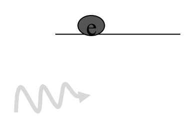
**L** light
**A** amplification by
**S** stimulated
**E** emission of
**R** radiation

?



## "Stimulated emission" of light

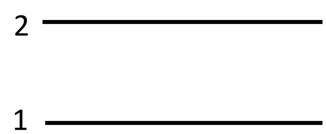
First realized by A. Einstein




Photon hits atom already in higher energy level,
original photon continues and atom emits second identical one

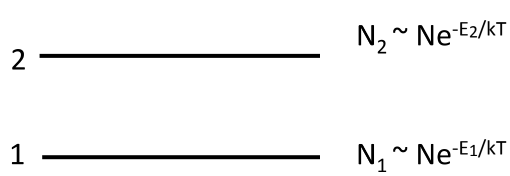
Second identical photon comes out. Atom goes down to ground state, cloning the photon.

If there are N total atoms and the temperature is T, how many atoms would be at each level?

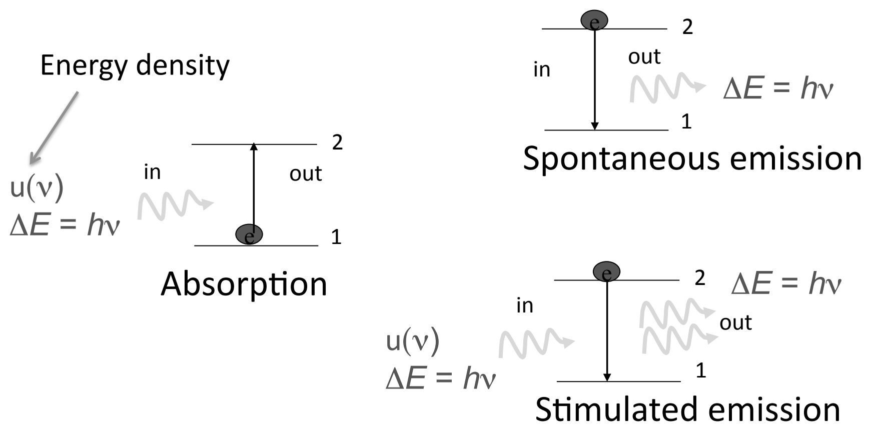




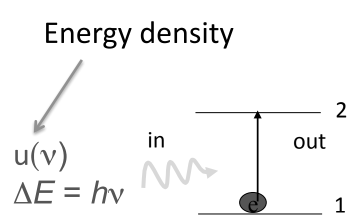

If there are N total atoms and the temperature is T, how many atoms would be at each level?



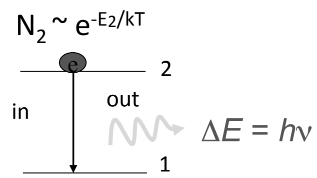
# Now we need to incorporate the absorption / emission processes:



