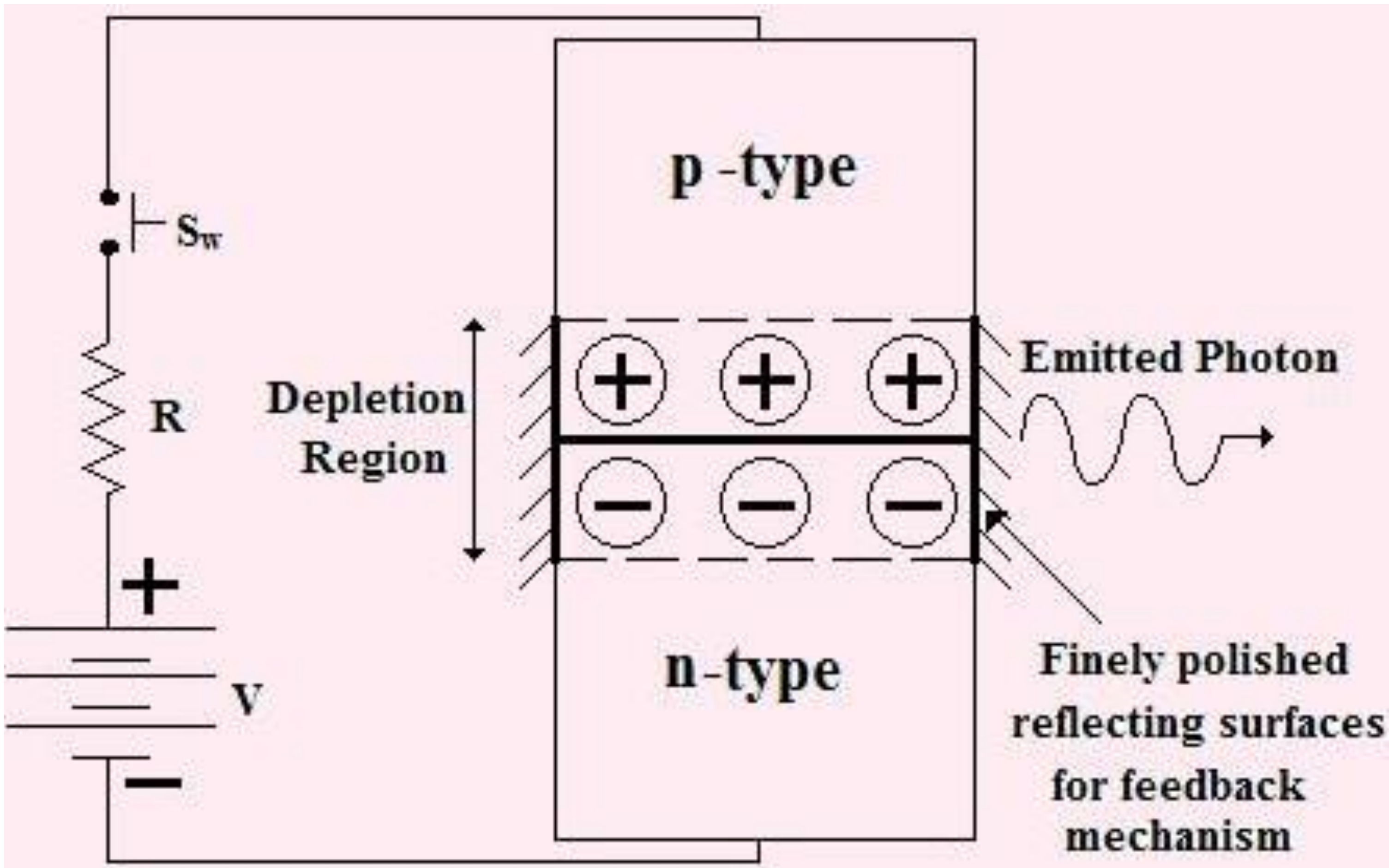
1. They are often used in integrated bar code readers.
2. He-Ne laser are used in laser surgery to position the powerful infrared cutting beam.
3. Surveyors take advantage of good quality of He-Ne laser beam to take measurement over long distance.

