كلية الهندســـة بشبرا
FACULTY OF ENGINEERING- SHOUBRA
BENHA UNIVERSITY

Optical Communications
ECE423/ELE424/CCE507/ELE480

LEC (06)
LASER Diodes – Part I

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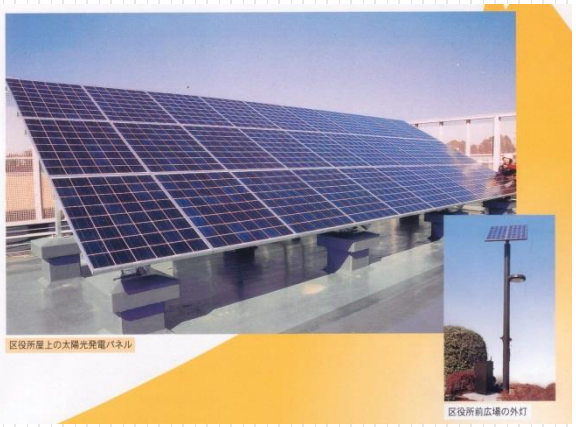


LECTURE OUTLINES

Drawbacks of LED
What is Laser
Basic concepts for a laser
Laser Characteristics (Properties)
Laser Radiation Properties
How does a laser work?
Laser Hazards

Drawbacks of LED

Drawbacks of LED:

Large line width (30-40 nm)

Large beam width (Low coupling to the fiber)

Low output power

Low Electrical/Optical conversion efficiency

- **Spontaneous emission (random polarization, phase, direction etc.)**

The Laser is designed to address all these issues

Laser everywhere

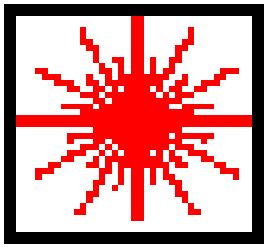
Laser everywhere

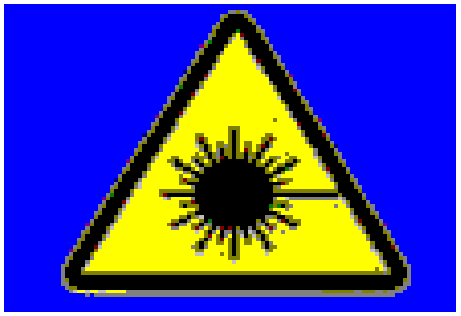
Laser printer

Laser pointer

Common Laser Signs and Labels

Common Laser Signs and Labels





What is Laser

- The laser is perhaps the most important optical device to be developed in the past 50 years (in the 1960s).
- A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

- **Laser** : is a device converts waves from different forms to EM wave (Light). But this light has a different characteristics than any other types of light.

- The word LASER is an acronym for :
  "Light Amplification by Stimulated Emission of Radiation"

- **Light**: All light is a form of electromagnetic radiation that is visible to the human eye.
- **Amplification**: This is simply the process of making something bigger or more powerful. When you turn up the volume on a radio, you are amplifying the sound; but with lasers, amplification makes the light brighter.
- **Stimulated**: To stimulate means to stir to action. Laser light is created when a burst of light (electricity) excites the atoms in the laser to emit photons. These photons then stimulate the creation of additional identical photons to produce the bright laser light.
- **Emission**: The word "emission" refers to something that is sent out or given off. Stimulated laser emission consists of large numbers of photons that create the intense laser light.
- **Radiation**: The laser light is a form of energy that radiates, or moves out, from the laser source.

- Laser is essentially an ***optical oscillator***.

- It is a **resonant** optical amplifier whose output is fed back into its input with **matching phase**. Any oscillator contains:

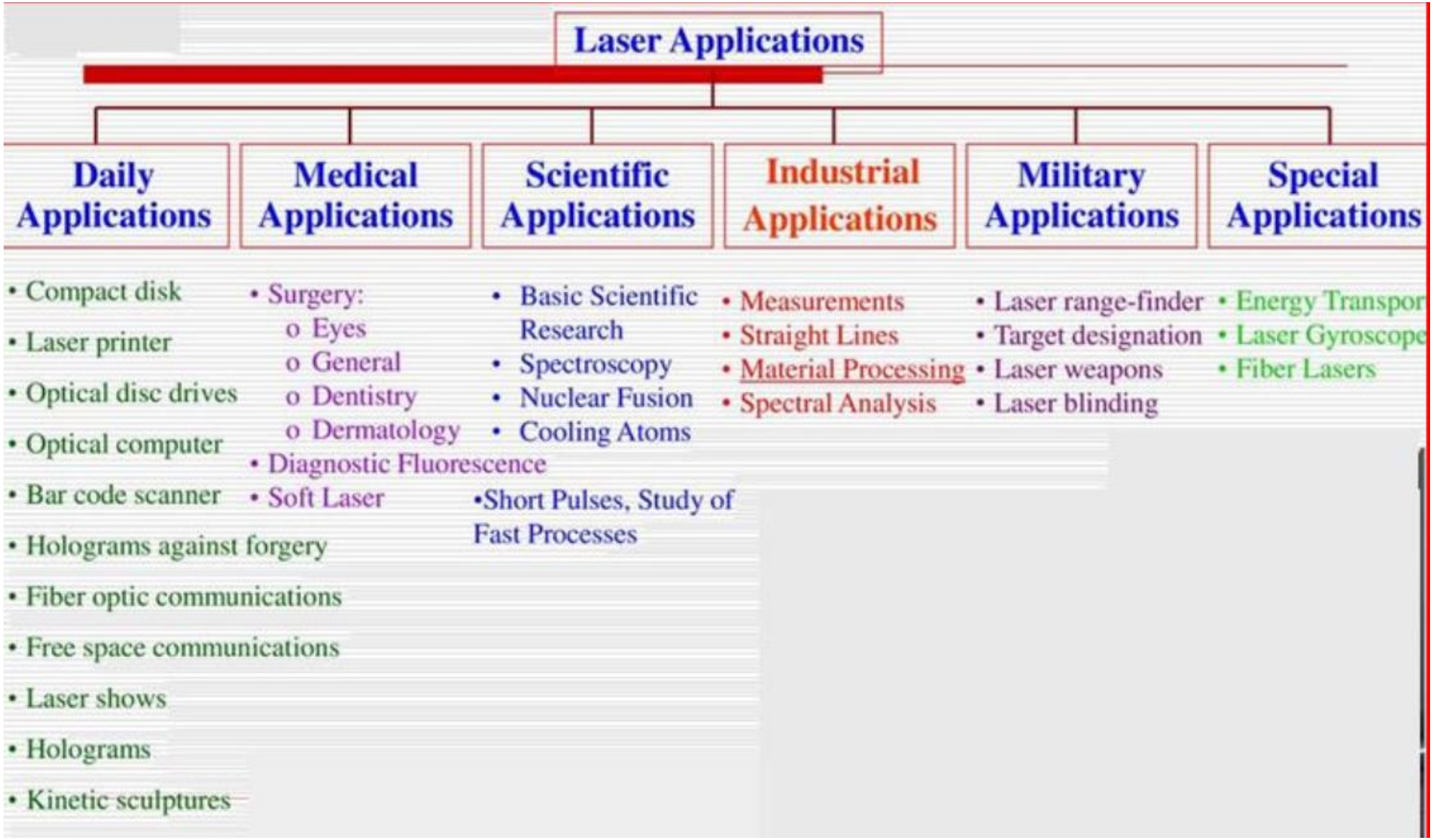
1- An amplifier (with gain-saturation mechanism)

