LASER: Lecture 1

LASER:


Phosphor
Dichroic Mirror
© Air Force Photo
© NIF
Figure 1
Vitreous Humor

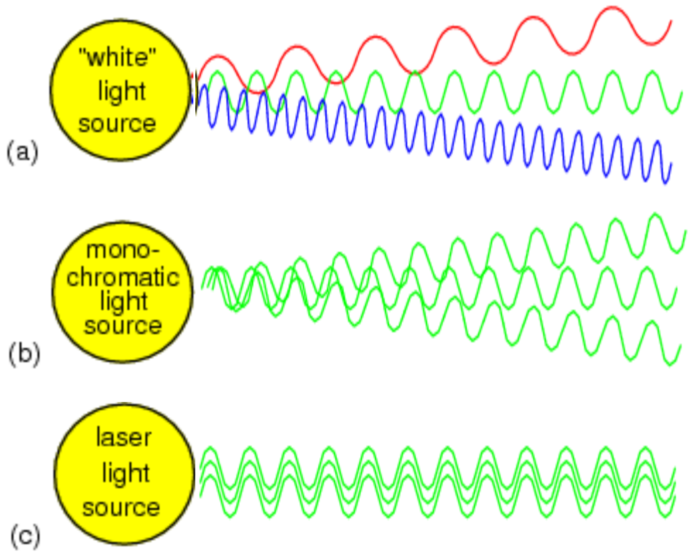
Laser

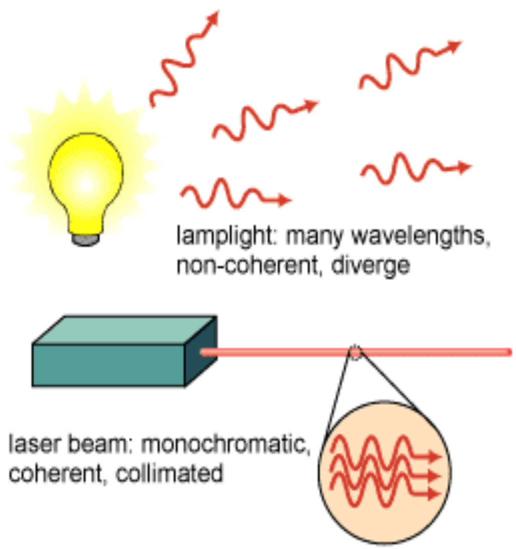
(acronym)

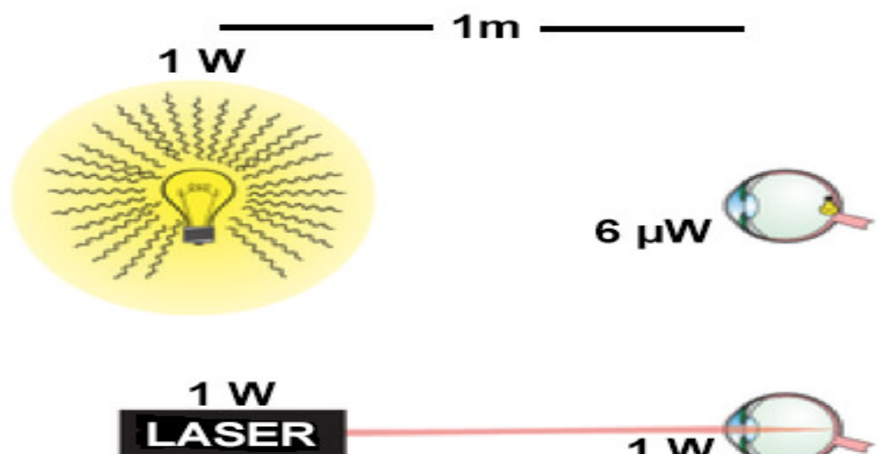
Light Amplification by Stimulated Emission of Radiation

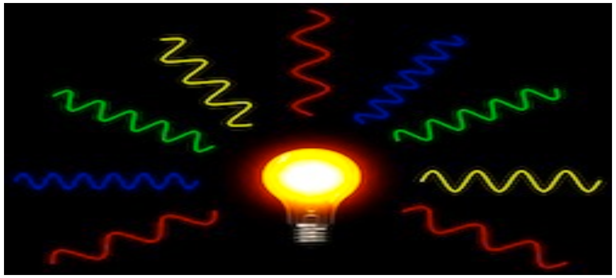
The laser is a device that produces coherent (All waves are exactly in phase with one another) nearly monochromatic, Less diverging and extremely intense light beam.

