Laser

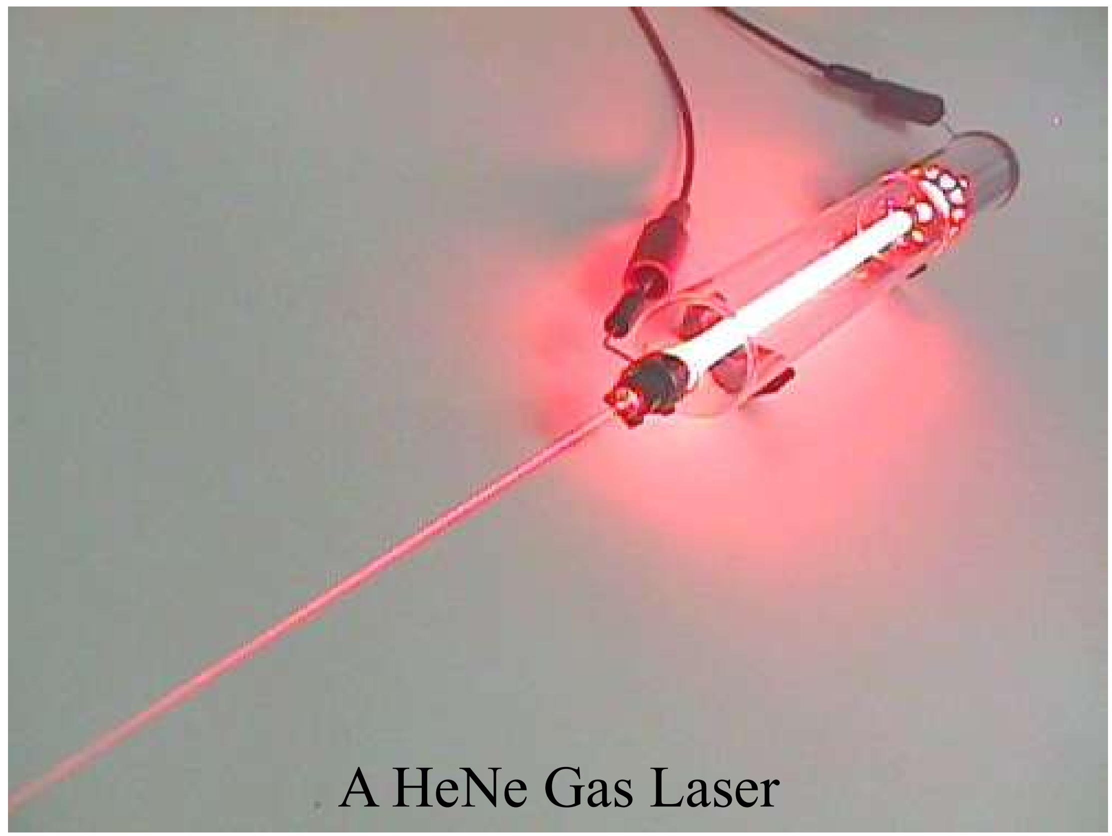
Laser = "light amplification by stimulated emission of radiation"

It is a mechanism to produce a beam of highly *coherent* and nearly monochromatic light from the *cooperative* emission from many atoms.

To understand it, need two new concepts from QM:

