1. Brief application of discharge lamps and atomic physics to more efficient light sources.

2. Laser (application of light-atom physics)

("light amplification by stimulated emission of radiation")

1. What is different/special about laser light.
2. Physics of interactions of atoms with light.
   (how use to make whole bunch of identical photons)
3. how to build a laser.

Goals

1) Be able to explain how laser light is different from ordinary light.

2) Be able to provide a basic design for a gas laser, giving the basic components and requirements for it to operate.

CQ. My reviewing after classes last week best described by
a. testing myself on what I remember, then checking notes
b. looking over posted notes and my own notes from class
c. just looking over the posted lecture notes
d. none of the above

Midterm on Friday.
Spend Wed covering models of atom
and electrons as waves, or reviewing past material?
a. review
b. move on

if a., will require > 50% of students looking over course goals covered so far, posting questions about specific goals on Webct discussion board by 8 AM Wed morning.

Student questions and responses--
Critical part of course.

<u>Developing understanding-</u>-
comparing against previous knowledge, reconciling and making sense, seeing where and how does and does not apply. Comes from the active processing of posing questions, thinking about answers, not just from hearing factual explanations.

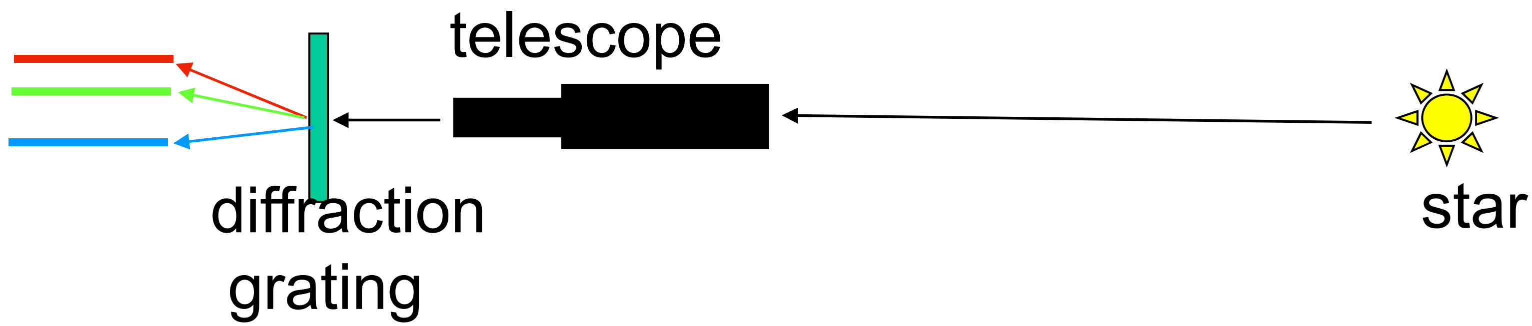
Some questions too complex or off topic-- good to know, but we limit responses or cut off discussion.
Rest are vital for learning.
You need to note question, think about, note answer.

to emphasize--At least one student question on every exam assuming some match learning goals

Applications of atomic spectroscopy (how it is useful)

1. Detecting what kind of atoms are in a material.
(stick in discharge lamp or flame, look with grating)

2. Knowing laws of physics are same away from earth.
Look at light from star with diffraction grating, see what lines there are- match up to atoms on earth, in sun, ...



3. Making much more efficient lights!

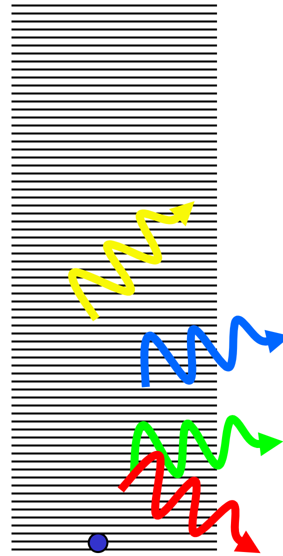
Incandescent light (hot filament)

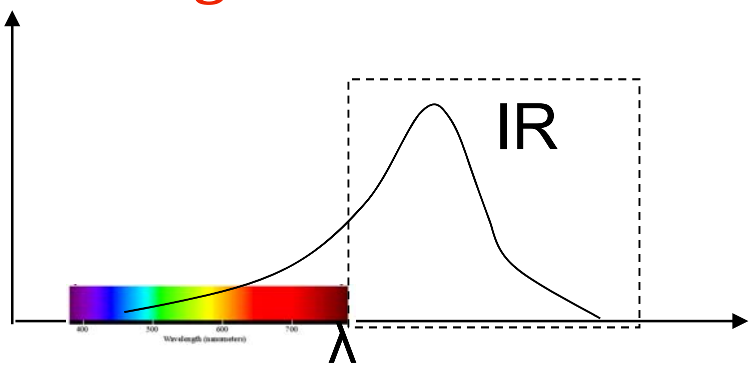
Temperature = 2500-3000K

Hot electrons jump between many very closely spaced levels (solid metal). Produce all colors. Mostly infrared at temp of normal filament.