Semiconductor/Diode LASER

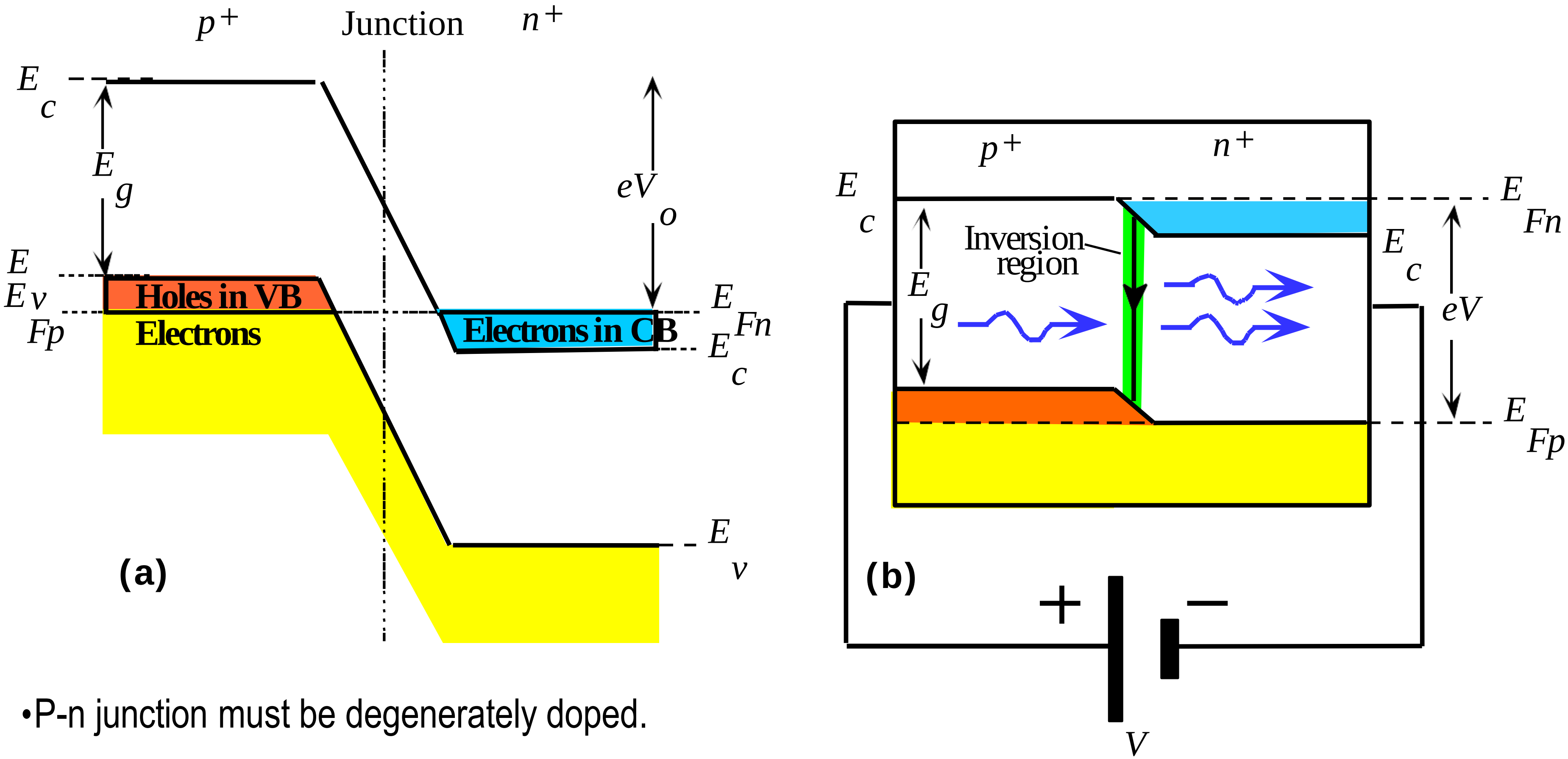


- Consider a p-n junction
- In order to design a laser diode, the p-n junction must be heavily doped.
- In other word, the p and n materials must be degenerately doped
- By degenerated doping, <u>the Fermi level of the n-side will lies in the conduction band whereas the Fermi level in the p-region will lie in the valance band.</u>

Diode laser- Applications



Diode Laser Operation



•P-n junction must be degenerately doped.