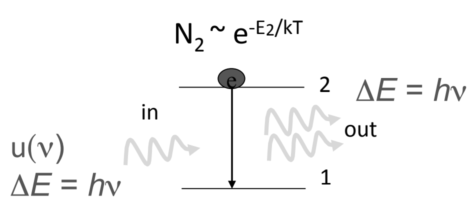


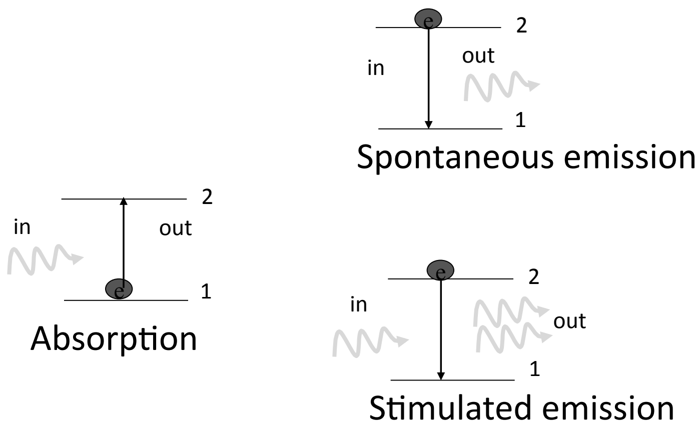




$N_1 \sim e^{-E_1/kT}$


$N_2 \sim e^{-E_2/kT}$
e
2
in
out
$\Delta E = h\nu$
1



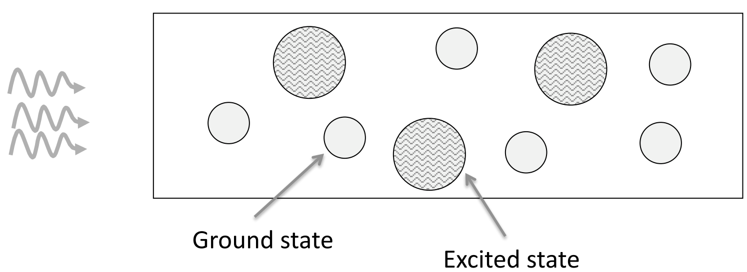

$N_2 \sim e^{-E_2/kT}$
e
2
$\Delta E = h\nu$
in
out
$u(\nu)$
$\Delta E = h\nu$
1




**Surprising fact:** Chance of stimulated emission of excited atom the same as chance of absorption by lower state atom.

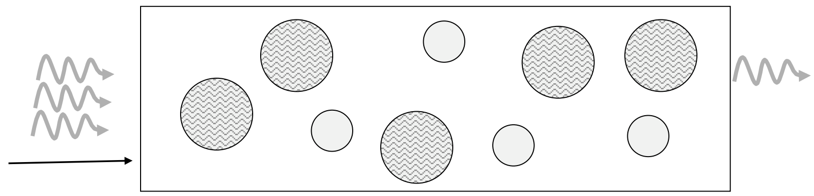


Discharge lamp (Glass tube full of atoms)




Expect that on average

a. more photons will come out right hand end of tube
b. less come out right hand end of tube
c. same number as go in come out
d. no photons will come out



b. less come out right

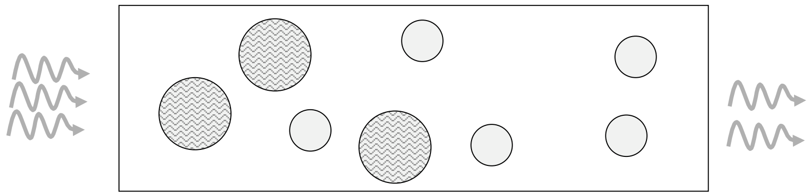
3 excited atoms can emit photons,
6 ground state atoms will absorb.

**Absorption wins.**

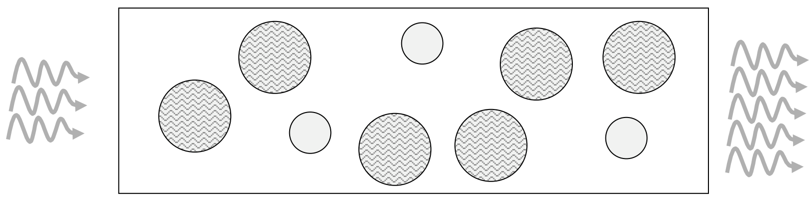


**L light**
**A amplification by** ?
**S stimulated**
**E emission of**
**R radiation**

To increase number of photons after going through the atoms need more in upper energy level than in lower: **"Population inversion"**



$N_{upper} < N_{lower}$, fewer out than in.

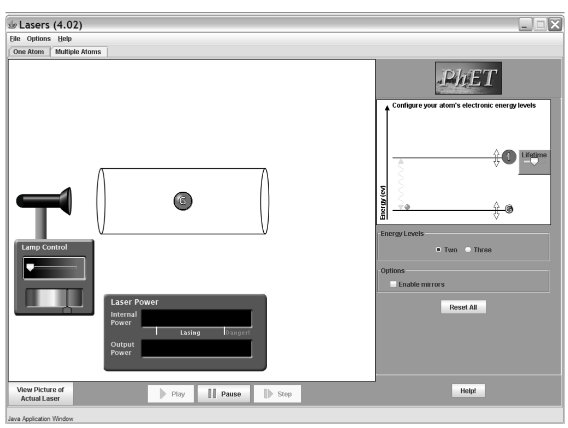


$N_{upper} > N_{lower}$

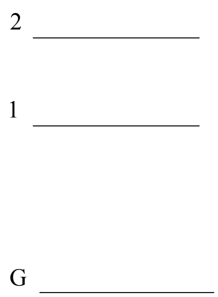


# How do we get population inversion?

http://www.colorado.edu/physics/phet/dev/lasers/4.02.31/



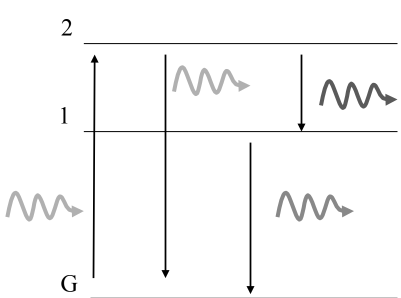
**To get population inversion, need <u>at least one more energy level involved.</u>**