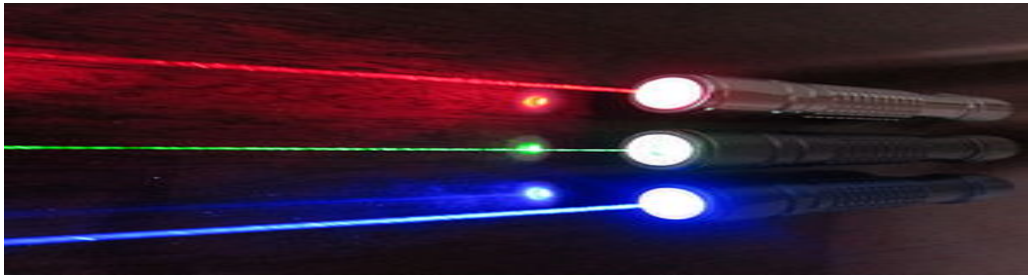
Difference b/w ordinary light and Laser







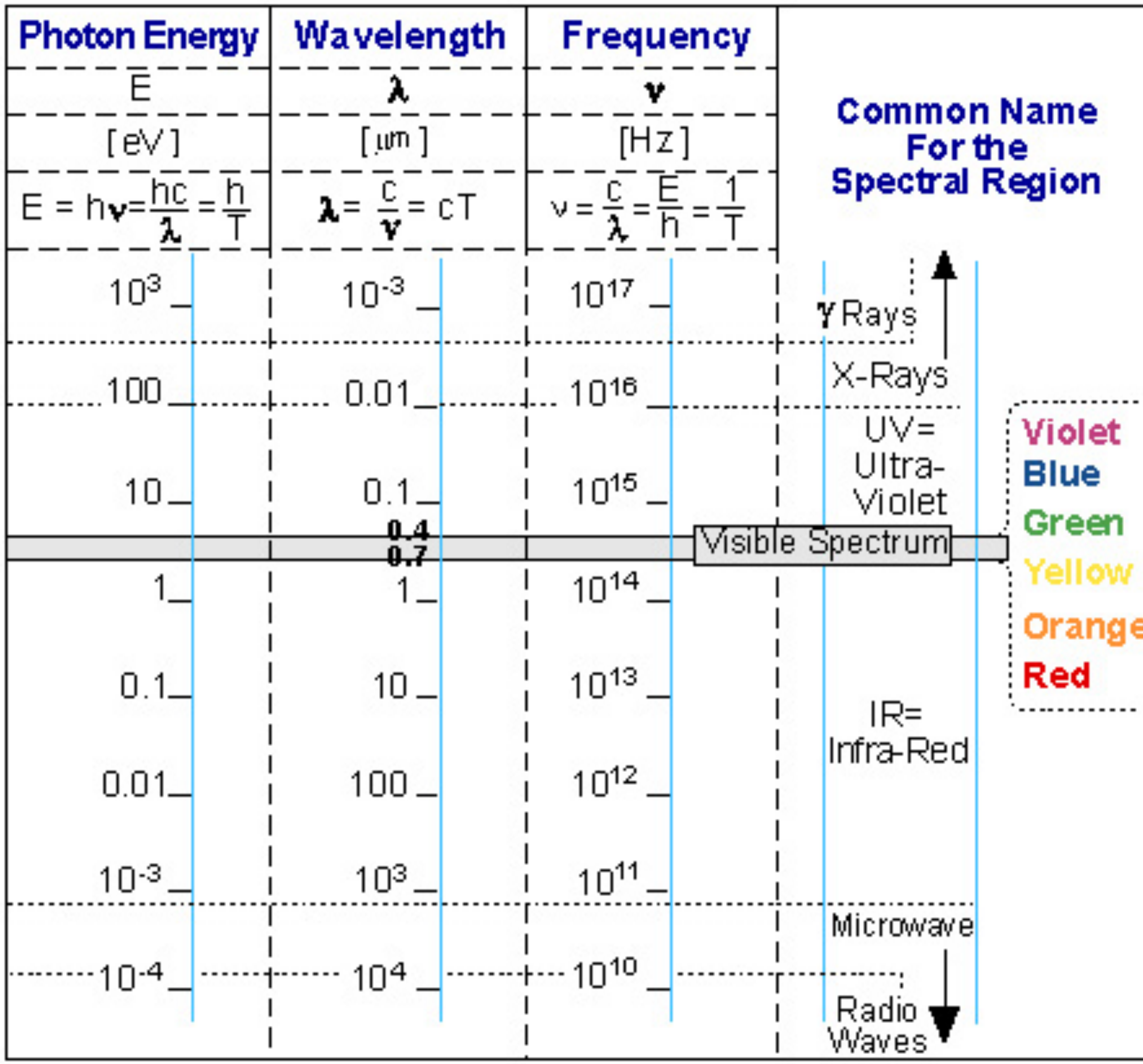




LASER Vs. LIGHT

LASER	LIGHT
✓ Simulated emission	✓ Spontaneous emission.
✓ Monochromatic.	✓ Polychromatic.
✓ Highly energized	✓ Poorly energized.
✓ Parallelism	✓ Highly divergence
✓ Coherence	✓ Not coherent
✓ Can be sharply focussed.	✓ Can not be sharply focussed.

