LASER

- LASER: Light Amplification by stimulated emission of radiation.

- MASER: Microwave Amplification by stimulated emission of radiation.

Presentation by

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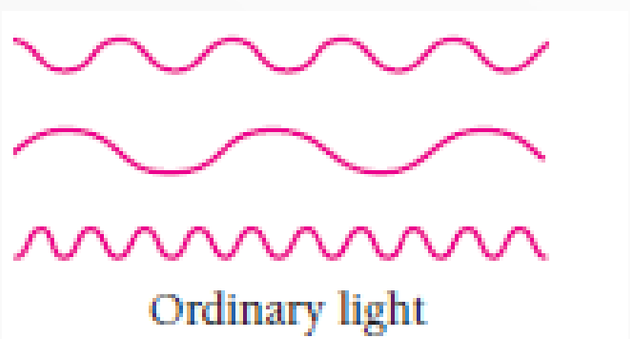
Properties of LASER

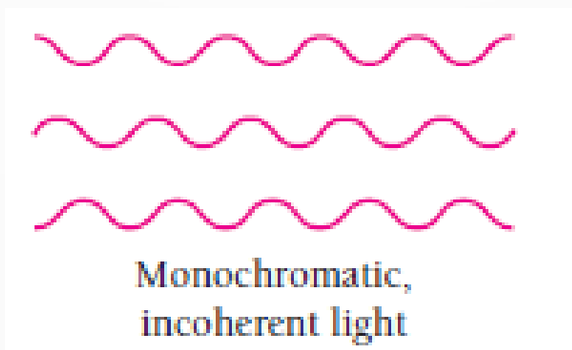
(i) The light is very nearly monochrmatic.

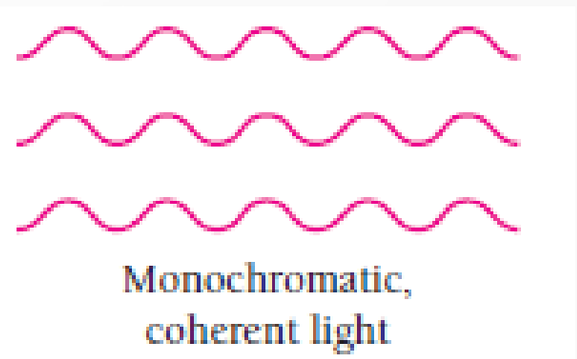
(ii) The light is coherent, with the waves all exactly in phase with one another.

(iii) A laser beam diverges at all.

(iv) The beam is extremely intense, more intense by far that the light from any other source. To Achieve the energy density equal to that in some laser beams, a hot object would have to be hot at a temperature of 10^{30} K.