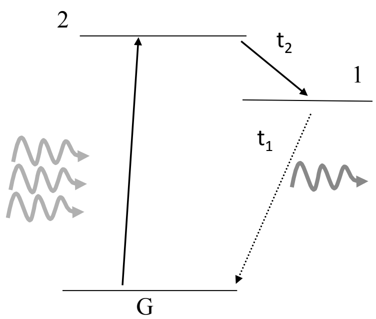

What emission processes / energies are possible?



**To get population inversion, need <u>at least one more energy level involved.</u>**




What emission processes / energies are possible?




"pumping" process to produce population inversion

To create population inversion between G and level 1 would need:

a. time spent in level 2 ($t_2$) before spontaneously jumping to 1 is long, and time spent in level 1 ($t_1$) before jumping to G is short.

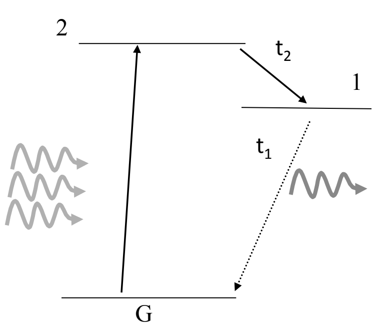
b. $t_1$=$t_2$

c. $t_2$ short, $t_1$ long

d. does not matter

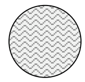


**To get population inversion, need <u>at least one more energy level involved.</u>**




"pumping" process to produce population inversion

c. $t_2$ short, $t_1$ long

Atom in excited state: 

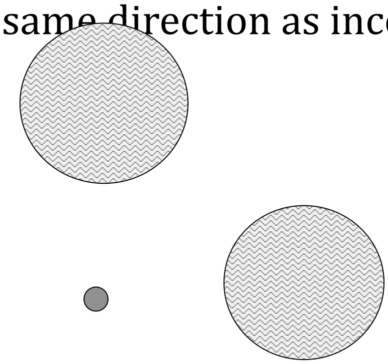
In which direction does the photon come out for
- spontaneous emission?
- stimulated emission?

a) random, random
b) both in opposite direction of absorbed photon
c) both in same direction as absorbed photon
d) random, opposite direction of incoming photon
e) random, same direction as incoming photon

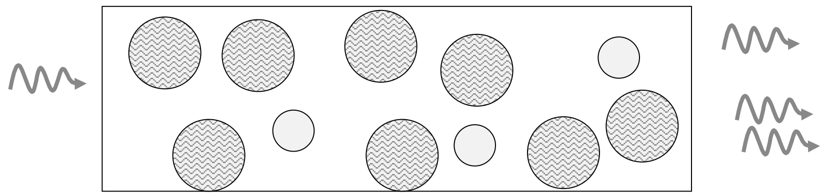


In which direction does the photon come out for
- spontaneous emission?
- stimulated emission?

e) random, same direction as incoming photon



Population inversion ⇒ amplification of photons (LASER).



Much easier if not all light escapes.

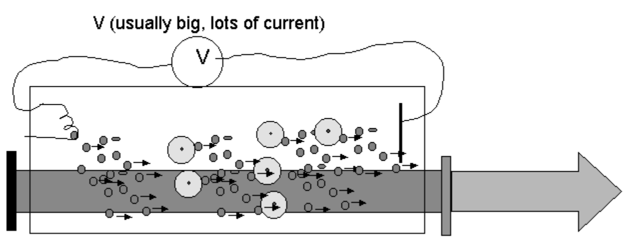
Number of photons between the mirrors: $n = n_0 e^{Gt}$

"gain" G >0 exponential increase.

Very quickly increases until nearly all input power is going into laser light, n can not increase any more.



Open laser He-Ne with exposed discharge tube and mirrors.




• Gas lasers, like Helium Neon. Just like neon sign with helium and neon mixture in it and mirrors on end.

• Diode laser, light from diode at P-N diode junction. Mirrors on it.