Electromagnetic spectrum



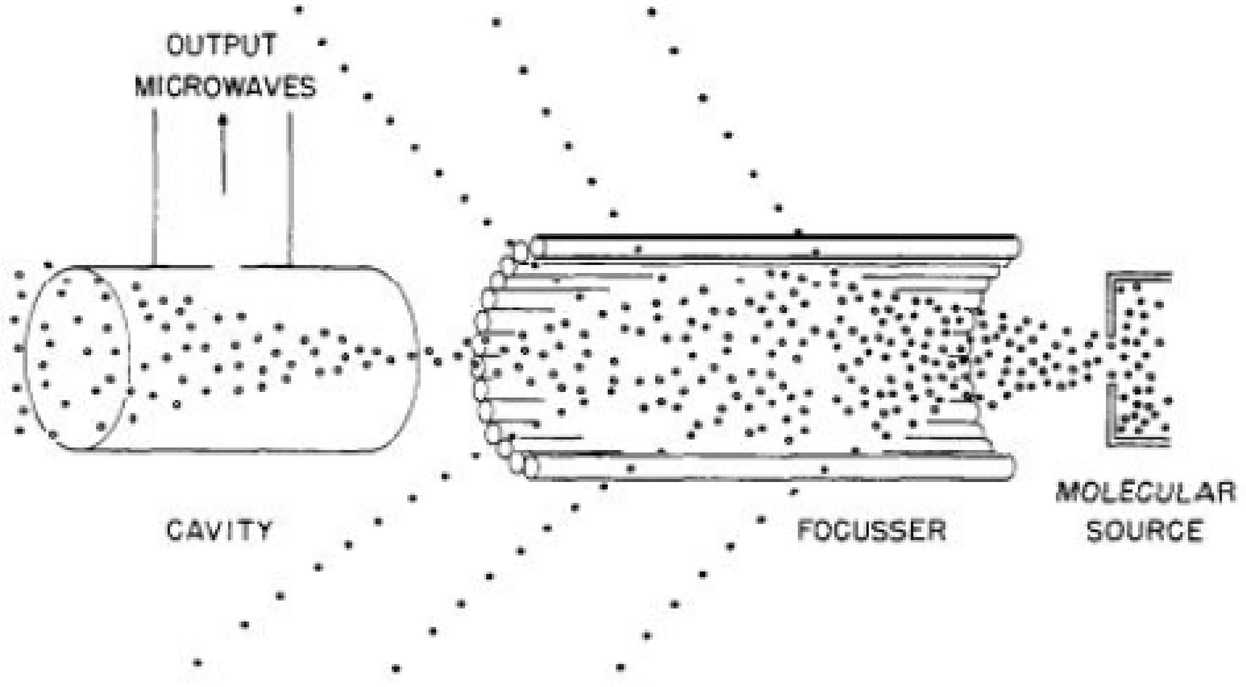
LASERS

History of the LASER

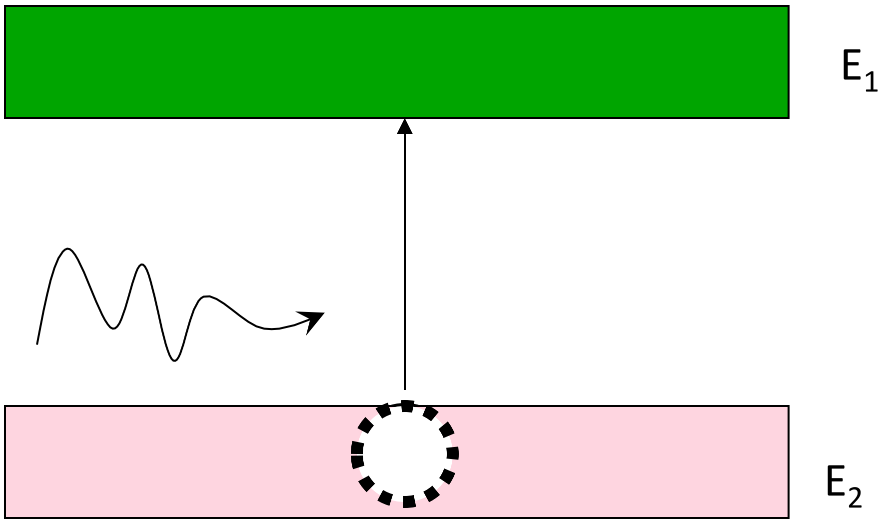
- 1917 – A. Einstein postulates photons and stimulated emission
- 1954 – First microwave laser (MASER), Townes, Shawlow, Prokhorov
- 1960 – First optical laser (Maiman)
- 1964 – Nobel Prize in Physics: Townes, Prokhorov, Basov