2- A positive feedback system

3- A frequency selection mechanism

4- An output coupling scheme

Laser Applications

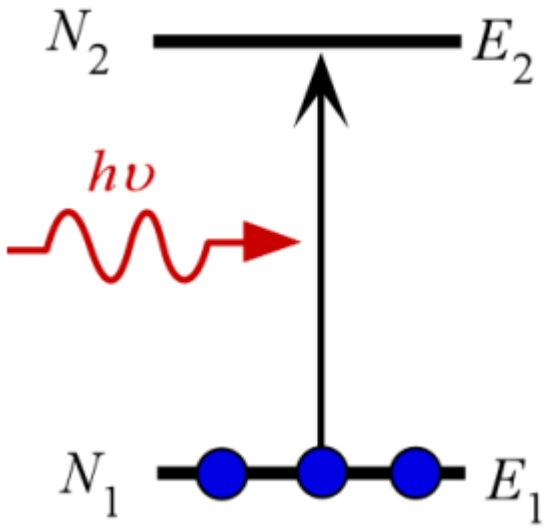

Laser Applications
Daily Applications
Medical Applications
Scientific Applications
Industrial Applications
Military Applications
Special Applications
• Compact disk
• Laser printer
• Optical disc drives
• Optical computer
• Bar code scanner
• Holograms against forgery
• Fiber optic communications
• Free space communications
• Laser shows
• Holograms
• Kinetic sculptures
• Surgery:
o Eyes
o General
o Dentistry
o Dermatology
• Diagnostic Fluorescence
• Soft Laser
• Basic Scientific Research
• Spectroscopy
• Nuclear Fusion
• Cooling Atoms
•Short Pulses, Study of Fast Processes
• Measurements
• Straight Lines
• Material Processing
• Spectral Analysis
• Laser range-finder
• Target designation
• Laser weapons
• Laser blinding
• Energy Transpor
• Laser Gyroscope
• Fiber Lasers

Basic concepts for a laser

Basic concepts for a laser

- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population inversion

Absorption / Stimulated Absorption

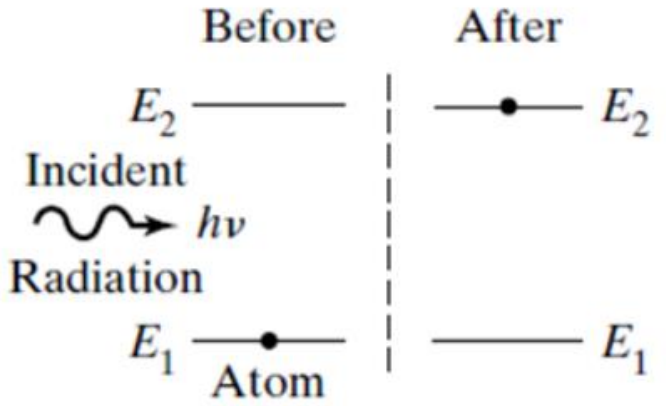


- Energy is absorbed by an atom, the electrons are excited into vacant energy shells.

Absorption

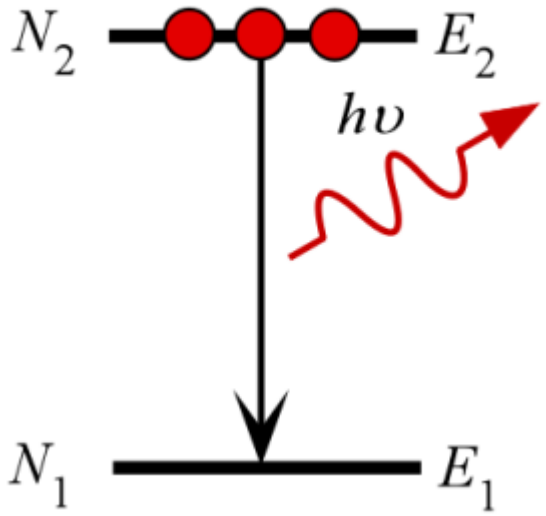
- Assume there is a total of *N* atoms, each of which is capable of being in one of two energy states:
  1. The *ground state*, with energy E_1 having N_1 atoms
  2. The *excited state*, with energy E_2, with $E_2 > E_1$, having N_2 atoms such that

- ***Absorption*** occurs whenever radiation containing photons of energy $h\nu = E_2 - E_1$ is incident on matter (atom) with ground state energy E_1 and arbitrary excited energy E_2.



