B.SC.III

LASERS

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Unit-III

Laser Physics

LASERS

History of the LASER

- Invented in 1958 by Charles Townes (Nobel prize in Physics 1964) and Arthur Schawlow of Bell Laboratories

- Was based on Einstein's idea of the “particlewave duality” of light, more than 30 years earlier
- Originally called MASER (m = “microwave”)

Laser: everywhere in your life

Laser printer

Laser pointer

What is Laser?

Light Amplification by Stimulated Emission of Radiation

- A device produces a coherent beam of optical radiation by stimulating electronic, ionic, or molecular transitions to higher energy levels
- When they return to lower energy levels by stimulated emission, they emit energy.

Properties of Laser

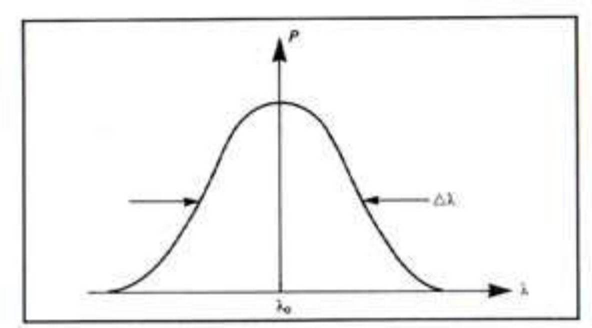
- The light emitted from a laser is monochromatic, that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.

- Lasers emit light that is highly directional, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.

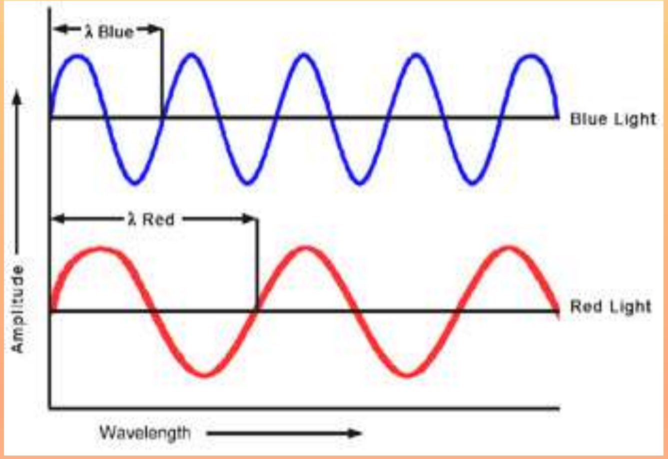
- The light from a laser is said to be coherent, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.

These three properties of laser light are what can make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.

Monochromacity

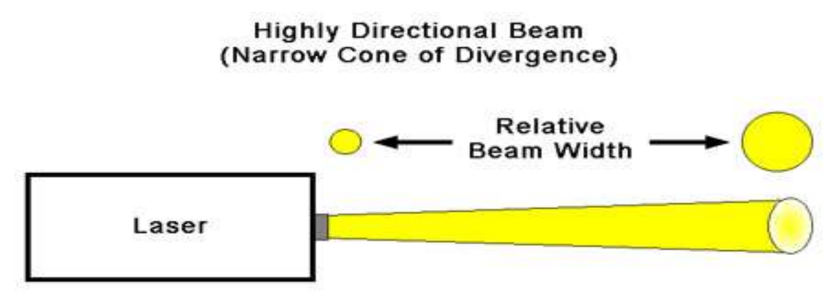


Nearly monochromatic light
Example:
He-Ne Laser
λ0 = 632.5 nm
Δλ = 0.2 nm
Diode Laser
λ0 = 900 nm
Δλ = 10 nm



Comparison of the wavelengths of red and blue light

Directionality



Conventional light source Divergence angle (θ_d)