Ordinary light

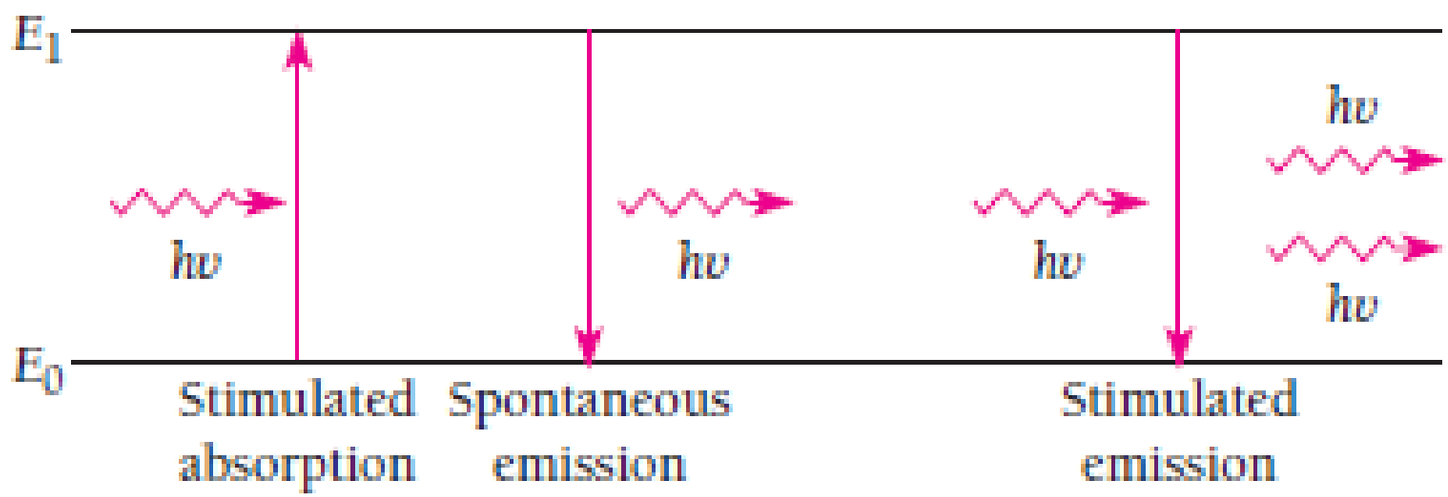

Monochromatic, incoherent light


Monochromatic, coherent light

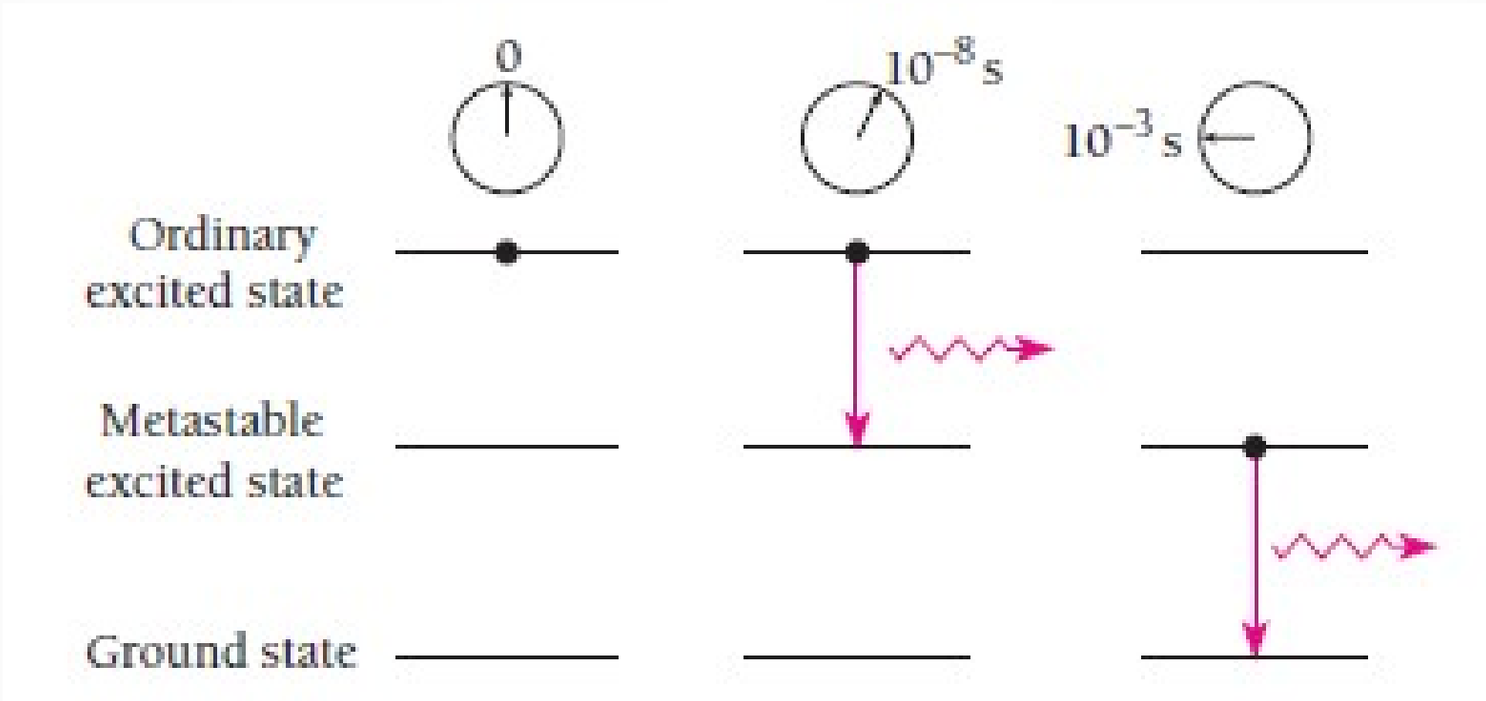
LASER Transitions

Three kinds of transitions involving electromagnetic radiation are possible.

