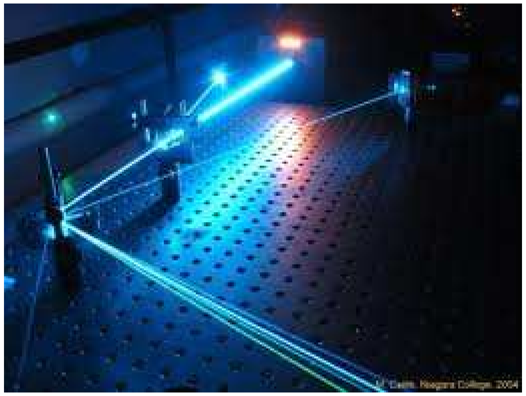
Lasers



L.A.S.E.R.

LIGHT

AMPLIFICATION

by STIMULATED

EMISSION

of RADIATION

History of Lasers and Related Discoveries

1917 Stimulated emission proposed by Einstein

1947 Holography (Gabor, Physics Nobel Prize 1971)

1954 MASER (Townes, Basov, Prokhorov, Physics Nobel Prize 1964)
but 1st maser constructed by Maiman in 1960

1958 LASER: optical maser
(Laser spectroscopy by Schawlow, Bloembergen, Physics Nobel Prize 1981)

1960 Ruby Laser: 1st laser

1963 Semiconductor heterostructures (Alferov, Kroemer, Physics Nobel Prize 2000)

1970 Corning glass (optical fiber)

1980 Laser cooling of atoms (Chu, Cohen-Tannoudki, Phillips, Physics Nobel Prize 1997)