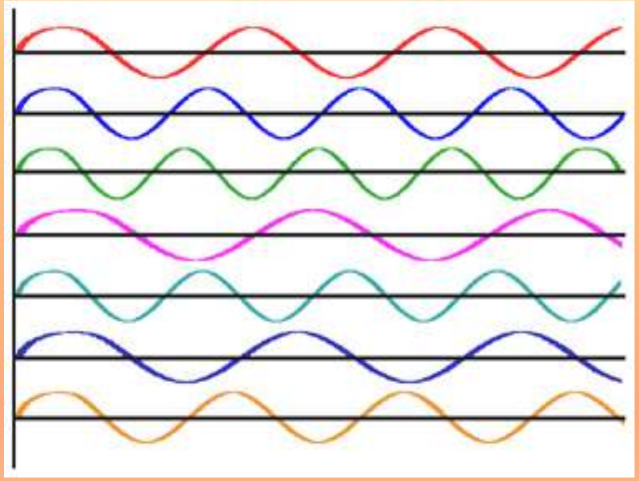
Beam divergence: $\boldsymbol{\theta_d = \beta \lambda / D}$

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

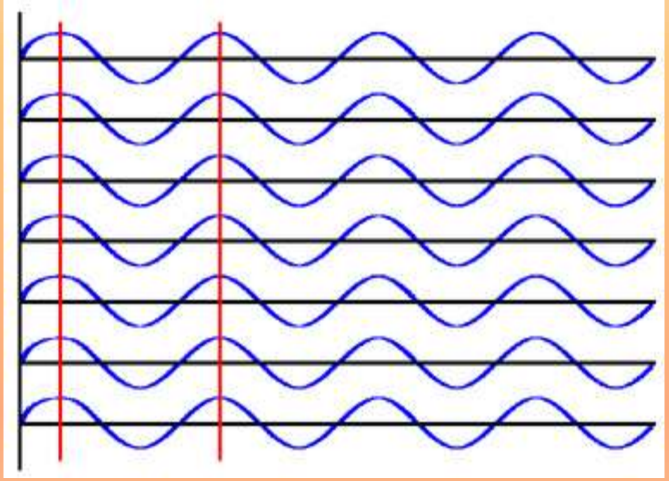
λ = wavelength

D = beam diameter

Coherence

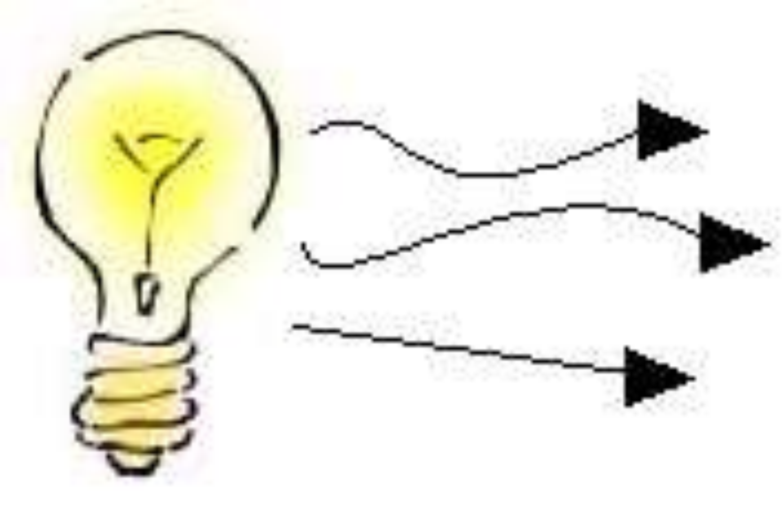


Incoherent light waves

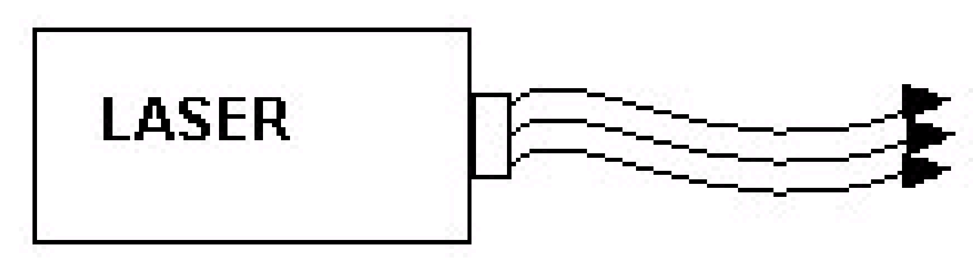


Coherent light waves

Incandescent vs. Laser Light



1. Many wavelengths