•Fermi level in valance band (p) and conduction band (n).

•No bias, built n potential; eV_o barrier to stop electron and holes movement

•Forward bias, $eV > E_g$

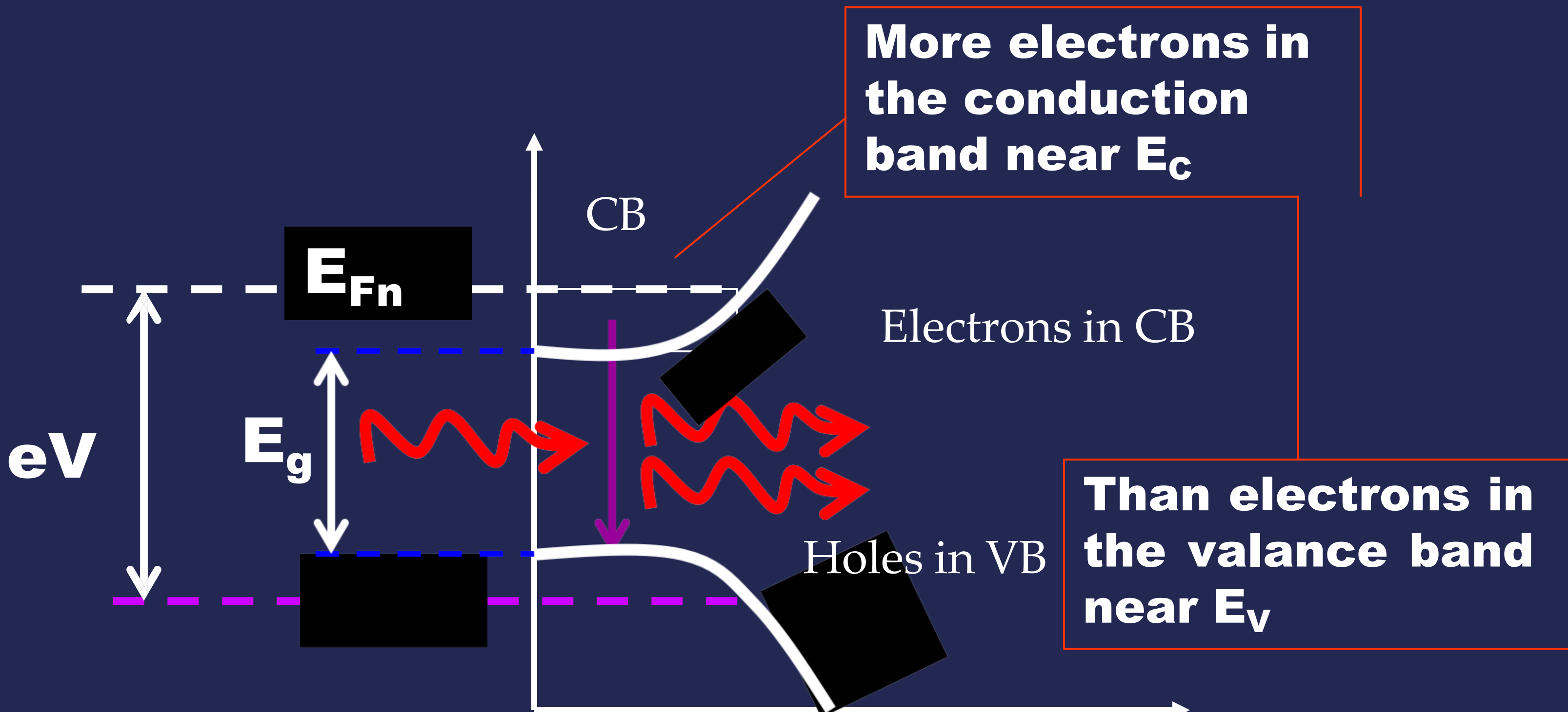
•Built in potential diminished to zero

•Electrons and holes can diffuse to the space charge layer

Application of Forward Bias

- Suppose that the degenerately doped p-n junction is forward biased by a voltage greater than the band gap; $eV > E_g$
- The separation between E_{Fn} and E_{Fp} is now the applied potential energy
- The applied voltage diminished the built-in potential barrier, eV_o to almost zero.
- Electrons can now flow to the p-side
- Holes can now flow to the n-side