- The resonant photon energy $h\nu$ raises the atom from energy state E_1 to E_2. In the process, the photon is absorbed.

Spontaneous Emission



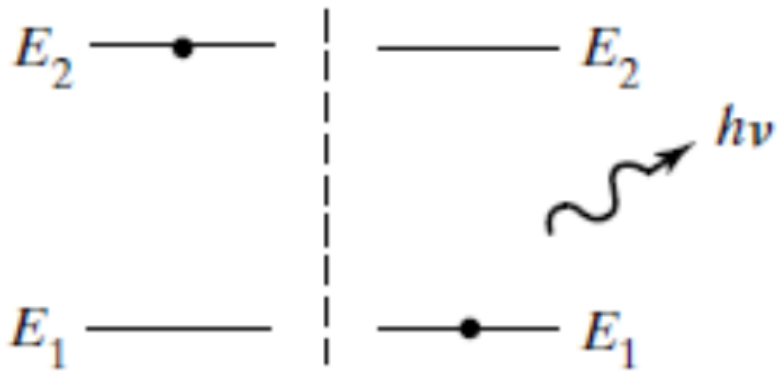
$$E = \hbar\omega = hf$$

- The atom decays from level 2 to level 1 through the emission of a photon with the energy $h\nu$. It is a completely random process.

Spontaneous emission

- ***Spontaneous emission*** *takes place whenever atoms are in excited state.*

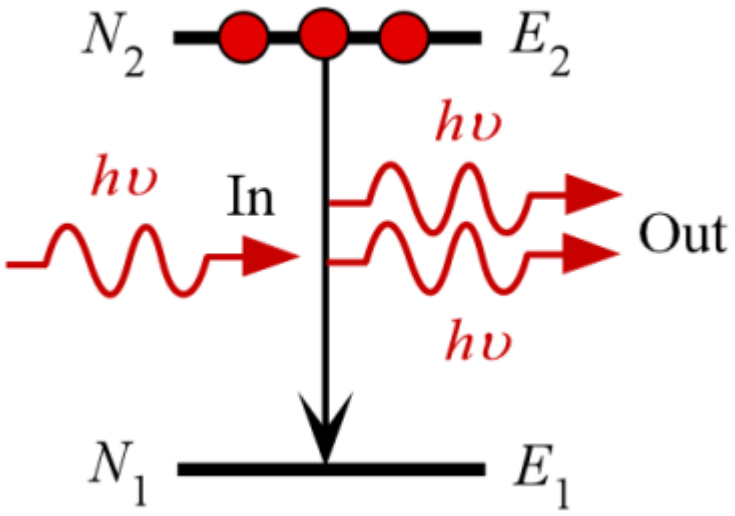
- *No external radiation is required to initiate the emission.*



- *In this process, when atom in an excited state* E_2 *spontaneously gives up its energy and falls to* E_1*, a photon of energy* $hv = E_2 - E_1$ *is released.*

- *The photon is emitted in a random radiation which is uncorrelated with the direction of the external radiation.*

Stimulated Emission ≡ Optical Amplification

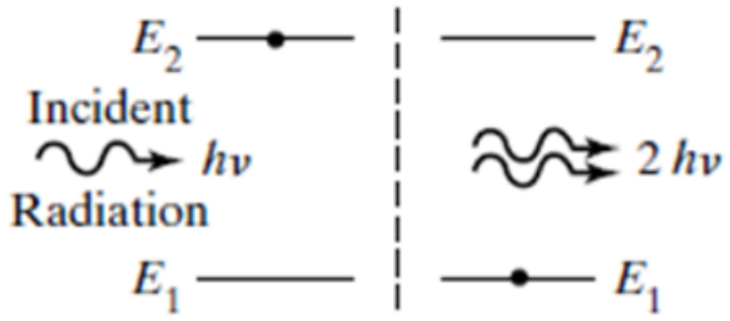


1 Incident Photon + Population Inversion= 2 Photons

atoms in an upper energy level can be triggered or stimulated in phase by an incoming photon of a specific energy.