2. Multidirectional
3. Incoherent

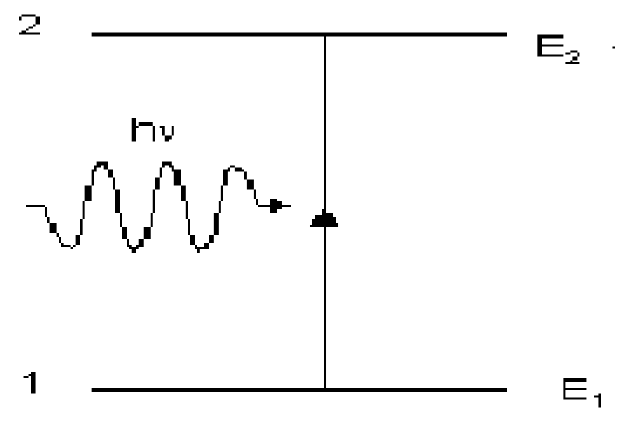


1. Monochromatic
2. Directional
3. Coherent

Basic concepts for a laser

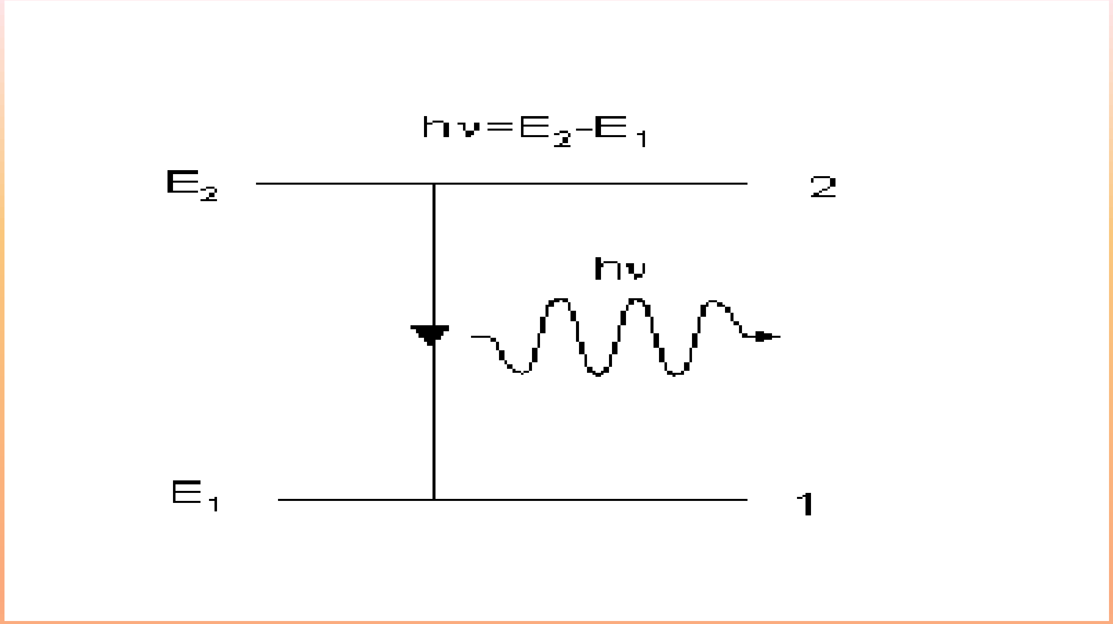
- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population inversion

Absorption



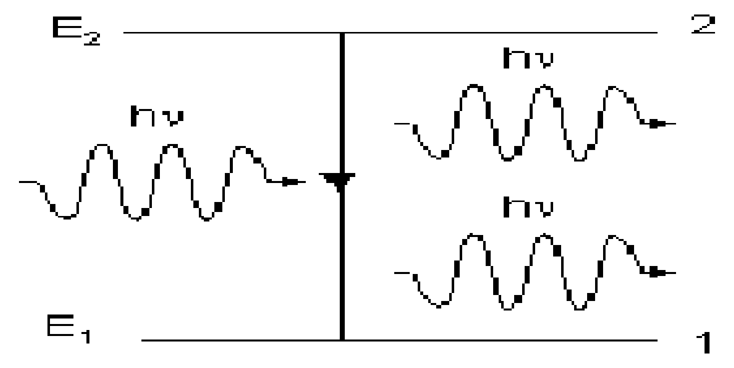
- Energy is absorbed by an atom, the electrons are excited into vacant energy shells.