Maser

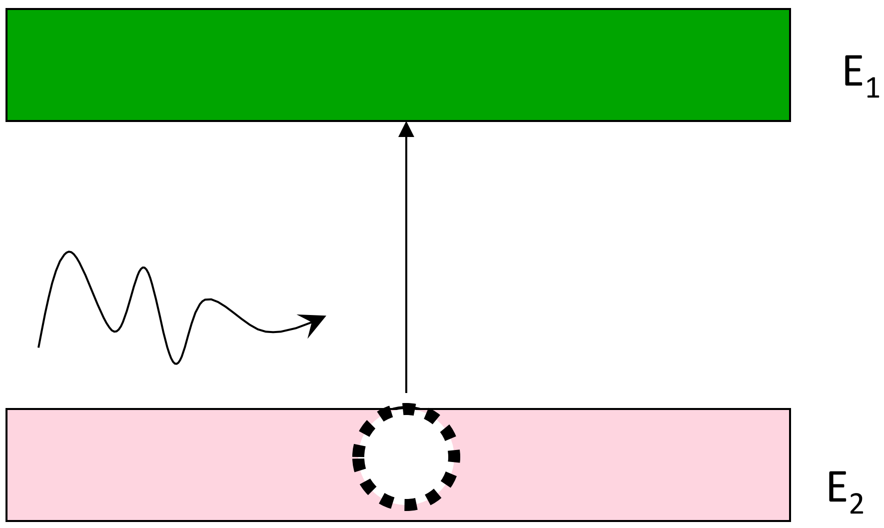
- Ammonia is the gain medium



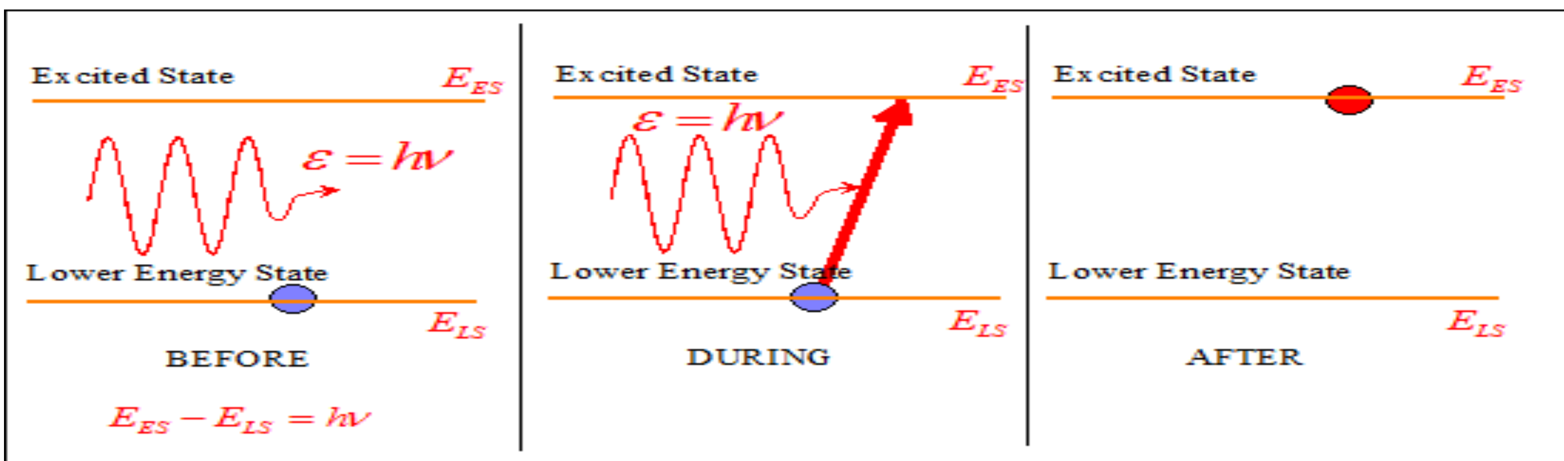
Absorption



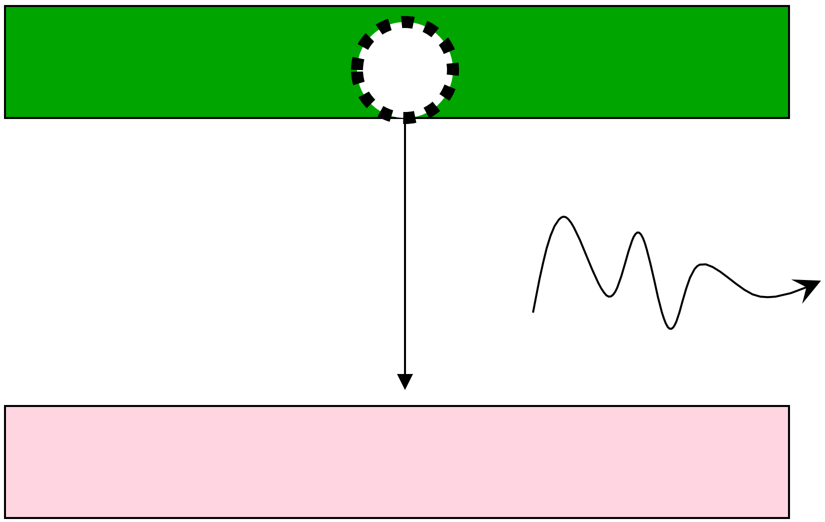
Absorption



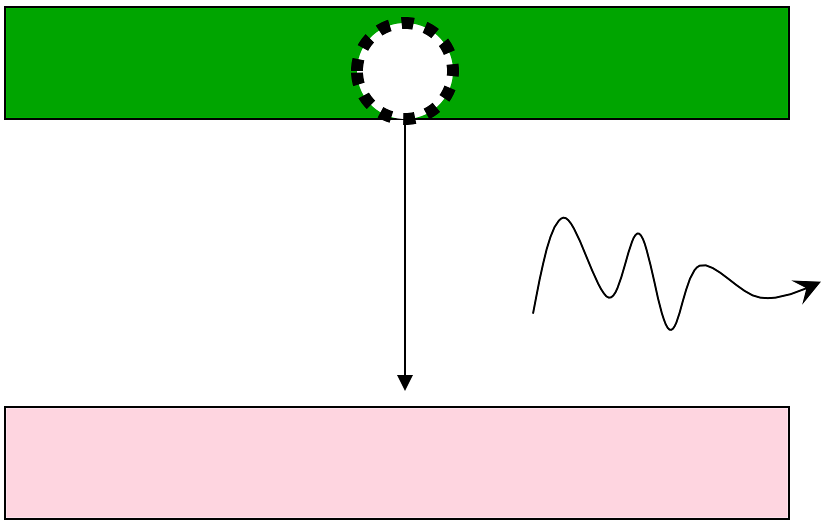
In this process a photon with an energy equals to the difference in energy between two of the atomic levels interacts with the atom. The electron of the atom is in the lower energy state, absorbs the photon, and jumps to the higher energy state (excited state). The photon is completely absorbed by the atom. The final state of the atom is excited.