Population Inversion in Diode Laser



$E_{Fn}-E_{fP} = eV$

$eV > E_g$

eV = forward bias voltage

Fwd Diode current pumping → injection pumping

- There is therefore a **<u>population inversion</u>** between energies near E_C and near E_V around the junction.
- This only achieved when degenerately doped p-n junction is forward bias with energy > E_{gap}

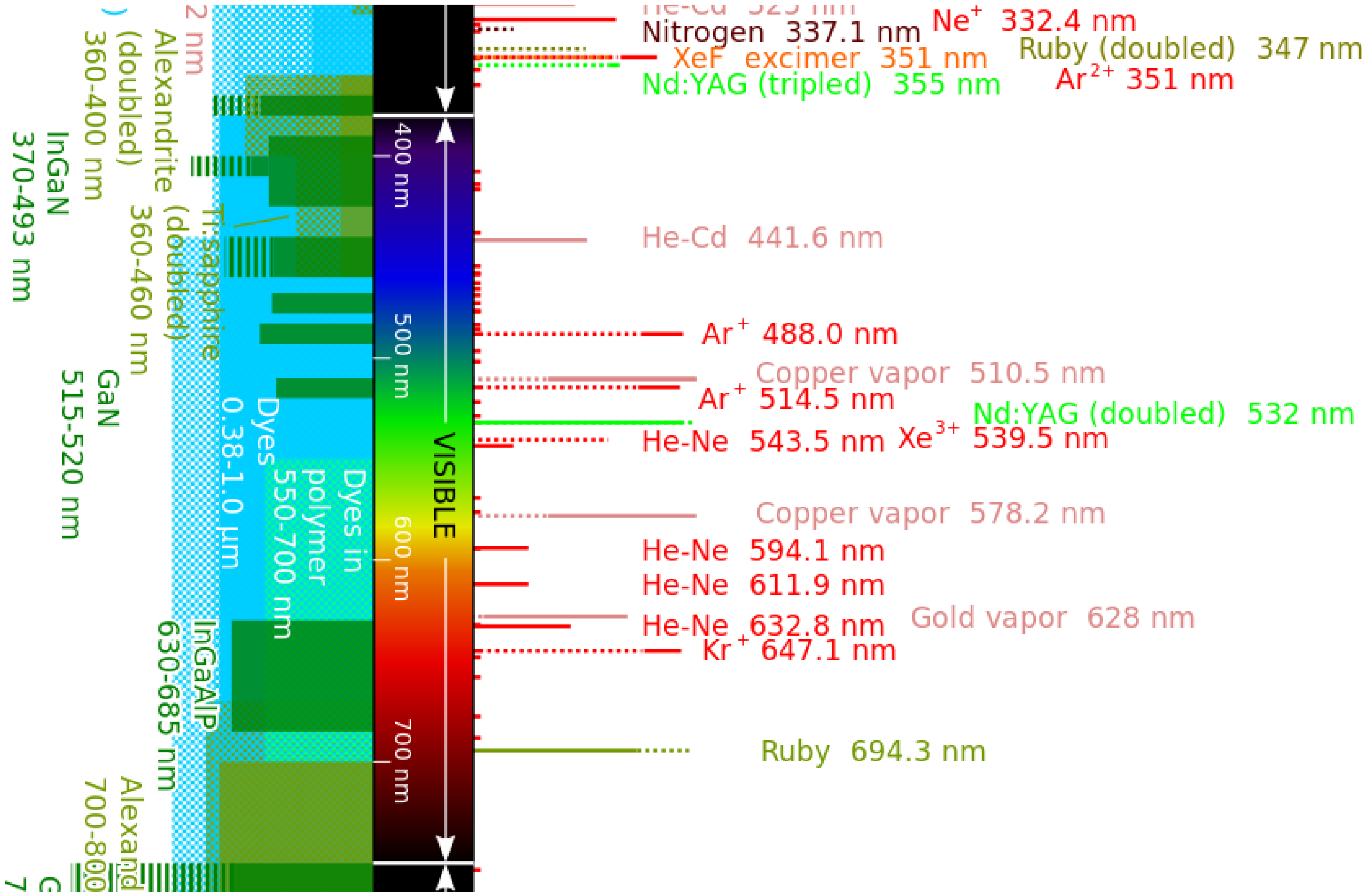
The Lasing Action

- The population inversion region is a layer along the junction also call inversion layer or active region
- Now consider a photon with E = Eg
- Obviously this photon can not excite electrons from E_V since there is NO electrons there
- However the photon CAN STIMULATE electron to fall down from CB to VB.
- Therefore, the incoming photon stimulates emission than absorption