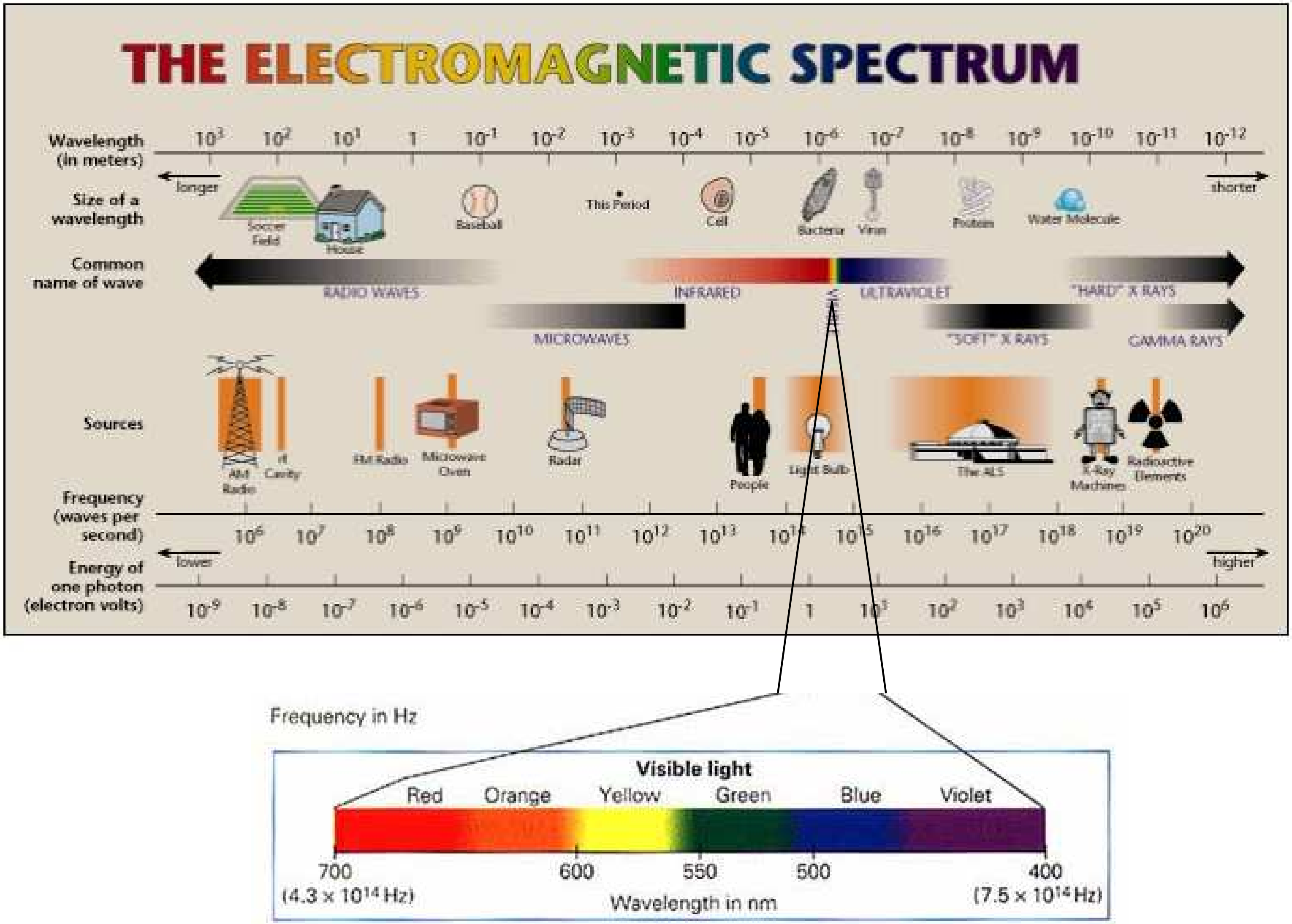
Applications of Lasers

CD
DVD
Blu-Ray
Bar code
Internet
Laser pointer
Laser sight (targeting)
Speed measurement
Laser distance meter
LIDAR (light detection and ranging)
Projection display
Spectroscopy (Raman, PL…)
Microscopy
Laser cooling
Nuclear fusion

Countermeasures
Dazzler
Surgery
Laser welding
Engraving
Curing (dentistry)
Optical tweezer
Laser printing
Alignment
Holography
Laser bonding
Free space communications

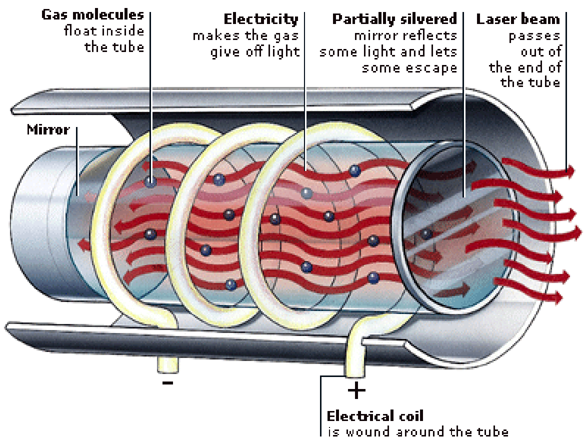
WHAT ELSE, WHAT CAN YOU ADD TO THE LIST? …

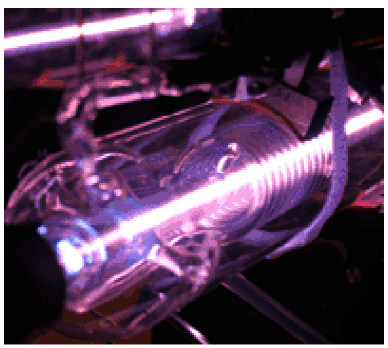
Spectral Range of Existing Lasers

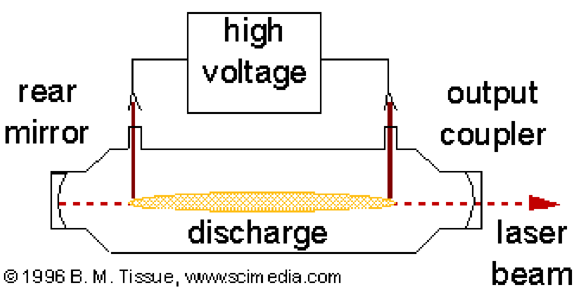


Types of Lasers

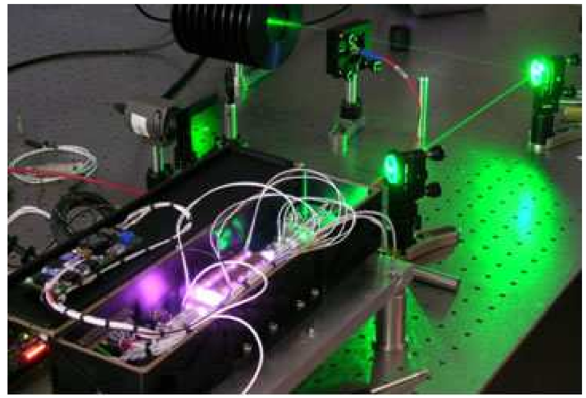
Gas Lasers (1 m)