Stimulated Emission

Population Inversion

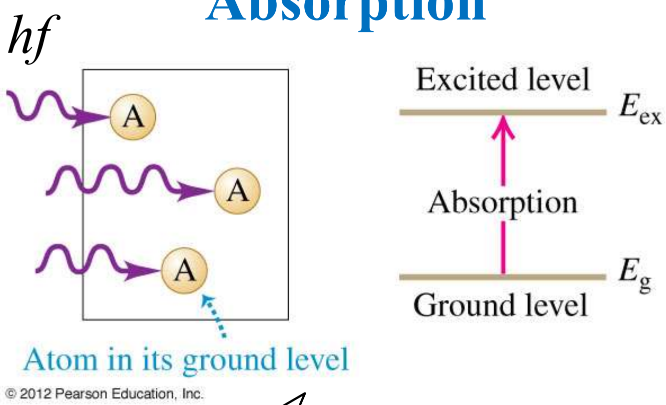


A HeNe Gas Laser

Atoms Interactions with Light

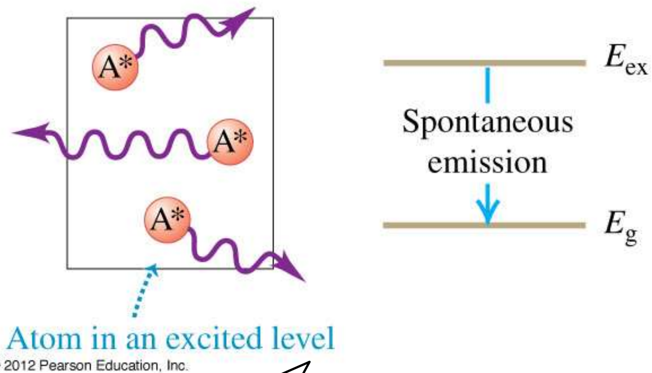
Atoms interact with light in three primary processes:

Absorption



Photons with $hf = E_{ex} - E_g$ is being absorbed by atoms (A) at ground level E_g

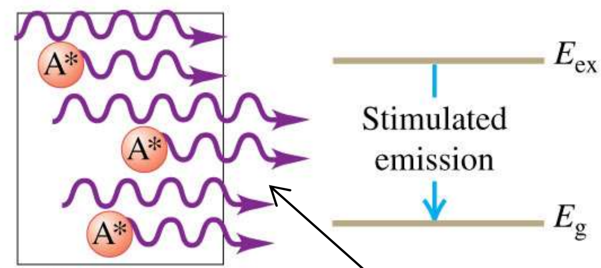
Spontaneous Emission



Excited atoms (A*) at E_{ex} relax back spontaneously (randomly) to ground level E_g

→Phase & direction of emissions are random !

Stimulated Emission



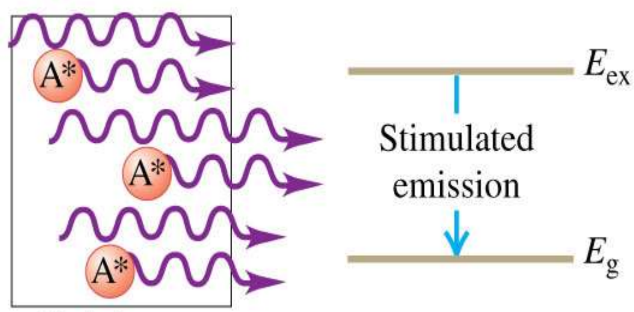
light amplification

Incident photon with the same energy $hf = E_{ex} - E_g$ encounters a previously excited atom and resulted in 2 *coherent* photons being admitted.

(Processes which we have learned previously)

(New "resonance" process)

Stimulated Emission & Population of Excited Atoms



Stimulated emission needs incident photon to interact with *previously* excited atoms

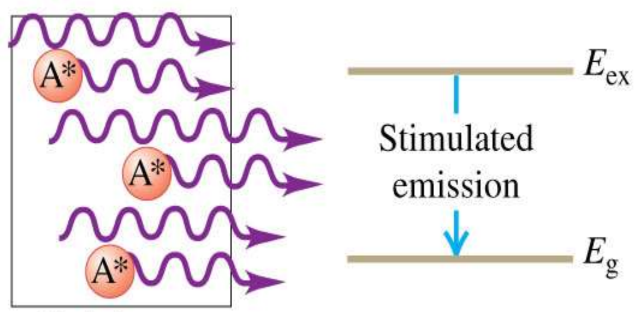
At *thermal equilibrium* at a given *T*, the number of atoms at a given energy state *E* is given by the Maxwell-Boltzman distribution (Ch. 18),

$$n(E) = Ae^{-E/kT}$$ (where *A* is a normalization constant)

So, if E_g is the ground state energy and E_{ex} is the energy for the excited state, the ratio of numbers of atoms in the two states is,

$$\frac{n_{ex}}{n_g} = \frac{Ae^{-E_{ex}/kT}}{Ae^{-E_g/kT}} = e^{-\left(E_{ex}-E_g\right)/kT}$$