Stimulated emission

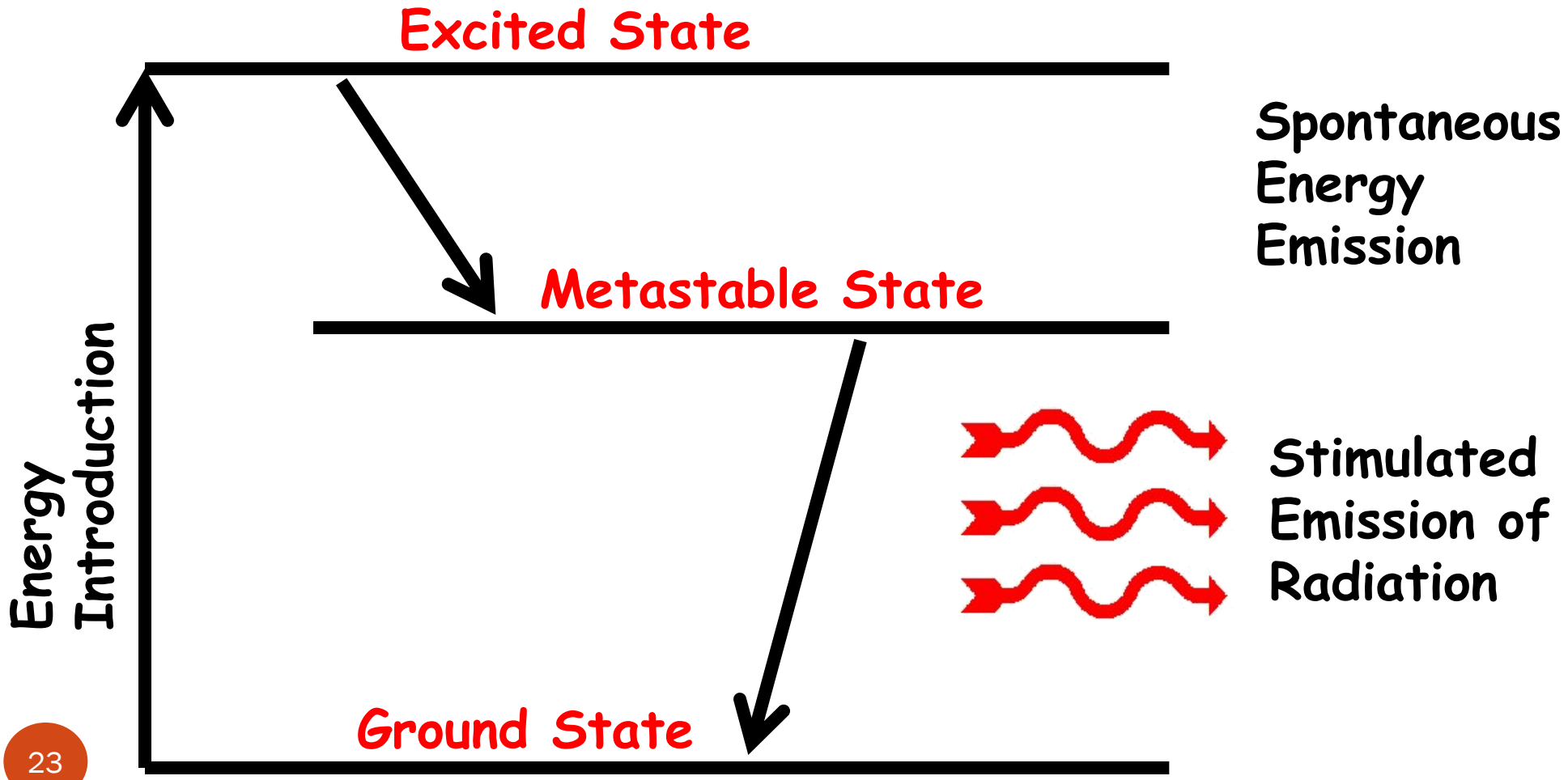
- ***Stimulated emission*** *requires of external radiation.*



- *When an incident photon of resonant energy* $h\nu = E_2 - E_1$ *passes by an atom in excited state* E_2 *, it simulates the atom to drop to the lower state* E_1.

- *In this process, the atom releases a photon of the same energy, direction, phase and polarization as that of the incident photon. The net effect is two identical photons.*

Lasing Action Diagram



Stimulated Emission

The stimulated photons have unique properties:

- In phase with the incident photon
- Same wavelength as the incident photon
- Travel in same direction as incident photon

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

Population Inversion

Population inversion ***REQUIRES*** ***Pumping*** **AT LEAST** ***more than***

Half **of the Total # of atoms** ***from*** E_1 ***to*** E_2 .

In semiconductor laser, population inversion is achieved by injecting electrons into the material to fill the lower energy states of the conduction band.

Satisfying Population Inversion **was quite hard**

(needed *44 years* !! from 1916 to 1960)

Remember: The original name of the LASER would be "LOSER" !!!

- Any oscillator contains:
  1- An amplifier (with gain-saturation mechanism)
  2- A positive feedback system
  3- A frequency selection mechanism
  4- An output coupling scheme

The Fundamental Physical Phenomenon:
'Stimulated Emission' of Radiation

Laser Characteristics (Properties)

Laser Characteristics

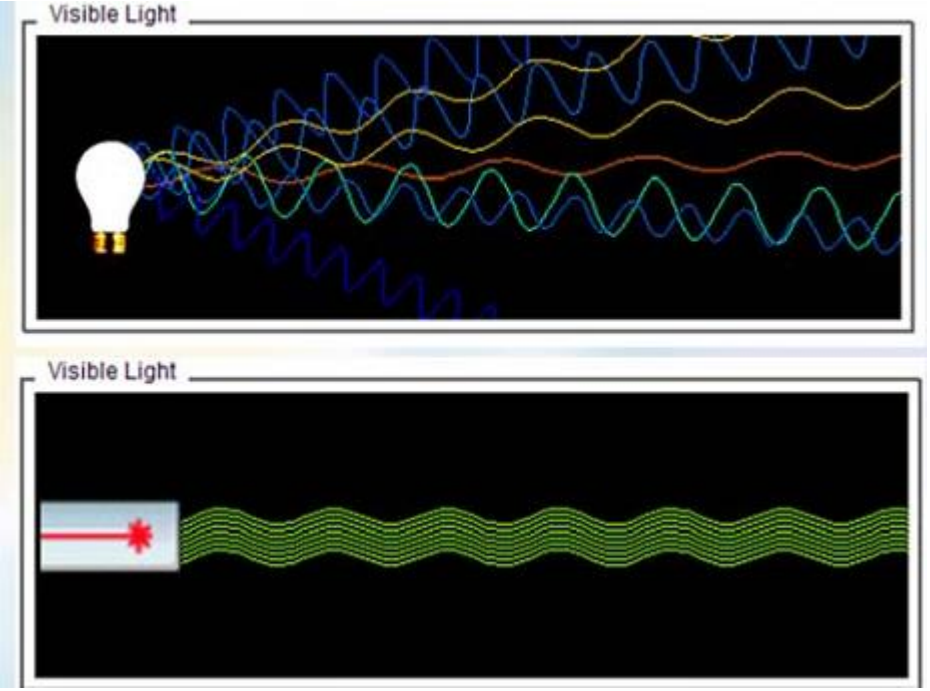
1. **Mono-chromaticity.**
2. **Directionality.**
3. **Coherence.**
4. **Brightness.**
5. **Polarization.**

- These Five properties make it more of a hazard than ordinary light.
- Laser light can deposit a great deal of energy within a very small area.