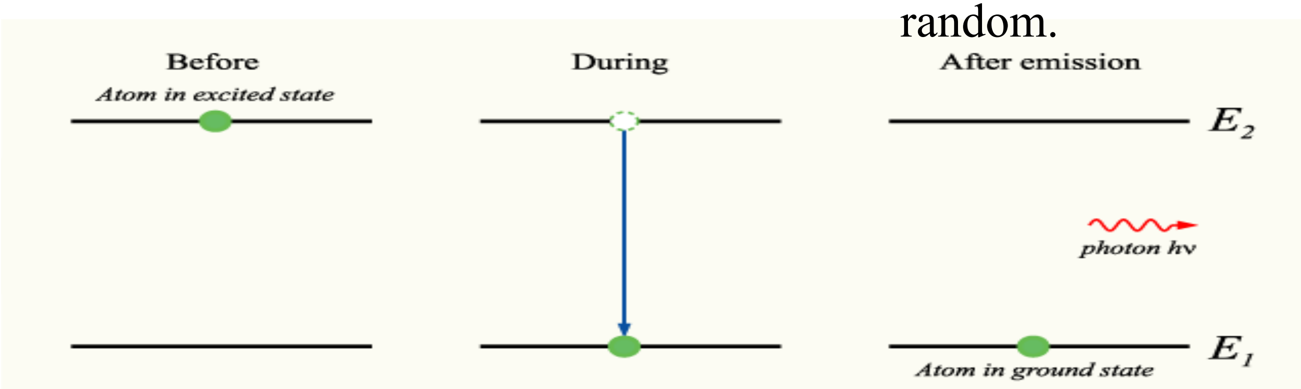
Spontaneous Emission



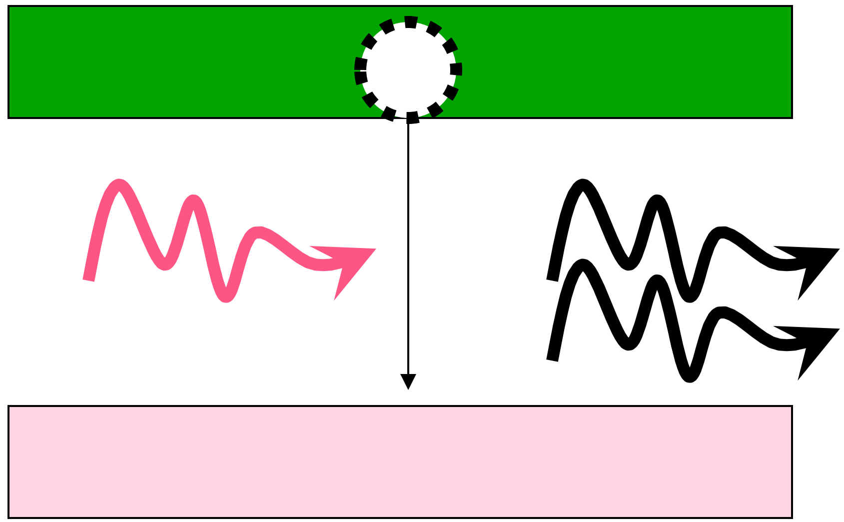
Spontaneous Emission



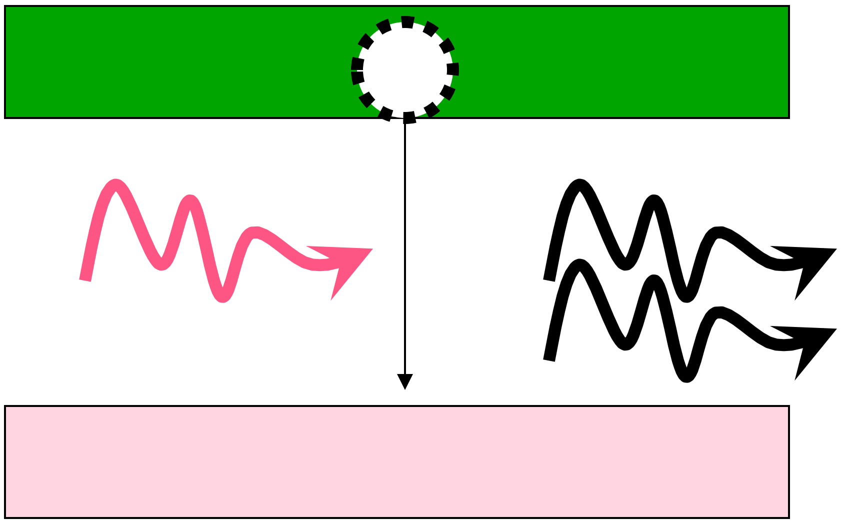
In this case, one of the electron is not in the lowest possible energy state; thus, the atom is excited. Spontaneously, the atom emits a photon with an energy equals to the difference in energy between the energy when the electron is in the excite state and the energy of the level when the electron is in the relaxed state (lower energy state). During this emission the electron jumps down to the lower energy state. The atoms give up energy which is carried by the emitted photon and it is left unexcited. On the other side, the emitted photon has an energy equals to the difference in energy between the two atomic states involved. However, there is not a prefer direction of motion for the emitted photon; in fact, the direction of emission is completely random.



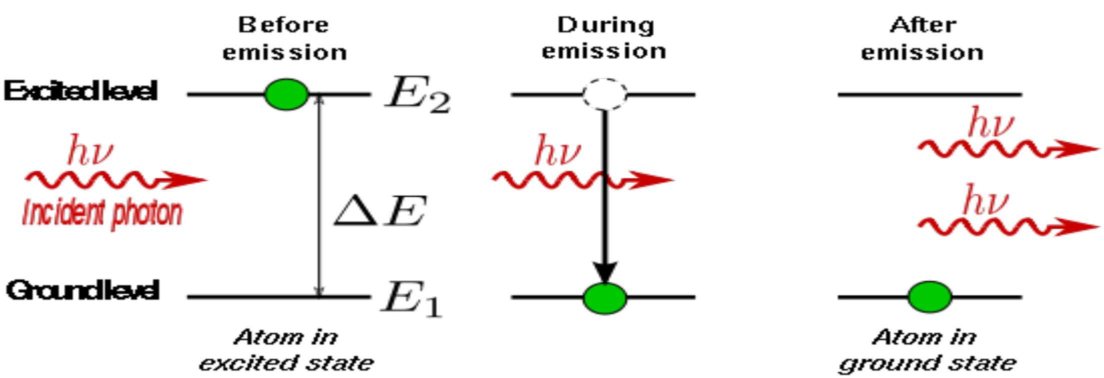
Stimulated Emission



Stimulated Emission



When a photon with the same energy as the difference between two atomic levels reaches the atom and the corresponding electron to those levels is in the excited state, the electron jumps down to the lower energy state emitting an additional photon. After this process, two photons are emerging from the atom for every incident photon that interacts with the atom inducing the emission.