(i) Stimuated absorption. (ii) Spontaneous emission. (iii) Stimulated emission.

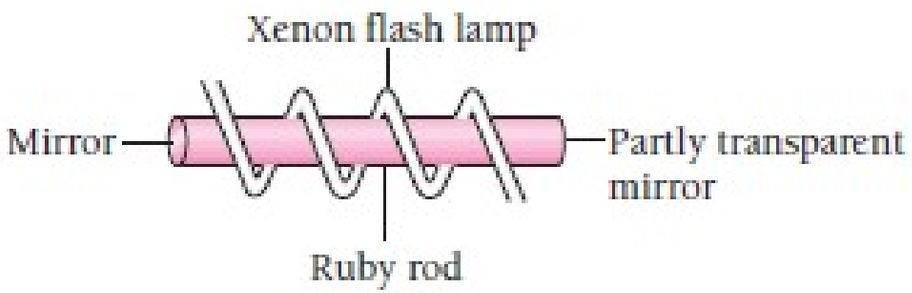


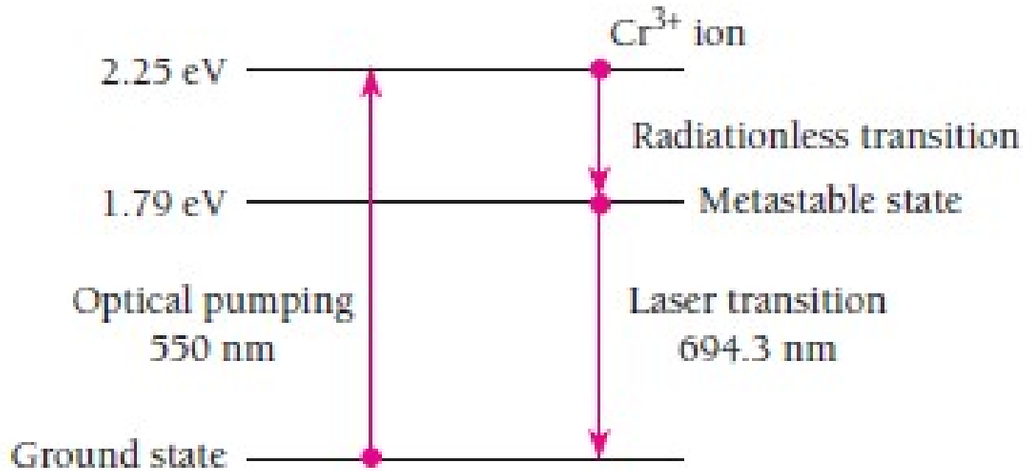
Metastable state



An atom can exist in a metastable energy level for a longer time before radiating than it can in an ordinary energy level.