Stimulated Emission & Population of Excited Atoms



Stimulated emission needs incident photon to interact with *previously* excited atoms

For a typical value of $E_{ex} - E_g = 2eV$ at $T = 3000K$,

$$\frac{E_{ex} - E_g}{kT} = \frac{(2eV)(1.6\times10^{-19}J/eV)}{(1.38\times10^{-23}J/K)(3000K)} = 7.73$$

And, the ratio of relative population between the excited & ground states is very small,

$$e^{-(E_{ex}-E_g)/kT} = e^{-7.73} = 0.00044$$

At equilibrium, almost all atoms are at the ground state !

Making a Laser

In order to have a sustained stimulated emission, i.e.,

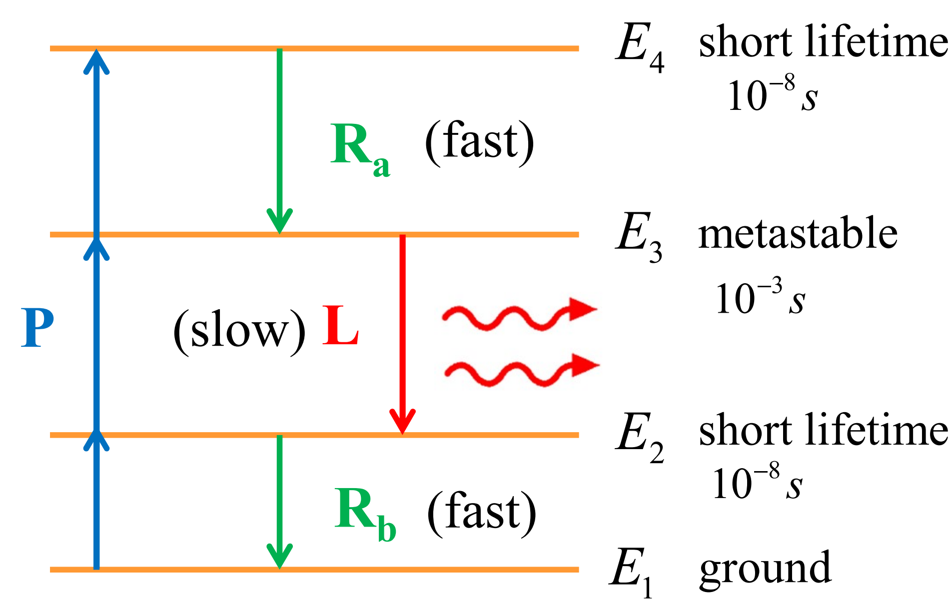
rate (stimulated emission) > rate (absorption)

We need to have an inverted ratio $\frac{n_{ex}}{n_g} > 1$. This is called **Population Inversion**.

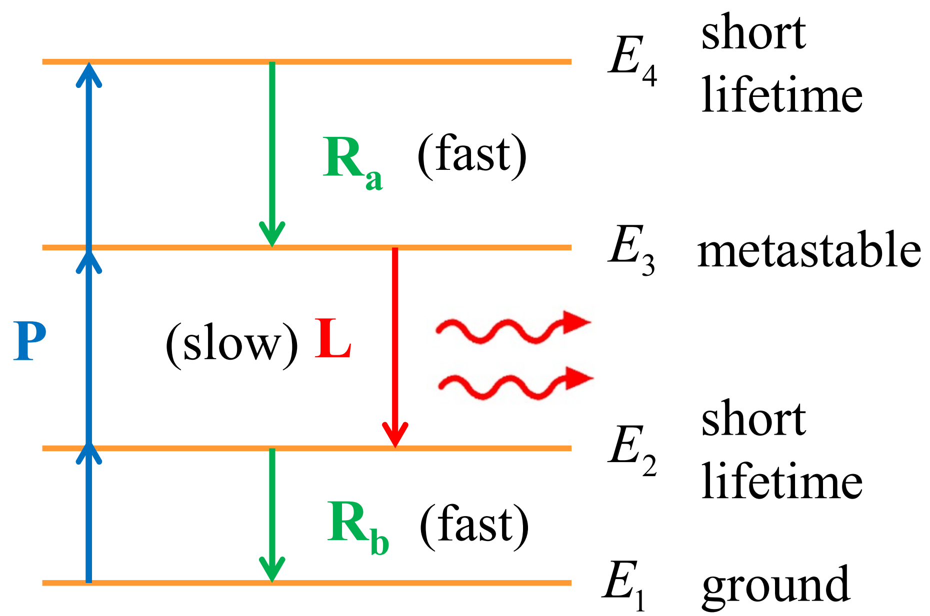
This is a *non-equilibrium* situation and it cannot occur without an external input AND with atoms having the right kind of excited states.