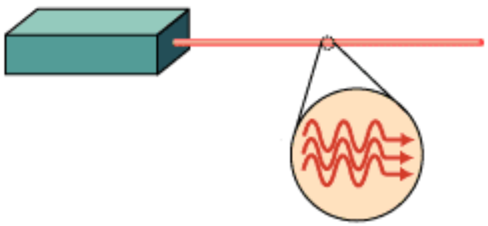


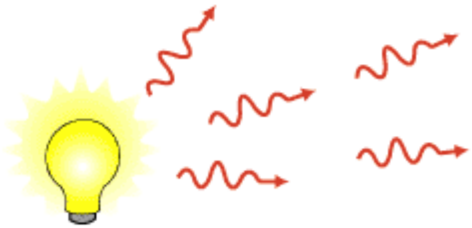
$$E_2 - E_1 = \Delta E = h\nu$$

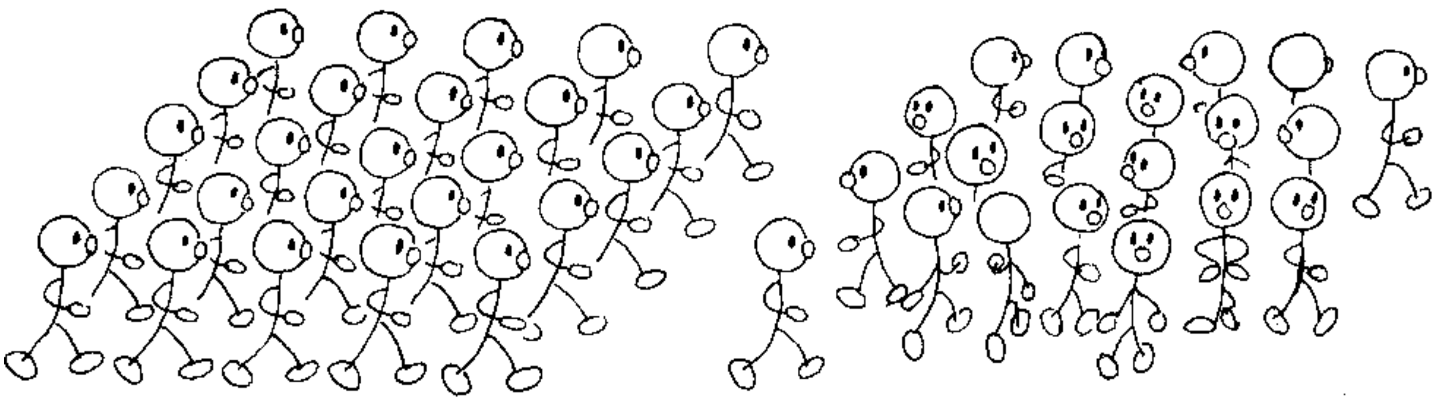
Light Amplification by Stimulated Emission of Radiation

Stimulated emission

Spontaneous emission



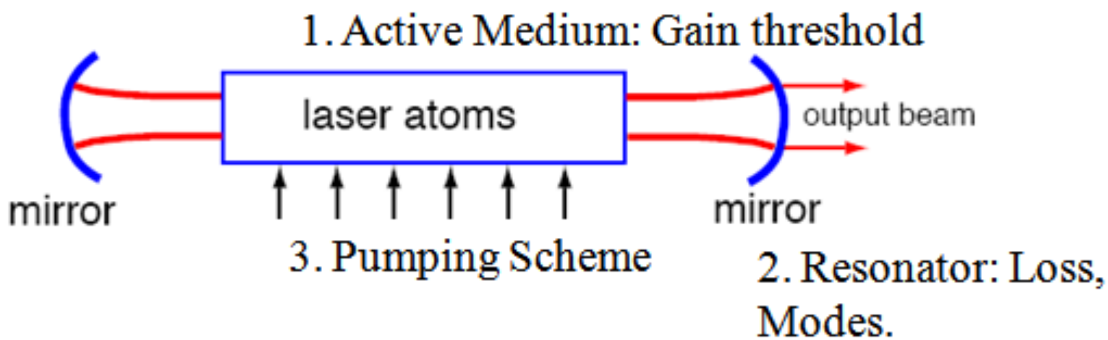




Coherent

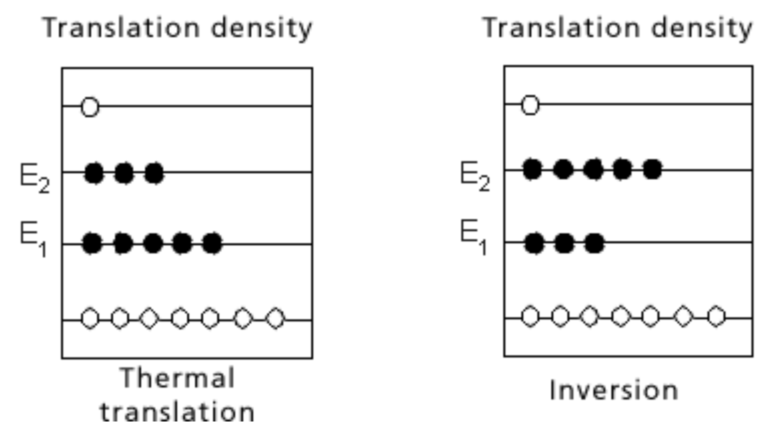
Incoherent

Active medium: The **active medium** is a collection of atoms or molecules, which can be excited into a population inversion situation, and can have electromagnetic radiation extracted out of it by stimulated emission. The **active medium** can be in any state of matter: solid, liquid, gas or plasma.



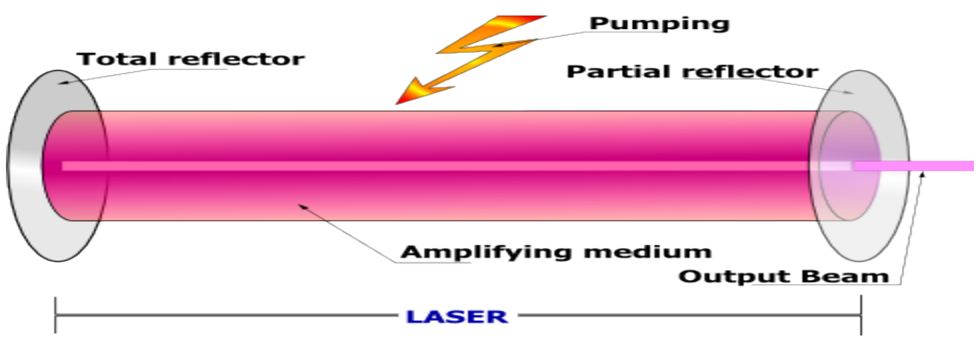
Population: number of Atoms belong to the corresponding energy state.

Population inversion: the redistribution of atomic energy levels that takes place in a system so that **laser** action can occur. Normally, a system of atoms is in temperature equilibrium and there are always more atoms in low energy states than in higher ones.