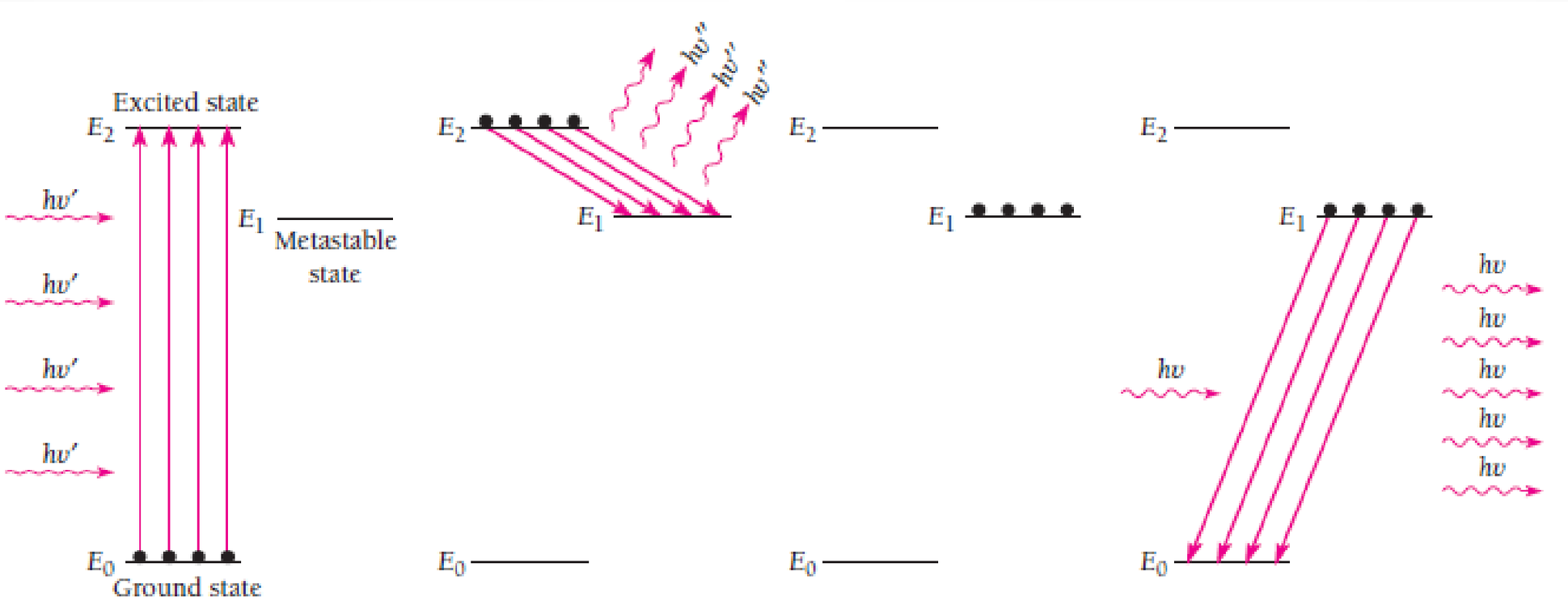
Population inversion and optical pumping





Assembly of atoms in whitch the majority are in energy levels above the ground state. Normally the ground state is occupied to the greatest extent.

Principle of a three level LASER



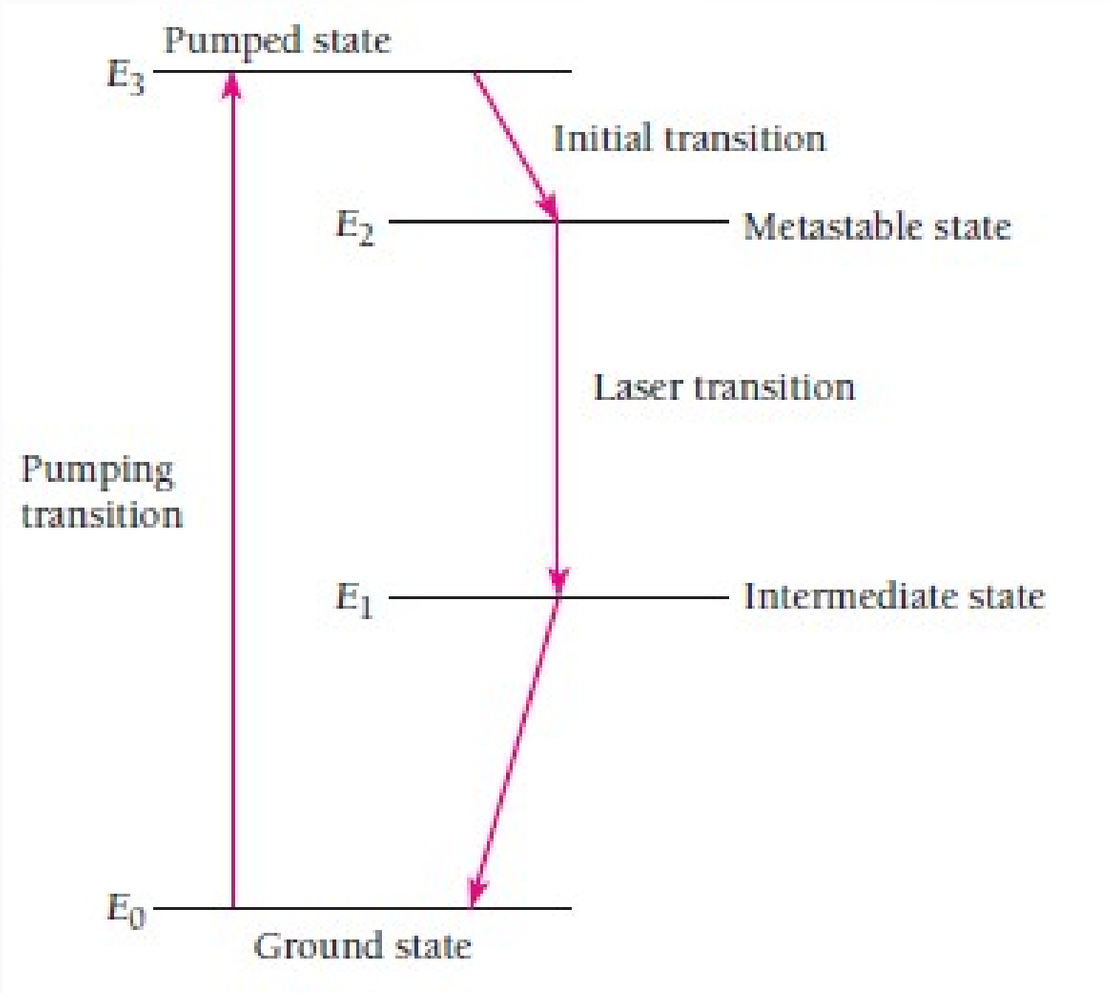
Atoms in ground state are pumped to state E_2 by photons of $h\nu' = E_2 - E_0$ (or by collisions).