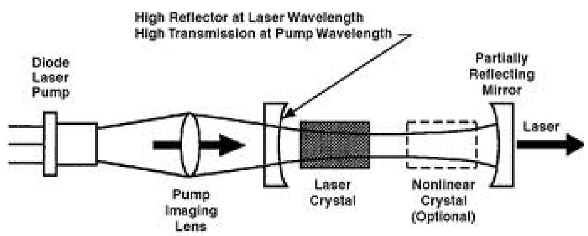


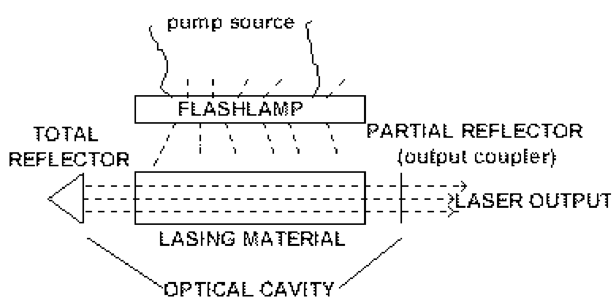




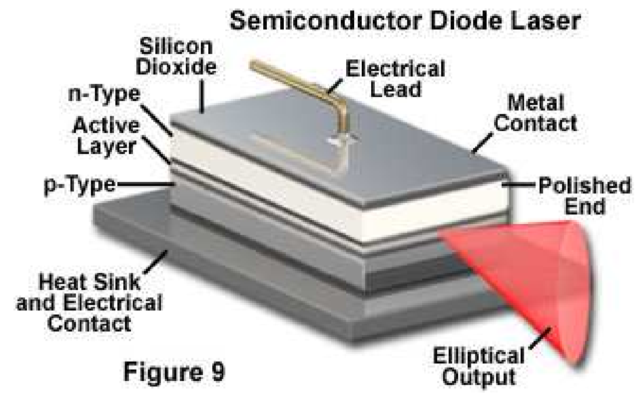
Solid State Lasers (1 cm)

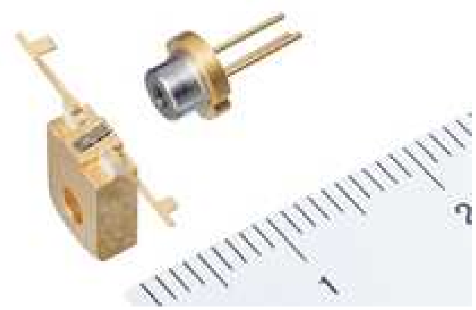






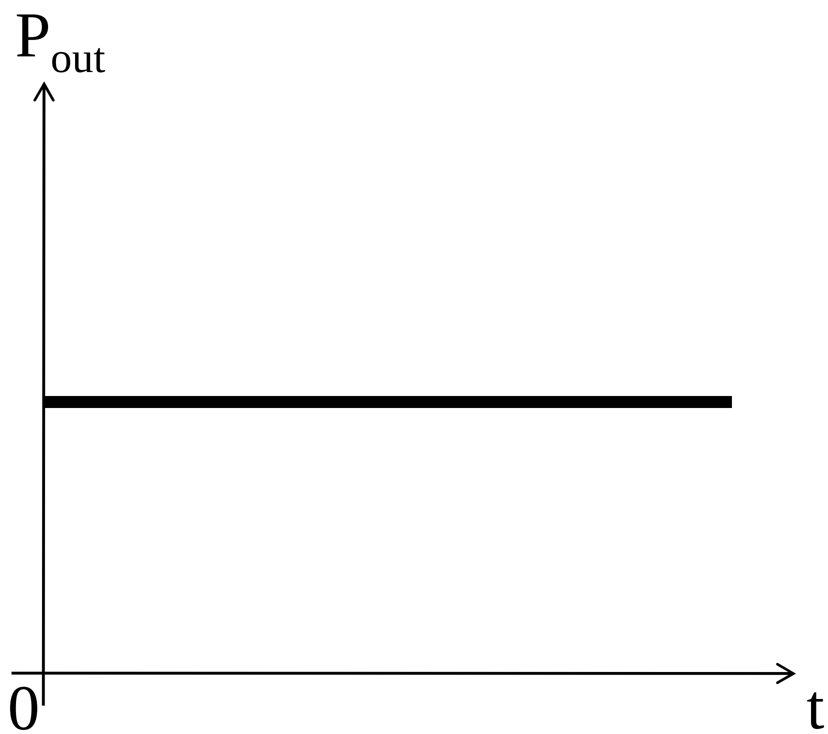
Semiconductor (Diode) Lasers (1 μm)