Spontaneous Emission



- The atom decays from level 2 to level 1 through the emission of a photon with the energy *hv*. It is a completely random process.

Stimulated Emission



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

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

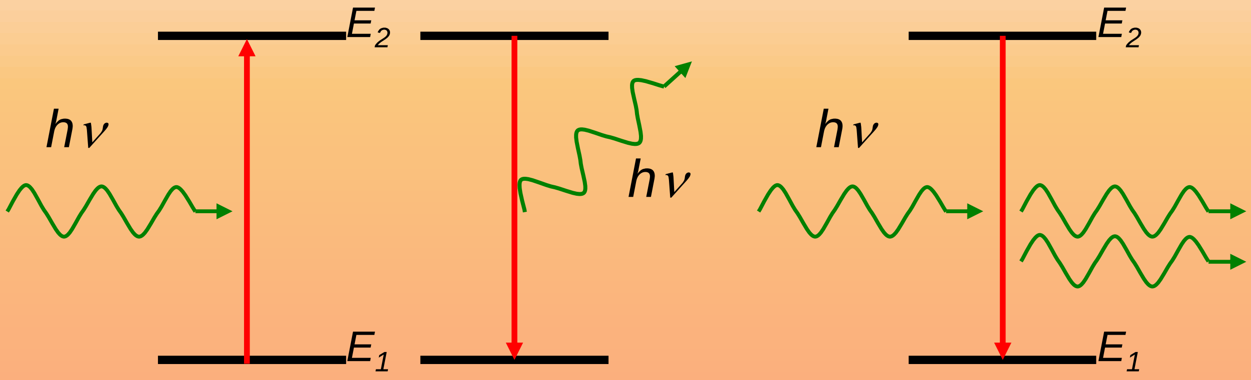
→by electrical discharge

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”

Two level system

$h\nu = E_2 - E_1$

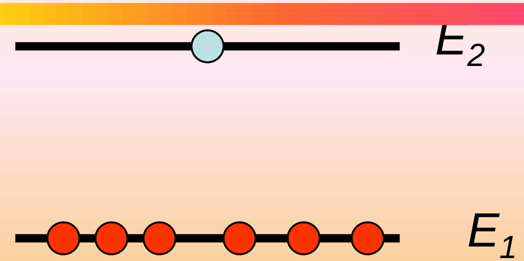


absorption

Spontaneous emission

Stimulated emission

Boltzmann's equation



$$\boxed{\frac{n_2}{n_1} = \exp\left(\frac{-(E_2 - E_1)}{kT}\right)}$$

example: T=3000 K E_2-E_1=2.0 eV

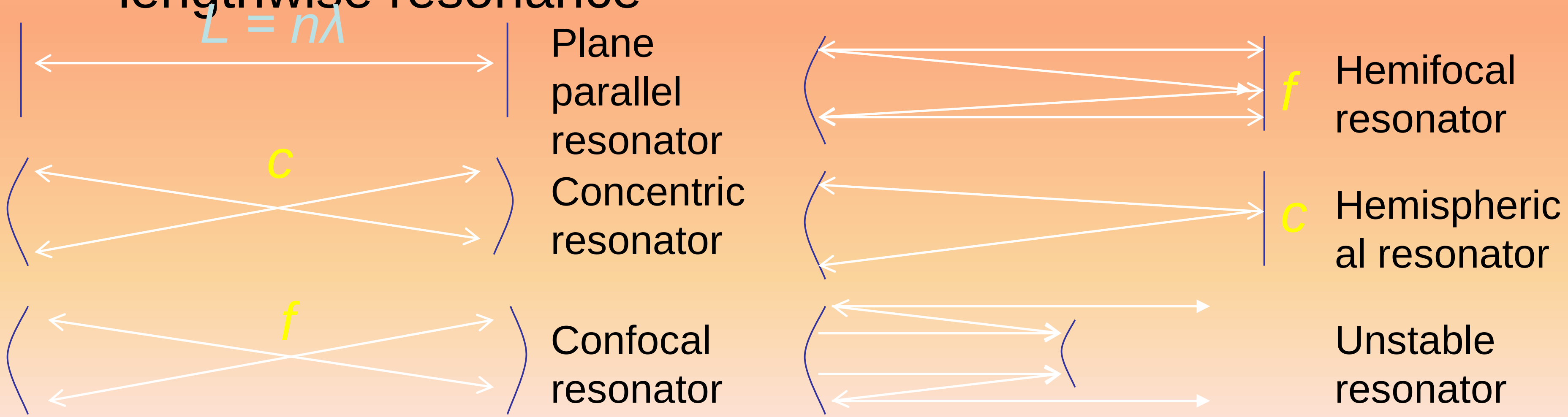
- n_1 - the number of electrons of energy E_1
- n_2 - the number of electrons of energy E_2