Rapid transition to metastable state E_1 by spontaneous emission of photons of $h\nu'' = E_2 - E_1$ (or in some other way).

Metastable states occupied in many atoms.

Stimulated emission occurs when photons of $h\nu = E_1 - E_0$ are incident, with the secondary photons themselves inducing further transitions to produce an avalanche of coherent photons.

Principle of a four level laser



Einstein's *A* and *B* coefficients

- Assumptions:

  (i) Consider a gas of atoms subjected to thermal radiations.

  (ii) The atoms can respond by making transitions between different energy levels.

  (iii) The atoms can absorb and emit photons when they make transitions.

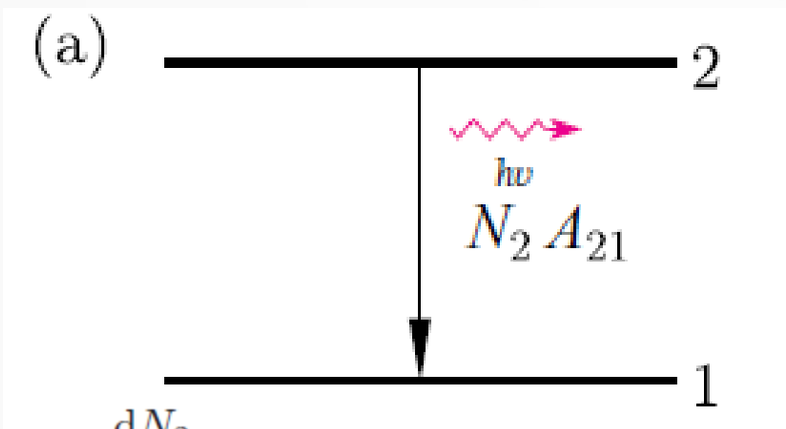
  (iv) The atoms are sitting in a bath of photons which we call radiation field (energy density u_ω).

  (v) We consider here a two level system represented by E_1 and E_2.

Einstein's *A* and *B* coefficients

Three processes are possible: (a) spontaneous emission, (b) stimulated absorption, and (c) stimulated emission.