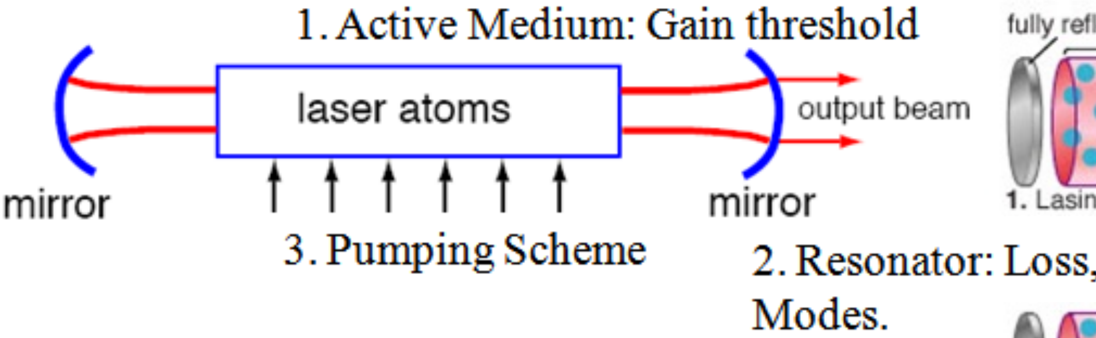


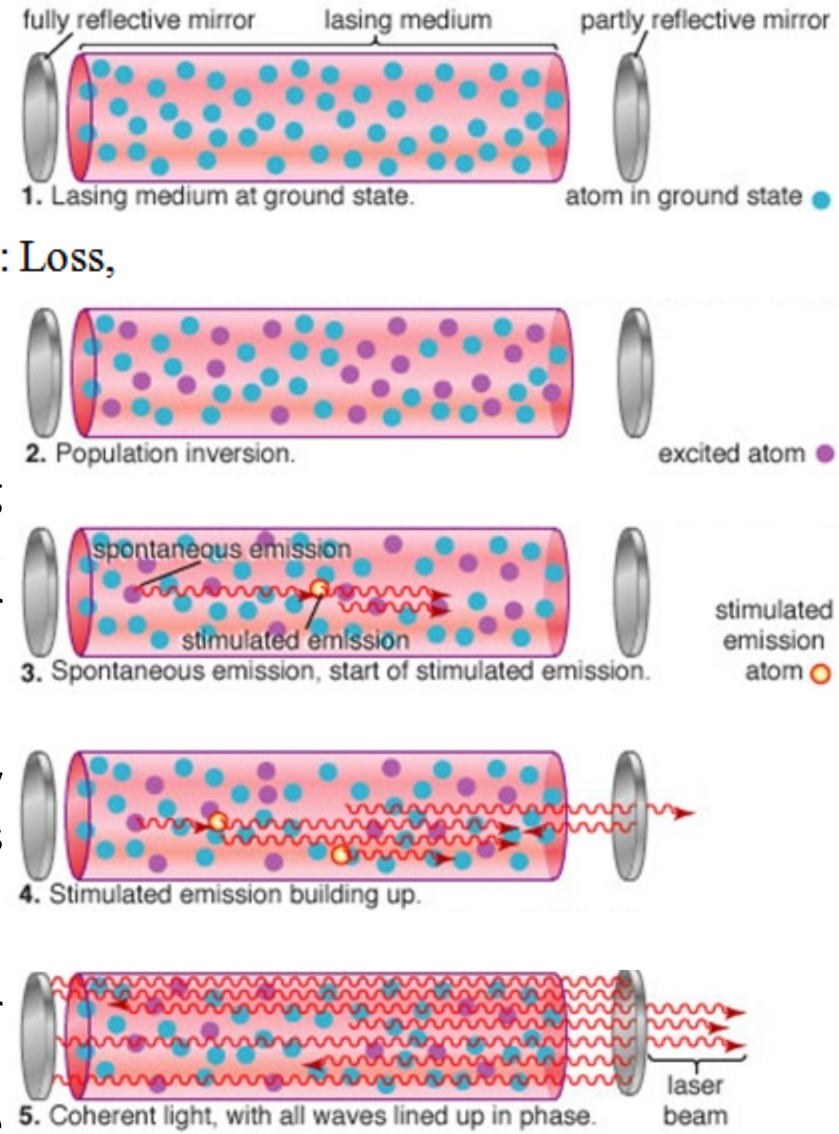
Pumping: the process of supplying energy to the medium to transfer it into state of population of inversion.

- Optical pumping: Ruby laser
- Electric discharge: gaseous ion laser
- Direct conversion: LEDs
- Inelastic atom-atom collisions: He-Ne laser
- Chemical pumping: CO2 laser



How laser works





The three main components of any laser are

1. ***The amplifying medium,*** The amplifying medium consists of a collection of atoms, molecules or ions which act as an amplifier for light waves.

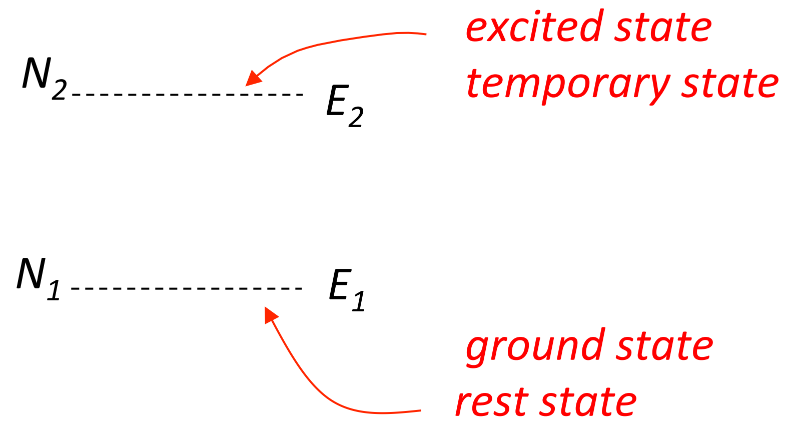
2. ***The pump*** The pump is the source of energy which maintains the medium in this population inverted state.