$$\frac{n_2}{n_1} = 4.4 \times 10^{-4}$$

- *Population inversion- n2>>n1*

Resonance Cavities and Longitudinal Modes

Since the wavelengths involved with lasers and masers spread over small ranges, and are also absolutely small, most cavities will achieve lengthwise resonance



Plane parallel resonator

Concentric resonator

Confocal resonator

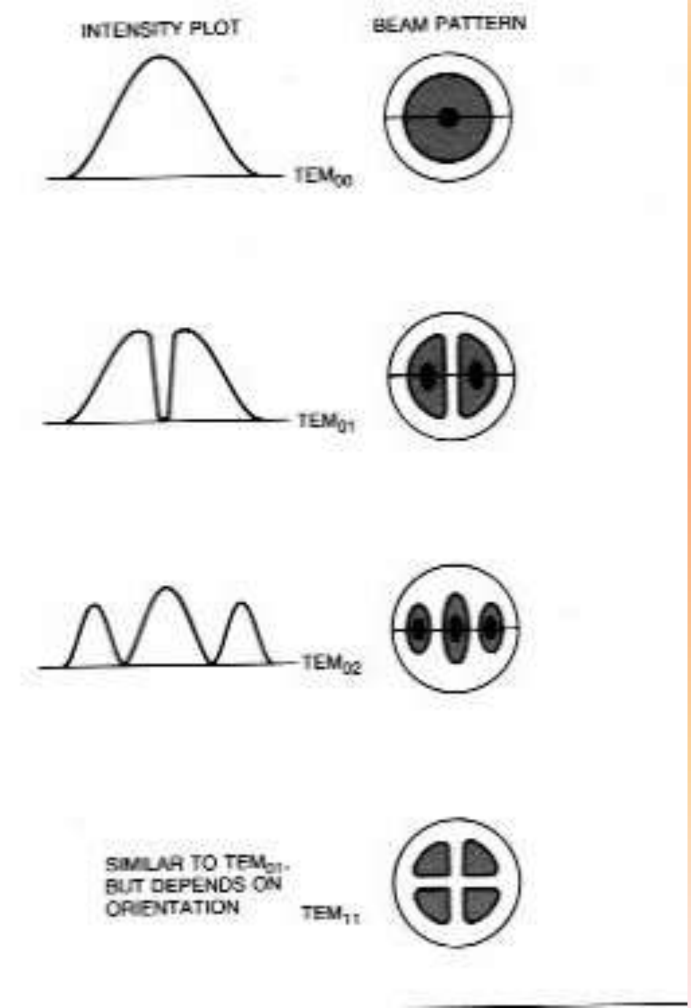
Hemifocal resonator

Hemispherical resonator

Unstable resonator

c: center of curvature, f: focal point

Transverse Modes



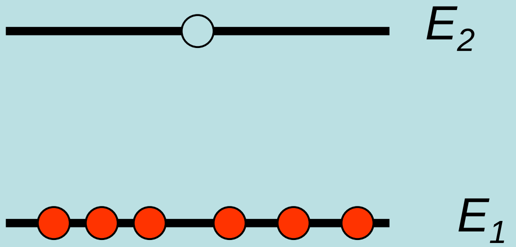
Due to boundary conditions and quantum mechanical wave equations