(a) Spontaneous emission of a photon:



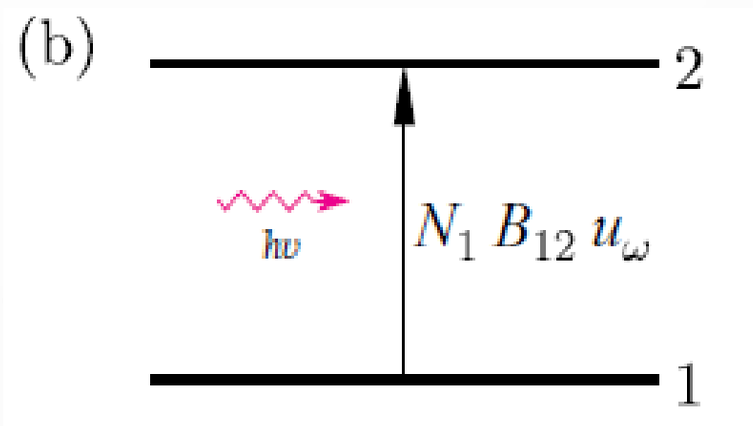
$$\frac{dN_2}{dt} = -A_{21}N_2,$$

$$N_2(t) = N_2(0)e^{-t/\tau}.$$

where $\tau \equiv 1/A_{21}$ Natural radiative time

A_{21} is the probability of spontaneous emission. N_2A_{21}= rate of spontaneous emission.

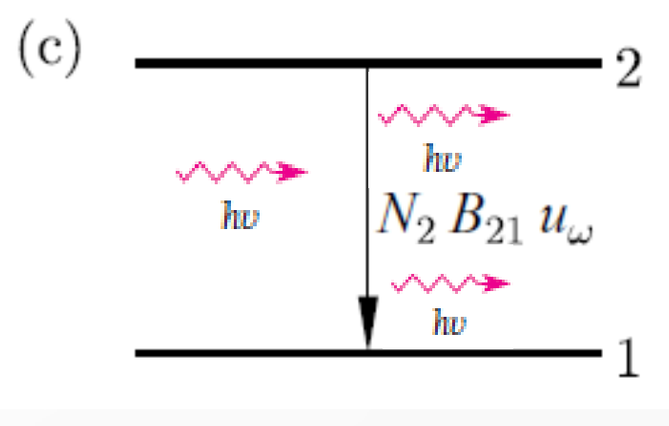
(b) Stimulated absorption of a photon.



$N_1B_{12}u_\omega$ = rate of stimulated absorption.

B_{12} = probability of stimulated absorption.

(c) Stimulated emission of photons.



$N_2B_{21}u_\omega$= rate of stimulated emission.

B_{21}= Probability of stimulated emission.

Einstein's *A* and *B* coefficients

In the steady state, all the three processes occuring simultaneously, we must have,

$$N_2 B_{21} u_\omega + N_2 A_{21} = N_1 B_{12} u_\omega .$$

This implies,

$$u_\omega = \frac{A_{21}/B_{21}}{(N_1 B_{12}/N_2 B_{21}) - 1}.$$

If the sstem is in thermal equilibrium, then the relative population of the two levels must be given by a boltzmann factor, i.e.,

$$\frac{N_2}{N_1} = \frac{g_1 e^{-E_1/kT}}{g_2 e^{-E_2/kT}} = \frac{g_1}{g_2} e^{-(E_2 - E_1)/kT} = \frac{g_2}{g_1} e^{-\hbar\omega/kT}$$

Where, g_1 and g_2 are the degeneracies of the levels E_1 and E_2 respectively.

Putting this value in the above equation we have,

$$u_\omega = \frac{A_{21}/B_{21}}{(g_1 B_{12}/g_2 B_{21})\mathrm{e}^{-\beta\hbar\omega} - 1},$$

Now the energy density distribution for the black body radiation is given by,

$$u_\omega = \frac{\hbar}{\pi^2 c^3} \frac{\omega^3}{\mathrm{e}^{\beta\hbar\omega} - 1}.$$

Compareing the above two equations we have,

$$\frac{B_{21}}{B_{12}} = \frac{g_1}{g_2} \qquad \text{and} \qquad A_{21} = \frac{\hbar\omega^3}{\pi^2 c^3} B_{21}.$$

A_{21}, B_{12} and B_{21} are known as Einstein's *A* and *B* coefficients.