1- Mono-chromaticity

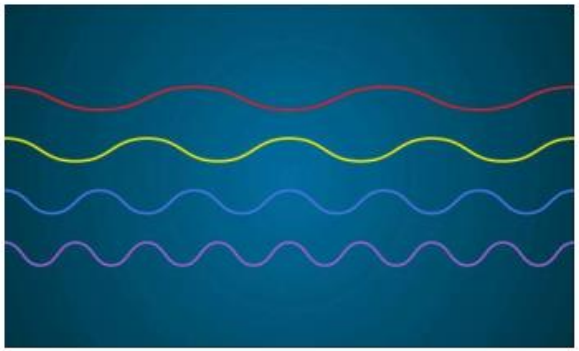
The light emitted from a laser is monochromatic, it is of one wavelength (color).

In contrast, ordinary white light is a combination of many different wavelengths (colors).

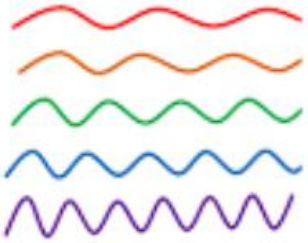


- The main characteristics of ordinary light, including natural light, are

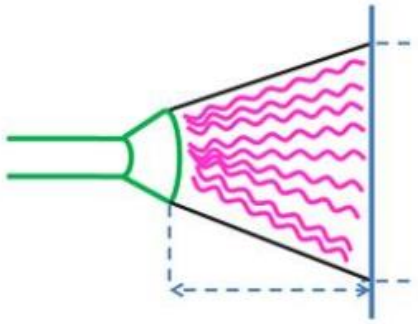
1. It is a mixture of different types of light of various wavelengths (polychromatic).
2. Wavelength phases (peaks and valleys of wavelengths) of each type of light are not synchronized (Incoherent).
3. It diverges from its light source and shines in all directions (non-collimated).



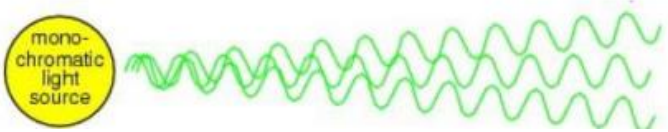
Polychromatic light



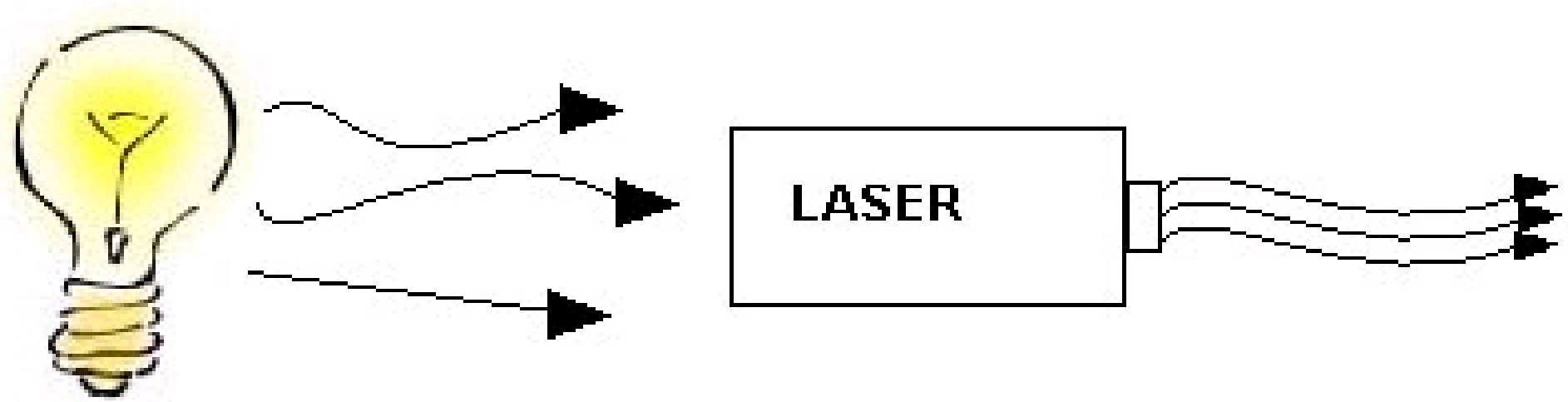
Incoherent Light Waves



Ordinary light



Incandescent vs. Laser Light



1. Many wavelengths
2. Multidirectional
3. Incoherent

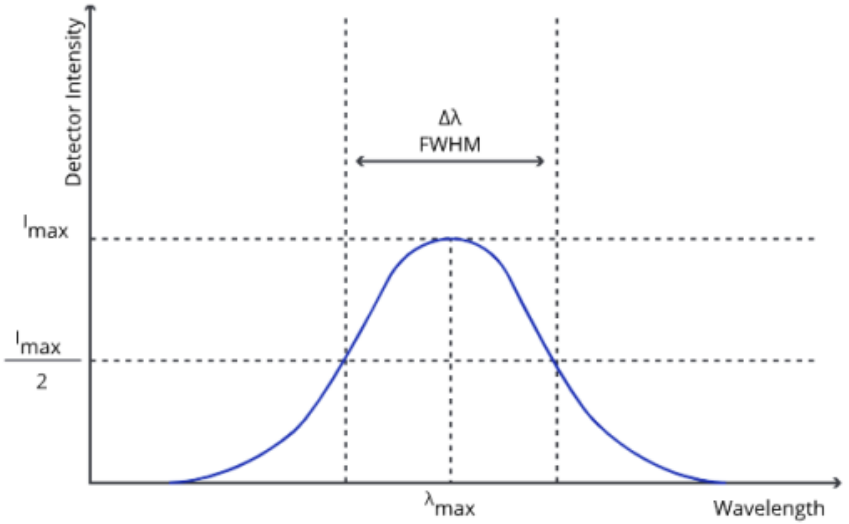
1. Monochromatic
2. Directional
3. Coherent