3. ***The optical resonator*** The optical resonator which consists of a pair of mirrors facing each other provides optical feedback to the amplifier so that it can act as a source of radiation.

Emission and Absorption – Basic ideas

Restrict ourselves to two level system

$$E_2 - E_1 = h\nu = hc/\lambda$$

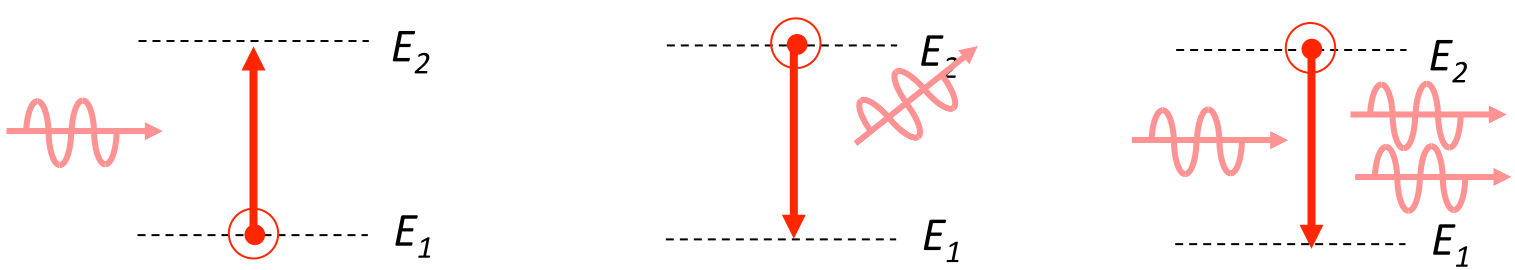


Number of atoms (or molecules) / unit volume

N = number density $N = N_1 + N_2$

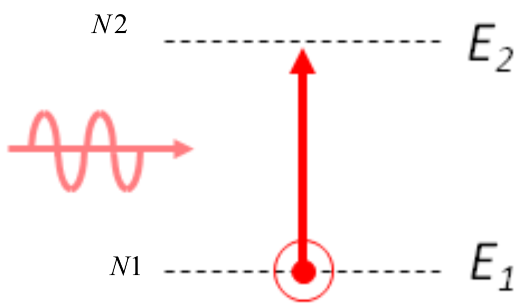
$N_{1,2}$ = *population of levels 1 & 2*

Three basic processes

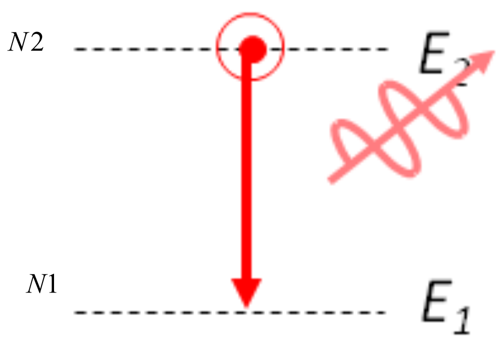


Absorption *Spontaneous Emission* *Stimulated Emission*

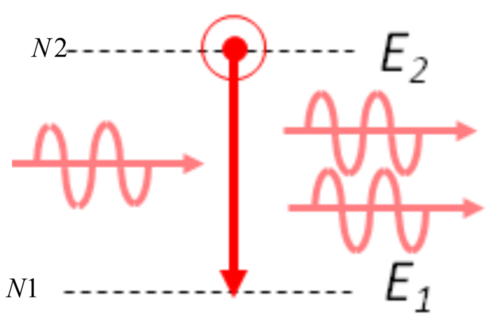
Three basic processes



Number of absorptions per unit volume per unit time $N_1 B_{12} u(v)$



Number of spontaneous emission per unit volume per time $N_2 A_{21}$



Number of stimulated emission per unit volume per time $N_2 B_{21} u(v)$

Here A and B are the coefficients of proportionality and are characterized by the energy levels.

Einstein relation between spontaneous and stimulated emission or transition probabilities

Let N_1 and N_2 are the population at any instant of the state 1 and 2 respectively. The probability of absorption that the number of atoms in state 1 that absorb a photon and rise to state 2 per unit time is given by

$$\boxed{N_1 P_{12} = N_1 B_{12} u(v)}$$

The probability of emission that the no. of atoms ispontaneously in state 2 to drop to lower state 1, either by spontaneous or under stimulation by, emitting a photon per unit time is the sum of two probabilities, that is

$$\boxed{N_2 P_{21} = N_2 [A_{21} + B_{21} u(v)]}$$

Einstein relation between spontaneous and stimulated emission or transition probabilities

At thermal equilibirium, the absorption probability is equal to the total emission probability, that is $N_1 P_{12} = N_2 P_{21}$

$$or \qquad N_1 B_{12} u(v) = N_2 [A_{21} + B_{21} u(v)]$$

$$or \qquad u(v) = \frac{A_{21}}{N_1 / N_2 B_{12} - B_{21}}$$

$$u(v) = \frac{A_{21}}{B_{21}} \left(\frac{1}{(N_1 / N_2)(B_{12} / B_{21}) - 1} \right)$$

According to Einstien, the probability of stimulated absorption is equal to the probability of stimulated emission, that is

$B_{12} = B_{21}$

$$u(v) = \frac{A_{21}}{B_{21}} \left(\frac{1}{(N_1 / N_2) - 1} \right)$$

Einstein relation between spontaneous and stimulated emission or transition probabilities

From Boltzmann's law, the ratio of the populations of two levels at temperature T is expressed as

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

where k is the Boltzmann's constant and h is the planck's constant. Therefore

$$u(v) = \frac{A_{21}}{B_{21}}\left(\frac{1}{e^{hv/kT} - 1}\right)$$

Now according to planck's law of radiation $u(v)$ is given by

$$u(v) = \frac{8\pi h v^3}{c^3}\left(\frac{1}{e^{hv/kT} - 1}\right)$$

where c is the velocity of light .

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{c^3}$$