Condition for population inversion

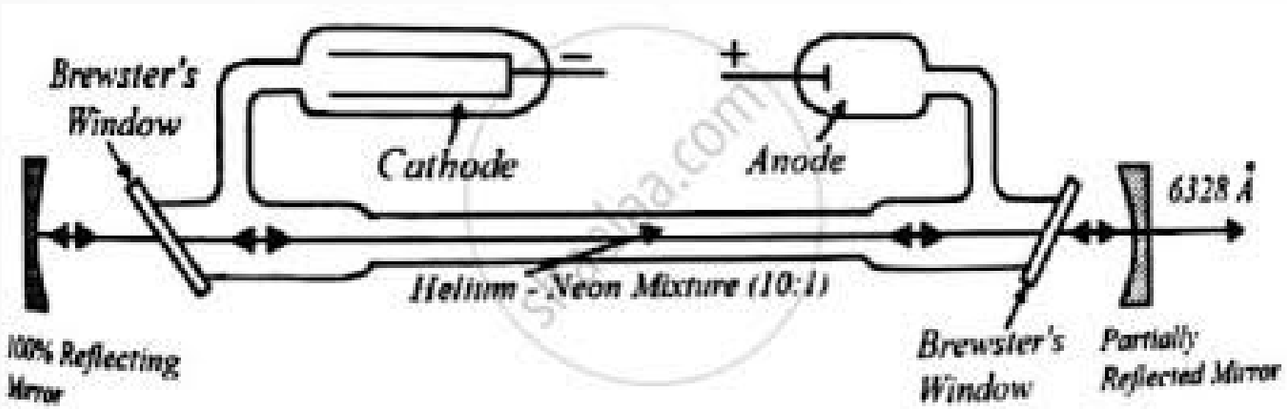
The atoms will produce more photons than they absorb if the rate of stimulated emission is greater than the absorption rate and this will occur when,

$$N_2 B_{21} u_\omega > N_1 B_{12} u_\omega,$$

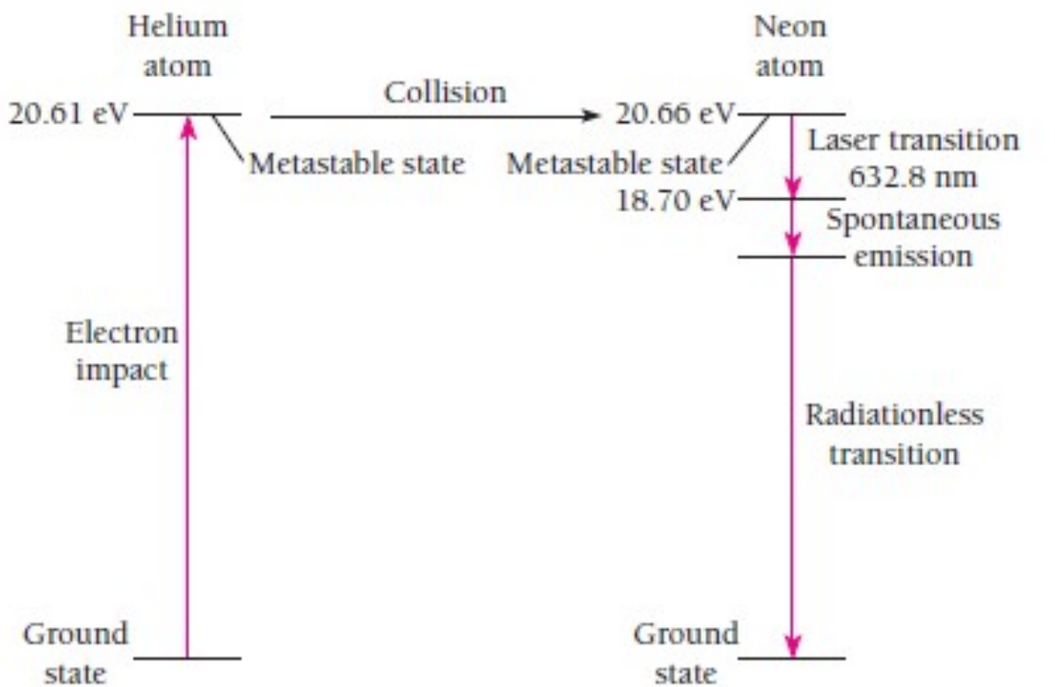
Which implies that,

$$\frac{N_2}{g_2} > \frac{N_1}{g_1}.$$

Helium-Neon gas Laser



(a) Construction



(b) Energy level diagram.