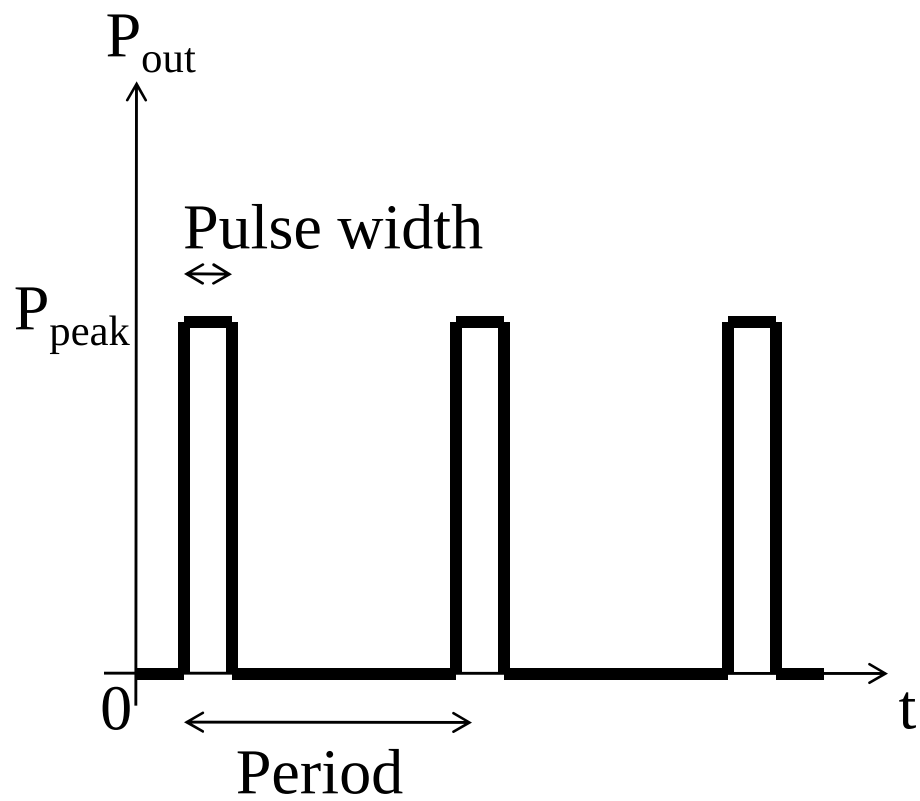


Types of Lasers

<u>Continuous Wave Operation</u>



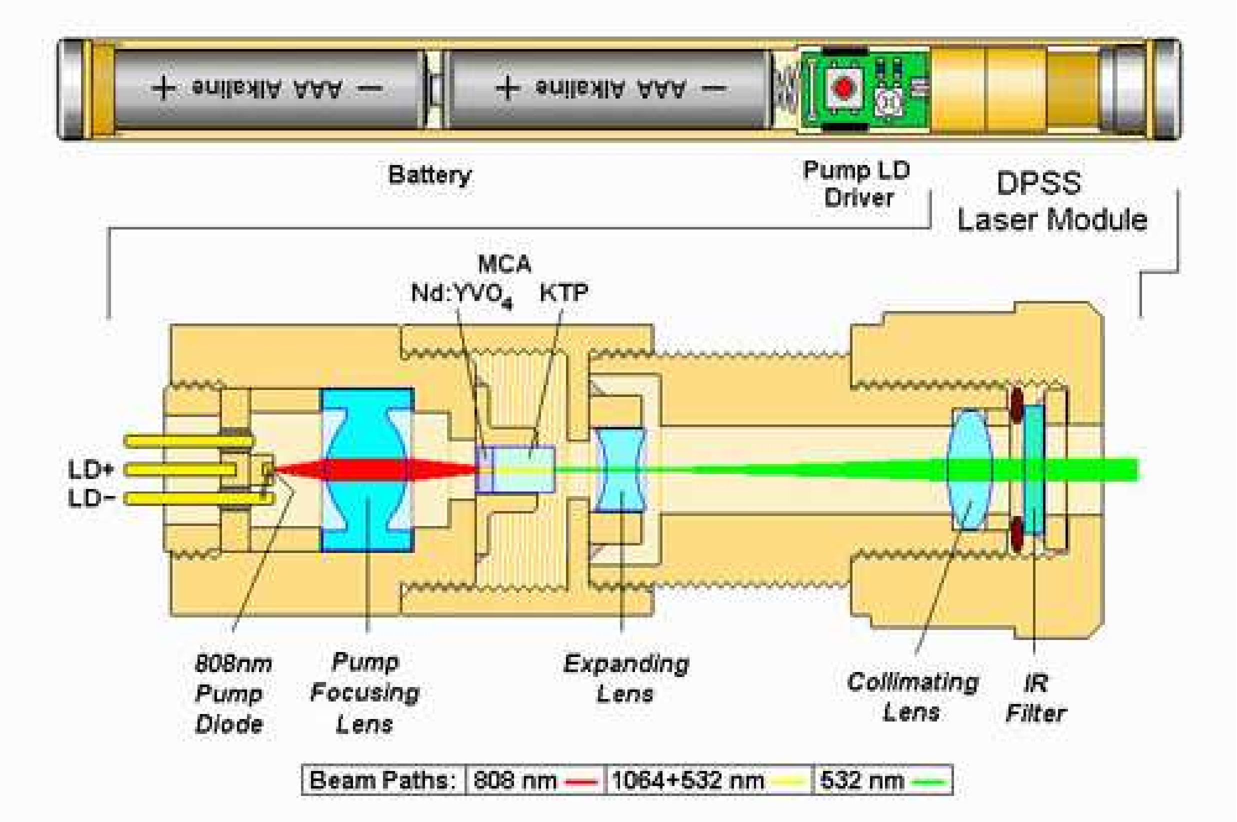
<u>Pulse Mode Operation</u>



- Higher peak powers
- Duty cycle (%)
- Average powers

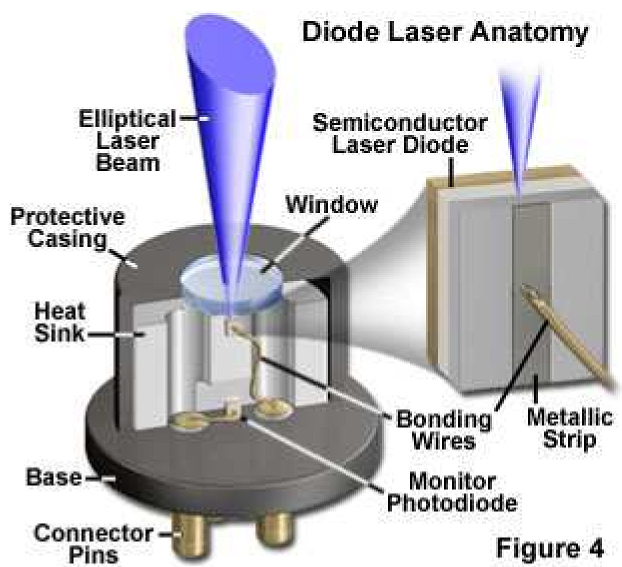
Green Laser Pointer

- Green light is from frequency doubling (2 photons combine energy into 1)