One such system is the *four-level laser*:

To provide the external input, the laser can be "pumped" optically, electrically, or by other means so as to excite atoms out from the ground state.



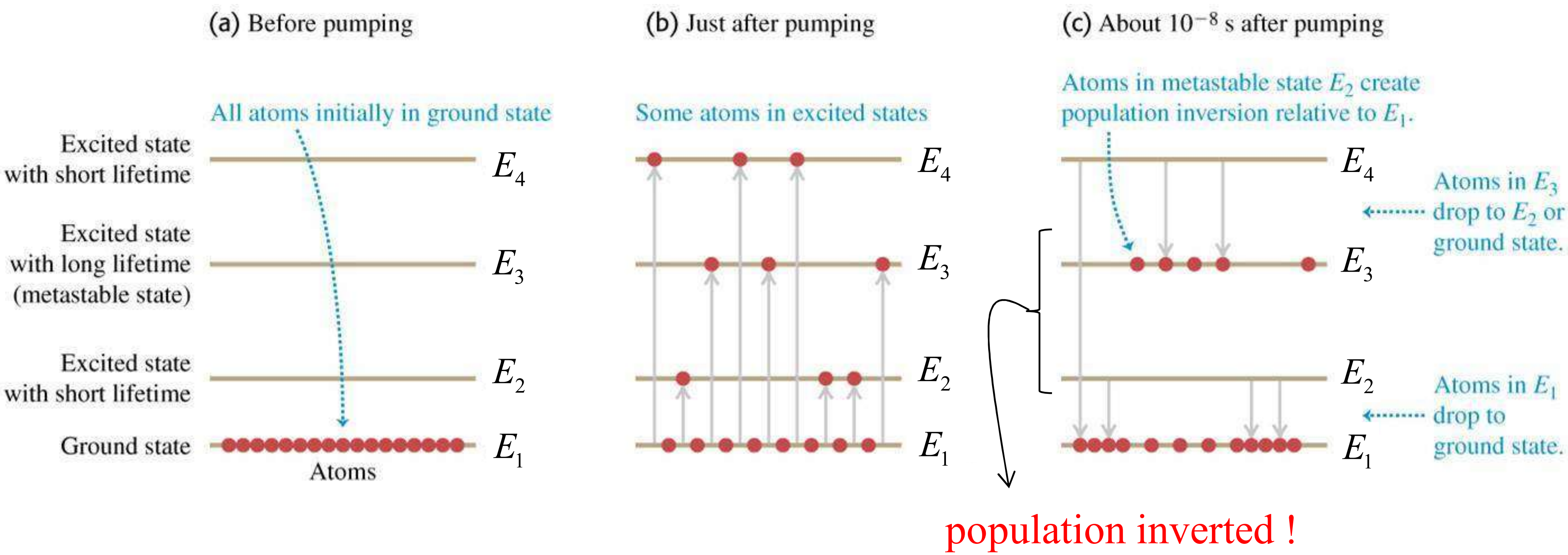
Making a Laser



(NOTE: I am calling the ground state as E_1 and the first excited state E_2 in the standard convention while your book starts the first excited state as E_1.)

Making a Laser

The key in the four-level laser system is the relatively long lifetime for $E_3\left(10^{-3}s\right)$ as compare with the other two excited states: E_2 and $E_4\left(10^{-8}s\right)$.



Over the next $10^{-3}s$, "enhanced" stimulated emission will then produce a coherent laser beam with frequency $f=\left(E_3-E_2\right)/h$.