88% is worthless IR

IR = longer than 680nm





12% of energy is useful visible light

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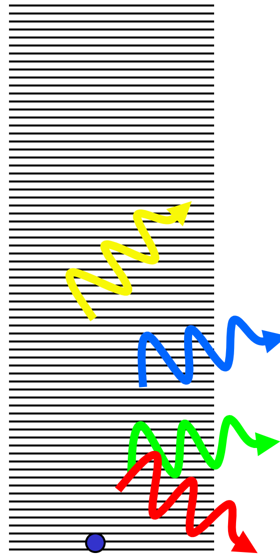
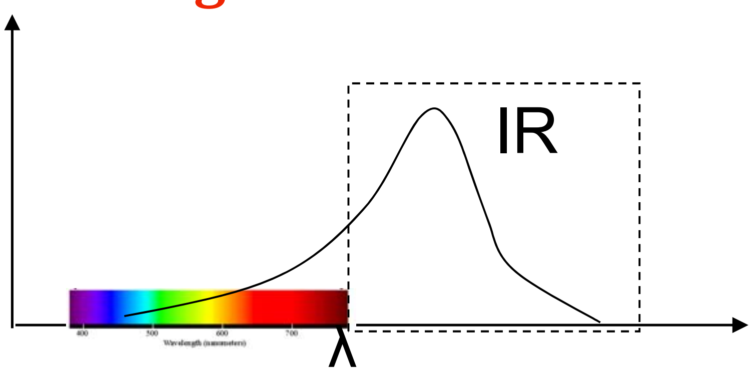


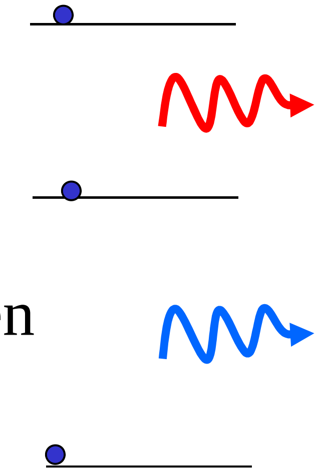


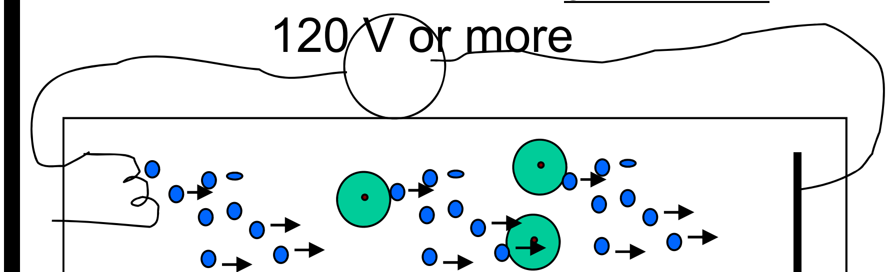
12% of electrical energy comes out as useful visible light

Discharge lamp

Energy levels in isolated atom.

kick up,
only certain wavelengths when come down.