1- Mono-chromaticity

- *Monochromatic refers to a single wavelength, or "one color" of light.*
- *The light emitted by a laser is almost pure in color (almost of a single wavelength or frequency).*

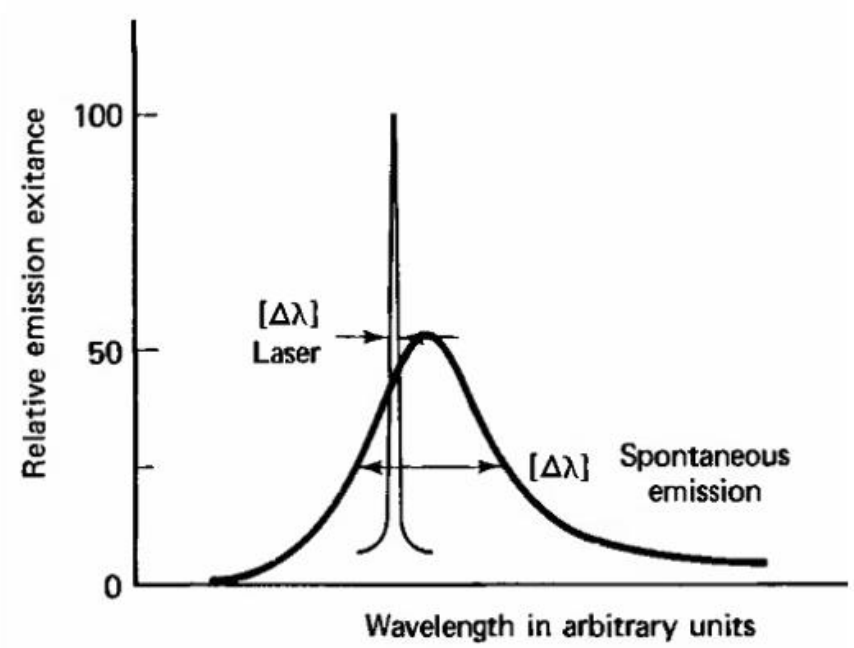
Note - Although no light can be truly monochromatic, laser light comes far closer than any other available source in meeting this ideal limit.

- The degree of monochromaticity is measured by the **spectral linewidth Δλ (or full width at half maximum - FWHM)** is very narrow which leading to light of a much high of monochromaticity



1- Mono-chromaticity

Comparison of line widths of a laser and an ordinary light source



2- Directionality

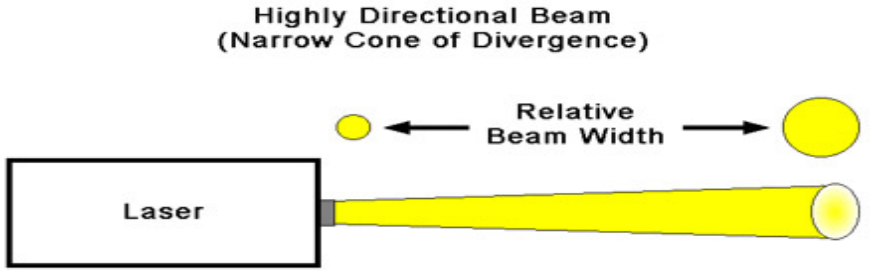
Lasers :

- emit light that is highly directional.
- It is emitted as a narrow beam in a specific direction. حيود مهمل

Ordinary light: (sun, light bulb, a candle)

- is emitted in many directions away from the source. حيود كبير

2- Directionality



Conventional light source Divergence angle (θ_d)

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

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

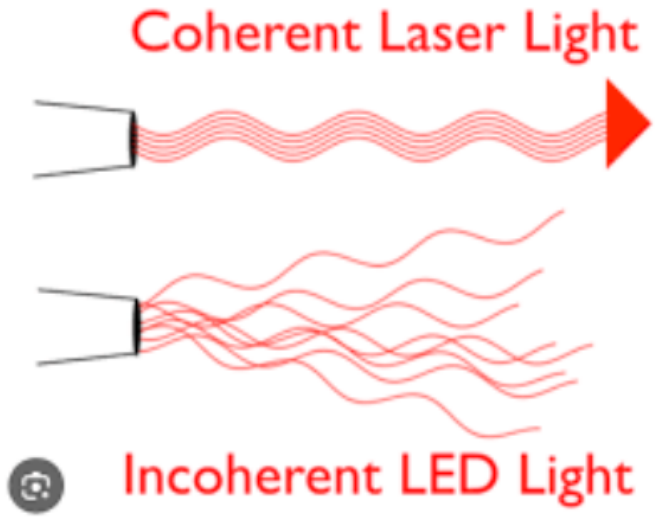
λ = wavelength

D = beam diameter

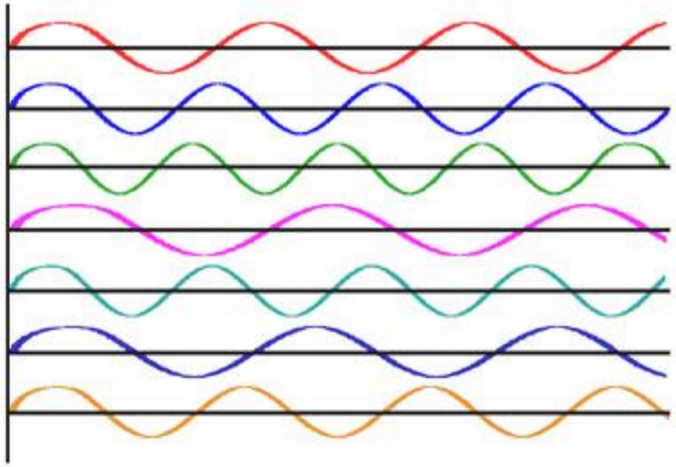
3- Coherence

- Coherence is a *measure of the degree of phase correlation* that is exists in the radiation field of a light source at different locations and different times.