- More generally:
  non linear optical effects i.e. add or subtract frequencies



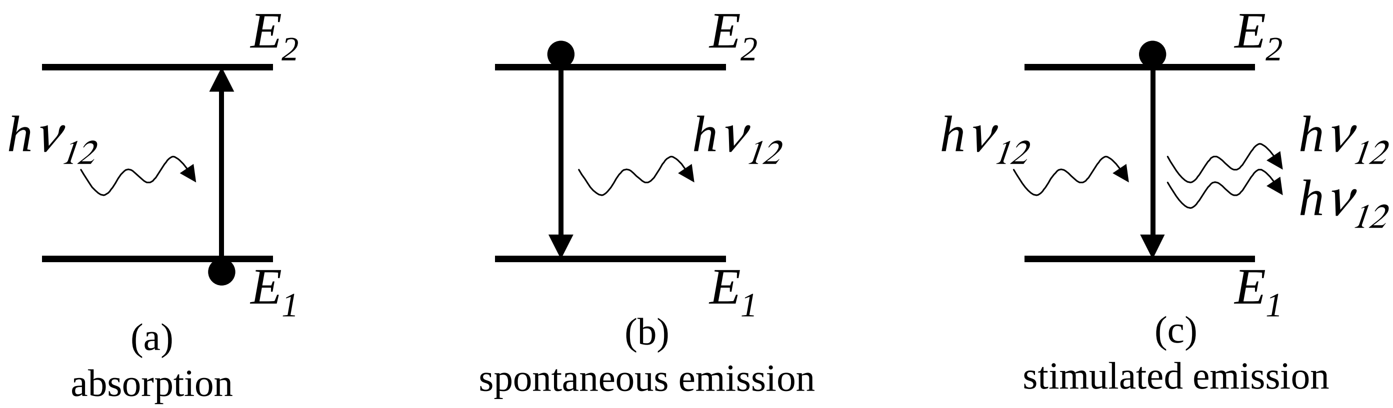
How a CD/DVD Laser Works

http://micro.magnet.fsu.edu/primer/java/lasers/compactdisk/index.html



Fundamentals of Lasers

Consider a two-level system (excited level state and ground level state). What can happen?