- The active region is then said to have ‘optical gain’ since the incoming photon has the ability to cause emission rather than being absorbed.

Pumping Mechanism in Laser Diode

- It is obvious that the population inversion between energies near EC and those near EV occurs by injection of large charge carrier across the junction by forward biasing the junction.
- Therefore the pumping mechanism is FORWARD DIODE CURRENT Injection pumping

Laser Materials



Laser are used in various field.

- MANUFACTURING (INDUSTRY)
- MADICAL
- METROLOGY
- DATA-STORAGE
- COMMUNICATIONS
- DISPLAYS
- SPECTROSCOPY
- MICROSCOPY
- ENERGY TECHNOLOGY
- MILITARY
- SCIENCE AND TECHNOLOGY

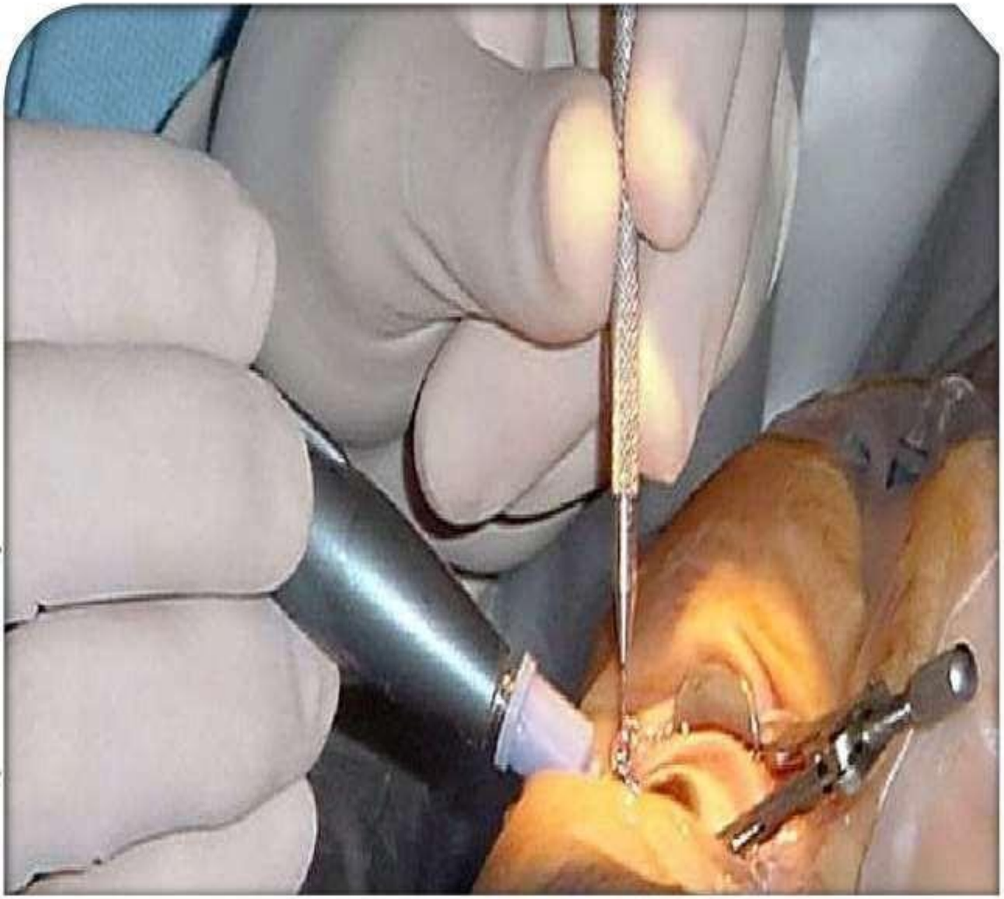
IN INDUSTRY:

WELDING & CUTTING OF METAL

- Lasers are widely used in manufacturing(industry), e.g.

  for- cutting, drilling, welding, cladding, soldering (brazing), hardening, ablating, surface treatment, marking, engraving, micromachining, pulsed laser deposition, lithography, alignment, etc.

IN MEDICAL:



- Use for the treatment of detached retinas.
- Use in performing bloodless surgery
- Use for the treatment of human and animal cancers and skin tumtors.

Laser communication:

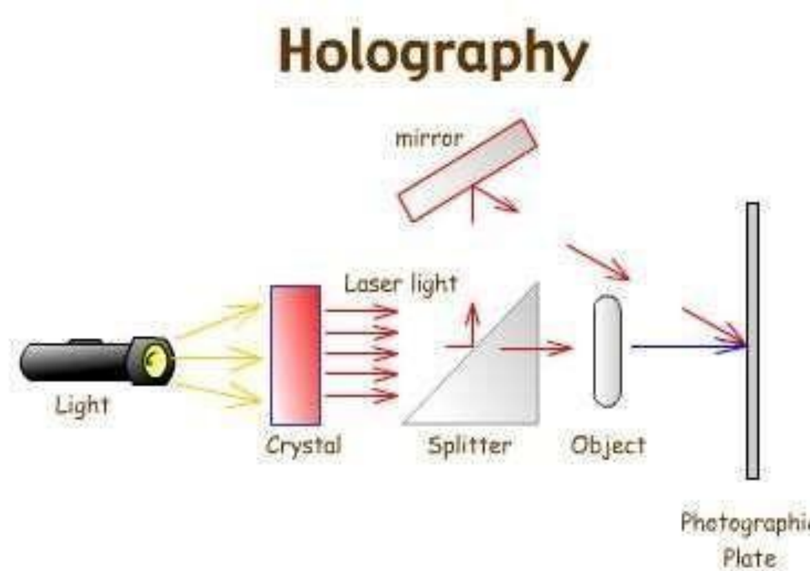
laser based communication system fig 1. ece

In communication

Laser communications systems are wireless connections through the atmosphere. They work similarly to fiber optic links, except the fact that, in lasers, beam is transmitted through free space.

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

Data Storage



- **Data Storage**
- Optical data storage e.g. in compact disks (CDs), DVDs, Blu-ray Discs and magneto- optical disks, nearly always relies on a laser source,

  which has a high spatial coherence and can thus be used to address very tiny spots in the recording medium, allowing a very high density data storage.

In Science and Technology.

Lunar Laser Ranging.

- In Lunar Laser Ranging Experiment, Laser beams are focused through large telescopes on Earth aimed toward the arrays, and the time taken for the beam to be reflected back to Earth measured to determine the distance between the Earth and Moon with high accuracy

In Military.

There are a variety of military laser applications. In relatively few cases,

lasers are used as weapons; Some high-power lasers are currently developed for potential use as directed energy weapons on the battle field, or for destroying missiles, projectiles and mines.

- In other cases, lasers function as target designators or laser sights (essentially laser pointers emitting visible or invisible laser beams), or as irritating or blinding (normally not directly destroying) countermeasures e.g. against

  heat-seeking anti-aircraft missiles. It is also possible to blind soldiers temporarily or permanently with laser beams, although the latter is forbidden by rules of war.

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