TEM$_{00}$:

$I(r) = (2P/\pi d^2)*\exp(-2r^2/d^2)$

(d is spot size measured to the $1/e^2$ points)

Einstein's coefficients



Probability of stimulated absorption R_{1-2}

$$R_{1-2} = \rho\,(\nu)\,B_{1-2}$$

Probability of stimulated and spontaneous emission :

$$R_{2-1} = \rho\,(\nu)\,B_{2-1} + A_{2-1}$$

assumption: n_1 atoms of energy ε_1 and n_2 atoms of energy ε_2 are in thermal equilibrium at temperature T with the radiation of spectral density $\rho\,(\nu)$:

$$n_1 R_{1-2} = n_2 R_{2-1} \qquad n_1 \rho\,(\nu)\,B_{1-2} = n_2\,(\rho\,(\nu)\,B_{2-1} + A_{2-1})$$

$$\Rightarrow$$

$$\rho\,(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{n_1}{n_2}\frac{B_{1-2}}{B_{2-1}} - 1}$$

According to Boltzman statistics:

$$\frac{n_1}{n_2} = \exp(E_2 - E_1)/kT = \exp(h\nu/kT)$$

$$\rho(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{B_{1-2}}{B_{2-1}}\exp(\frac{h\nu}{kT}) - 1} = \frac{8\pi h\nu^3/c^3}{\exp(h\nu/kT) - 1}$$

Planck's law

$B_{1-2}/B_{2-1} = 1$

$$\frac{A_{2-1}}{B_{2-1}} = \frac{8\pi h\nu^3}{c^3}$$

The probability of spontaneous emission $A_{2\text{-}1}$ /the probability of stimulated emission $B_{2\text{-}1}\rho(\nu)$:

$$\frac{A_{2-1}}{B_{2-1}\rho(\nu)} = \exp(h\nu/kT) - 1$$

1. Visible photons, energy: 1.6eV – 3.1eV.

2. kT at 300K ~ 0.025eV.

3. stimulated emission dominates solely when $h\nu/kT \ll 1$!

(for microwaves: $h\nu < 0.0015$eV)

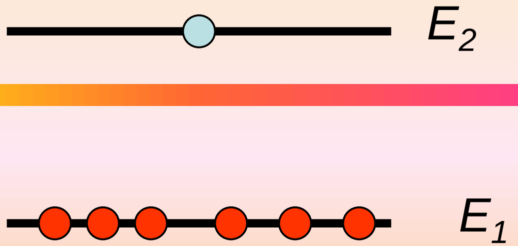
The frequency of emission acts to the absorption:

$$x = \frac{n_2 A_{2-1} + n_2 B_{2-1}\rho(\nu)}{n_1 B_{1-2}\rho(\nu)} = [1 + \frac{A_{2-1}}{B_{2-1}\rho(\nu)}]\frac{n_2}{n_1} \approx \frac{n_2}{n_1}$$

if $h\nu/kT \ll 1$.

$x \sim n_2/n_1$

Condition for the laser operation



If $n_1 > n_2$

- radiation is mostly absorbed absorbowane
- spontaneous radiation dominates.

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

- most atoms occupy level E2, weak absorption

- stimulated emission prevails

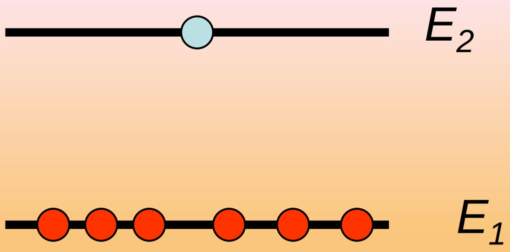
- light is amplified

Necessary condition:
population inversion

How to realize the population inversion?

Thermal excitation:

$$\frac{n_2}{n_1} = \exp\left(\frac{-\Delta E}{kT}\right)$$



impossible.

The system has to be „pumped”

Optically,
electrically.

THANK YOU