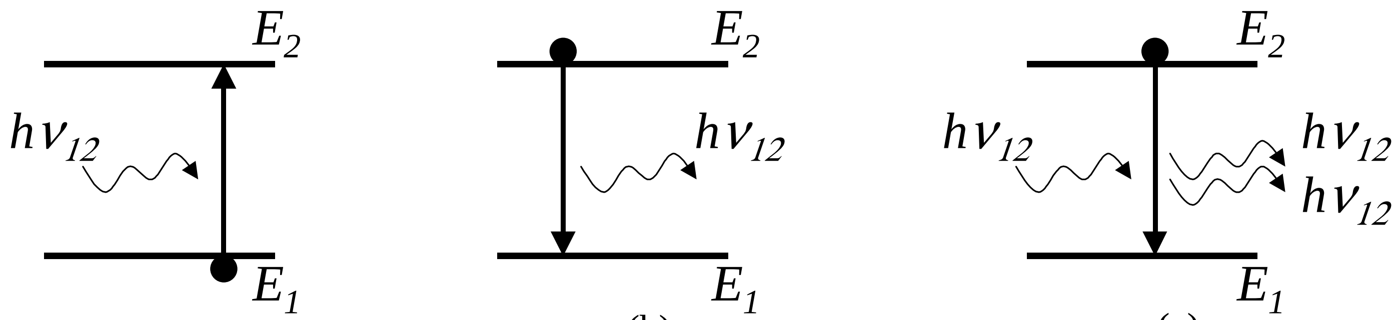


Absorption: Annihilation of a photon, whose energy is taken to excite an electron/atom/molecule from the ground state to an excited state.

Spontaneous Emission: Relaxation of the electron/atom/molecule from the excited state to the ground state releases a photon in the absence of external stimulus.

Stimulated Emission: Relaxation of the electron/atom/molecule from the excited state to the ground state due to the interaction with another photon of the same energy, wavelength

Rate Equations – Einstein Coefficients A,B



(a) absorption

(b) spontaneous emission

(c) stimulated emission

$$\frac{dn_1}{dt} = -B_{12} n_1 u(\nu_{12})$$

n_1: density of lower states
u: photon density

$$\frac{dn_1}{dt} = +A_{21} n_2$$

Spontaneous emission depends only on the amount of excited states

$$\frac{dn_1}{dt} = +B_{21} n_2 u(\nu_{12})$$

At thermal equilibrium, the following must be satisfied:

$$\frac{dn_1}{dt} = -B_{12} n_1 u(\nu_{12}) + A_{21} n_2 + B_{21} n_2 u(\nu_{12}) = 0$$

i.e.: **absorption=spontaneous emission + stimulated emission**

Rate Equations – Einstein Coefficients

$$B_{12} n_1 u(\nu_{12}) = A_{21} n_2 + B_{21} n_2 u(\nu_{12})$$

absorption=spontaneous emission + stimulated emission

- **<u>At thermal equilibrium</u>**, concentrations n_1 and n_2 of state levels 1 and 2 are governed by Boltzmann statistics
  => $n_1 > n_2$ i.e. there are always more lower energy states than higher energy states.

- Laser action occurs when two conditions are satisfied:
  - More stimulated emission than absorption
    $n_1 < n_2$ i.e. **POPULATION INVERSION**

    $$\frac{\text{Stimulated emission}}{\text{Absorption}} = \frac{B_{21}}{B_{12}} \frac{n_2}{n_1}$$

    Gain medium

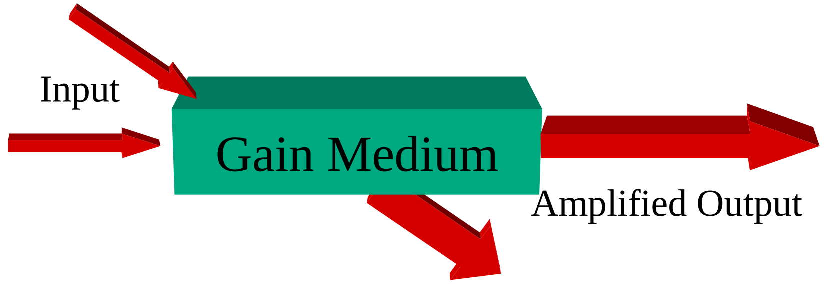
  - High photon density u

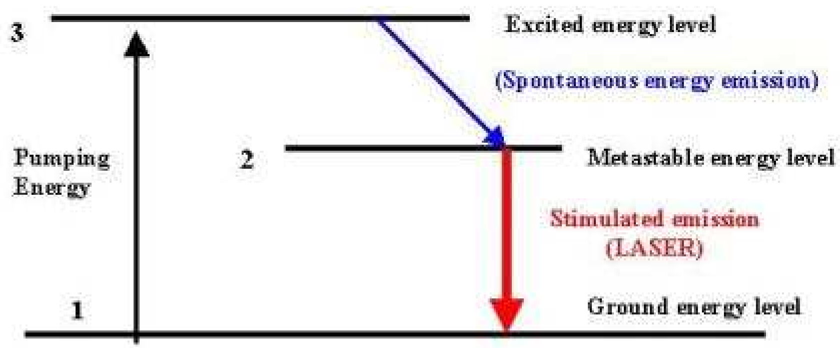
    $$\frac{\text{Stimulated emission}}{\text{Spontaneous emission}} = \frac{B_{21} n_2 u(\nu_{12})}{A_{21} n_2} = \frac{B_{21}}{A_{21}} u(\nu_{12})$$