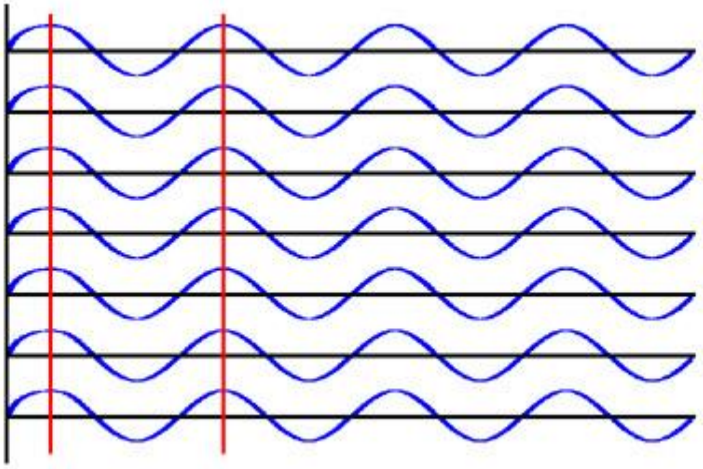
- The degree of coherence in the direction of wave propagation is referred to as ***longitudinal or temporal coherence***.



3- Coherence



Incoherent light waves



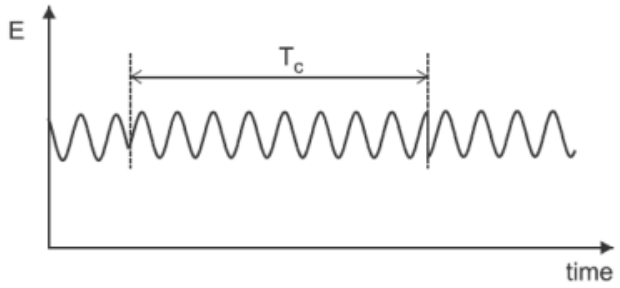
Coherent light waves

3- Coherence

- Perfect or ideal longitudinal coherence for an optical wave implies that the planes of constant phase are uniformly spaced without interruption.

- In practice, light sources never have perfect temporal coherence.

- The coherence time (T_c) is the average time over which the phase of the laser wave is unchanged.



- The longitudinal coherence length (L_c) is the average distance (in the direction of propagation) over which the laser wave is coherent.

3- Coherence

- The relation between coherence length and longitudinal coherence time (in vacuum) is

$$L_c = \mathrm{c}\, T_c$$

- To increase the coherence time, we should reduce the frequency linewidth ($\Delta\nu$) of laser source (according to the relation)

$$T_c \approx \frac{1}{\Delta\nu}$$

4- High Intensity

4. High intensity laser beam

- A sheet of paper can be burnt simply by focusing sunlight on it, using a convex lens. A laser is much more concentrated and can weld two pieces of steel together.

- Irradiance ***I*** (or flux density) is a term of radiometry that describes the amount of radiant power incident on a surface per unit area [units W/m^2].

$$I = \frac{P}{A}$$

For ordinary lightbulb
(radiates in all direction - spherical solid angle)

$$I = \frac{P}{\Omega\, r^2} = \frac{P}{4\pi\, r^2}$$

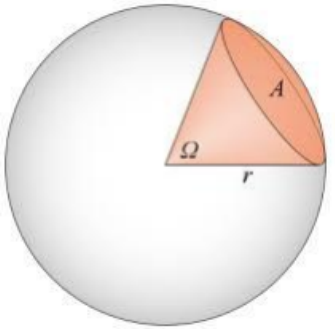
For laser
(D is the diameter of laser spot)

$$I = \frac{P}{A} = \frac{P}{\pi\,(D^2/4)}$$

$$solid\ angle\ \ \Omega = \frac{A}{r^2}$$

$\Omega = \pi$ For hemisphere

$\Omega = 4\pi$ For sphere



4- High Intensity

Example

- Lightbulbs spread their output uniformly in all directions, so that the irradiance **1 m** from a lightbulb with a light power output of **10 W** would be:

$$I = \frac{P}{4\pi r^2} \quad \Rightarrow \quad I = \frac{10}{4\pi (1)^2} = 0.796 \ \ \mathrm{W/m^2}$$

- For He-Ne laser with output power of 1 mW, if the laser beam radius after 1m is 2 mm, then, the irradiance is

$$I = \frac{P}{A} = \frac{0.001}{\pi (0.002)^2} = 79.6 \ \ \mathrm{W/m^2}$$

4- High Intensity

- To get the magnitude (or amplitude E) of the electric field of a laser beam in a laser medium of index of refraction n:

Since $I = \frac{1}{2}\varepsilon_o c n E_o^2$ $\Rightarrow$ E_o^2 $\Rightarrow$ $E_o^2 = \frac{2I}{\varepsilon_o n c}$