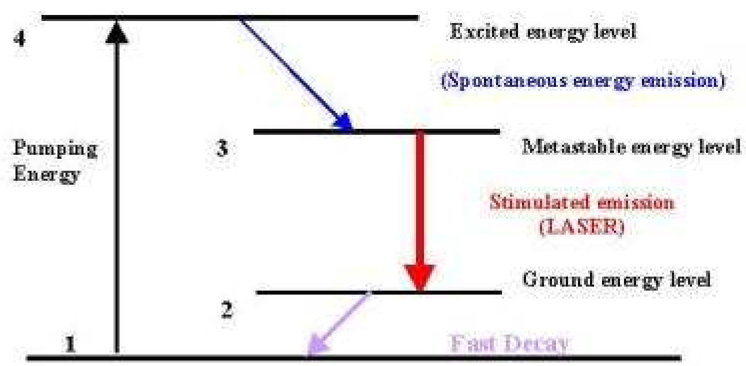
    Cavity

Fundamentals of Lasers

1. **Amplification (Gain) Medium**:





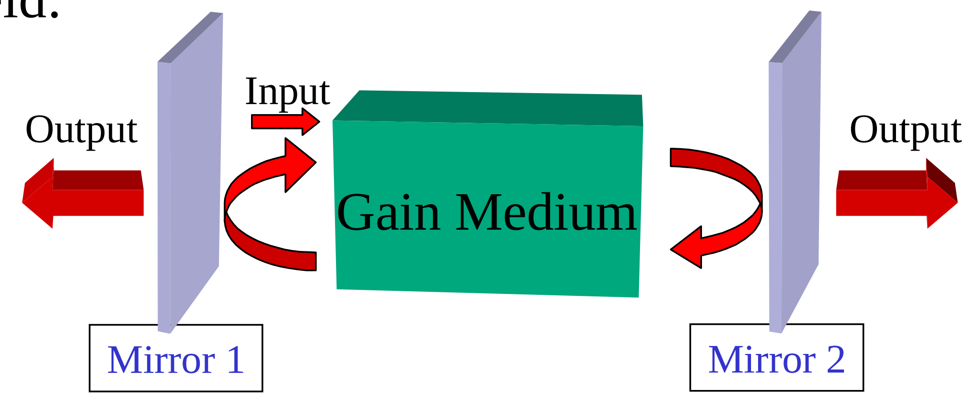


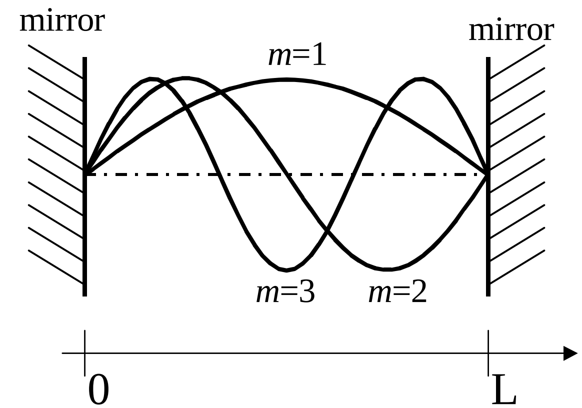
- To achieve population inversion, needs an external "pump" to supply the extra states n_2.
  ➔ need at least 3 levels.

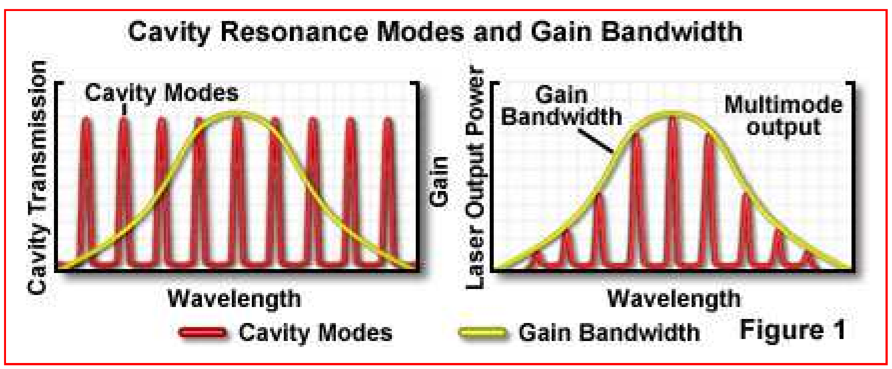
- This can be done optically (flashlamp pump, diode pump) or electrically (current).

Fundamentals of Lasers

2. **Fabry-Perot cavity** (➔ laser is an optical oscillator) to enable light feedback using appropriate mirrors and achieve coherent photon (E&M) field:

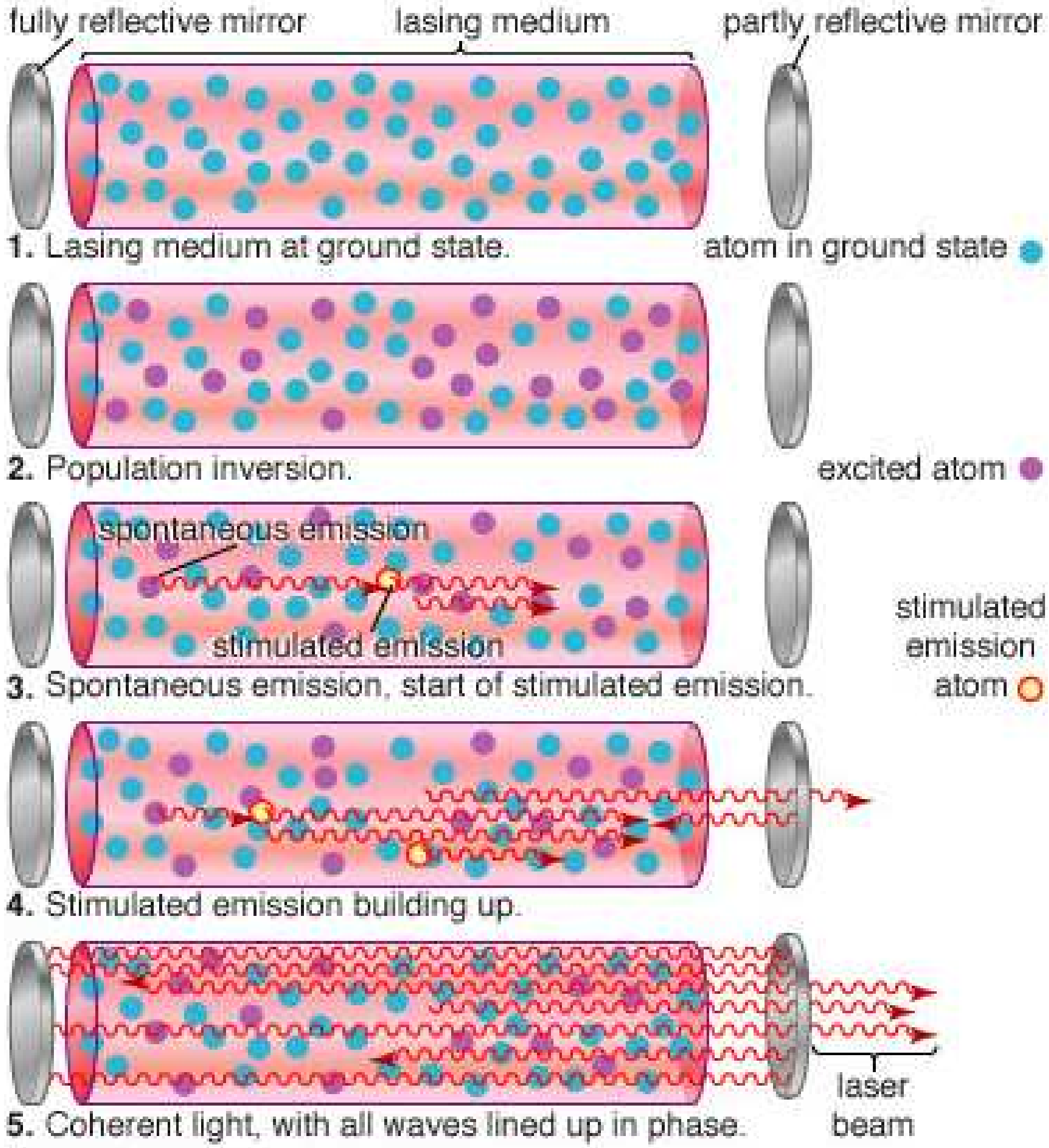






$$m\lambda = 2L$$

Stimulated Emission



- In gain medium, stimulated emission causes a cascade process that multiplies photons.
- **A stimulated emitted photon** have the same wavelength, phase, polarization, propagation direction as the **stimulating photon**.
- With the help of the cavity, we get: **Temporal and spatial coherence**.