$\Rightarrow$ $$E_o = \sqrt{\frac{2I}{\varepsilon_o n\, c}}$$

- Thus, we can get the magnetic field density (B_o) as follows

$$B_o = \frac{E_o}{(c/n)}$$

$\varepsilon_o = 8.85 \times 10^{-12}$ F/m is the *permittivity* of free space

Laser Radiation Properties

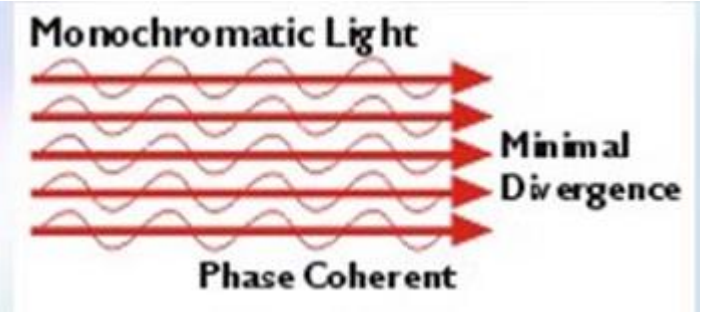
In Summary: **Laser Radiation Properties**

1.Very small divergence of the beam. The beam is almost a parallel beam and move in one direction in space - Directionality..

2.High degree of mono-chromaticity. The radiation is almost one wavelength, as can be measured by the very narrow spectral width.

3.Coherence.

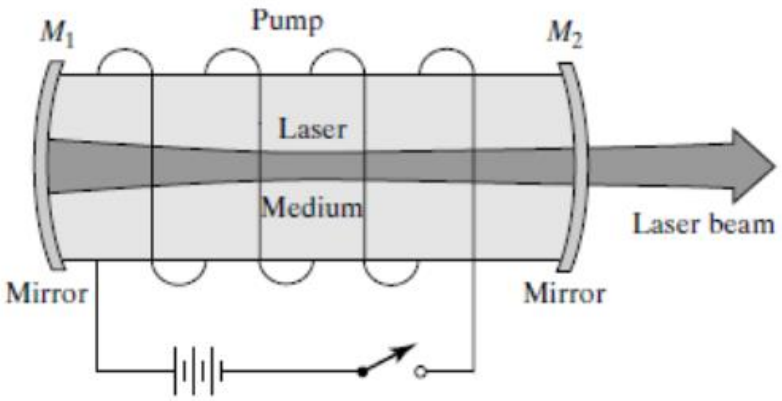
The combination of these properties gives the laser radiation many advantages, like achieving very high power densities, not available from other sources.

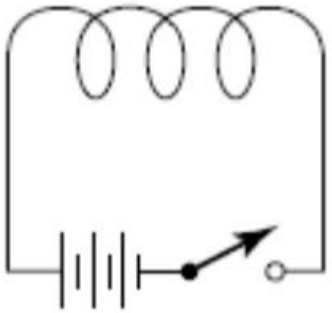


Main Elements of LASER

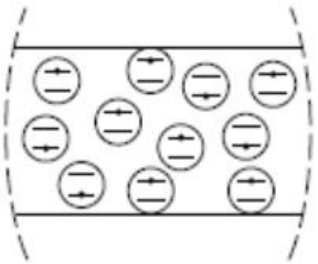
- *The laser device is an optical oscillator that emits an intense, highly collimated beam of coherent radiation.*

- *The device consists of three essential elements:*
  1. *External energy source (or pump)*
  2. *Laser medium (gain medium)*
  3. *Optical cavity (or resonator).*

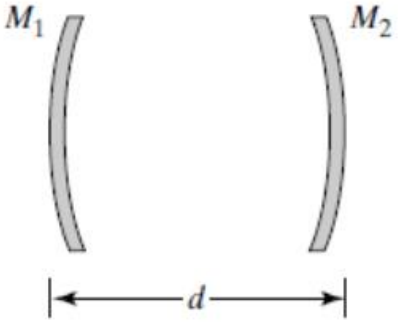




Pump



Laser medium



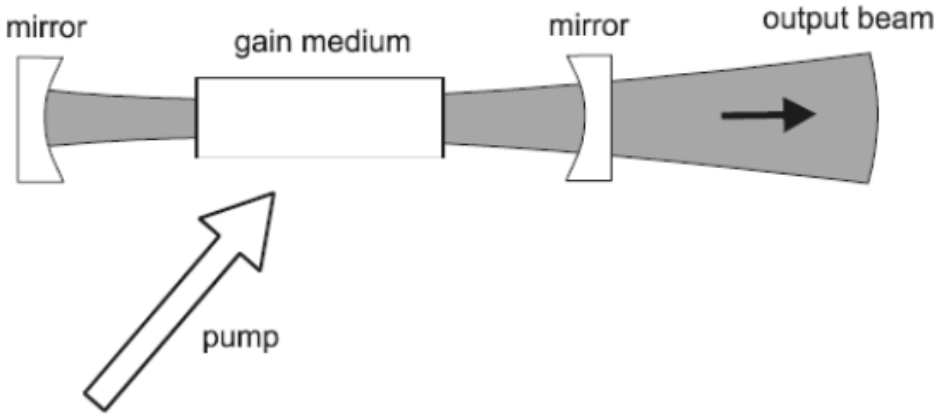
Resonator

- *The pumping mechanism* supplies energy to the laser medium to achieve the population inversion.
- A *gain medium* amplifies the light.
- Mirrors (or other reflective devices) provide *optical feedback.* The mirrors are arranged to circulate the light back and forth through the gain medium, forming an optical *cavity* or *optical resonator.*
  - This constitutes optical feedback in the sense that some of the amplified output is “fed back” to become input for additional amplification.

The Pump

- The pump is an external energy source that produces a population inversion $(N_2 > N_1)$ in the laser medium.

- Pumps can be optical, chemical, or electrical, to provide energy that can be coupled into laser medium to excite the atoms and create the required population inversion.



Thank you for your attention