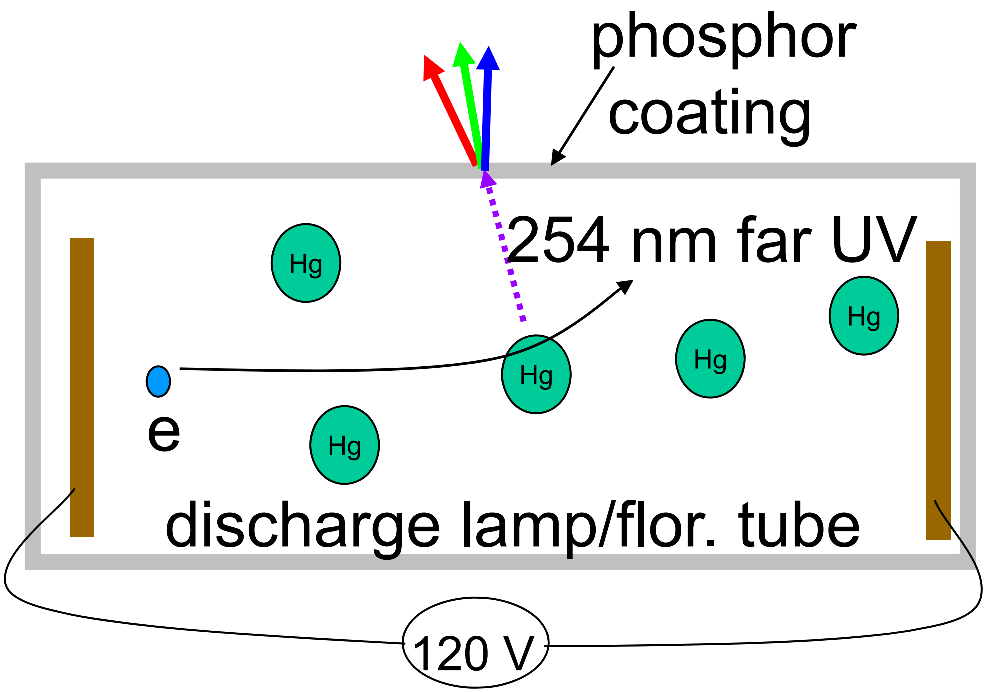


Right atom, right pressure and voltage, mostly visible light.

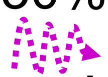
Streetlight discharge lamps (Na or Hg) 80% efficient.

Florescent Lights. Discharge lamp, but more complicated to get light that looks white to eye. White= Red + green +blue
40-60% efficient (electrical power⇒visible light)

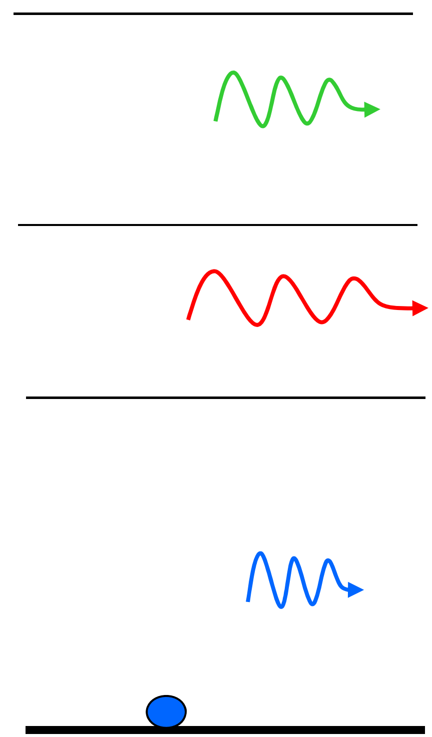
Converting UV light into visible photons with “phosphor”.
Phosphor converts 254 nm UV to red+ green+blue.



phosphor wastes 20-30% energy ⇒ heat



for more info on why looks white--
see *color vision* phet sim



energy of electron
in phosphor molecule

Lasers

1. How is laser light different from normal light.

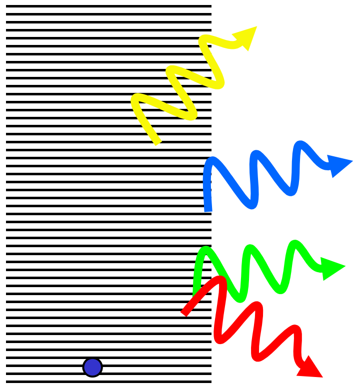
2. interaction of light with atoms

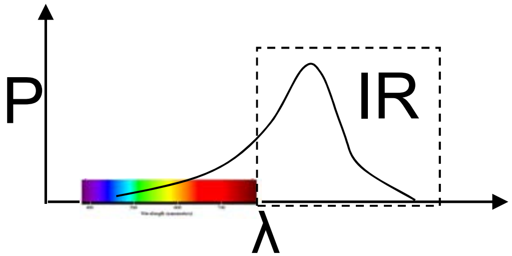
3. physics of a laser

sources of light (traditional):

light bulb filament

Hot electrons.
very large # close energy levels (metal)
Radiate spectrum of colors. Mostly IR.

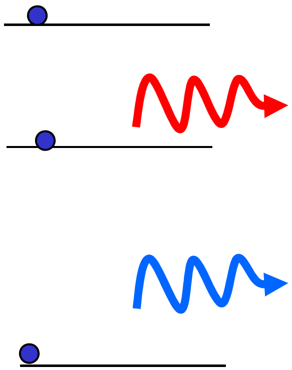


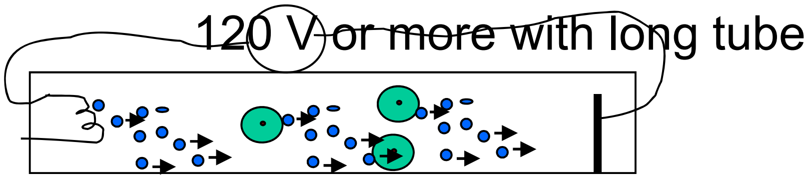


atom discharge lamps

Electron jumps to lower levels.

Only specific wavelengths.





- •Light from extended source
- •Going different directions
- •Range of wavelengths

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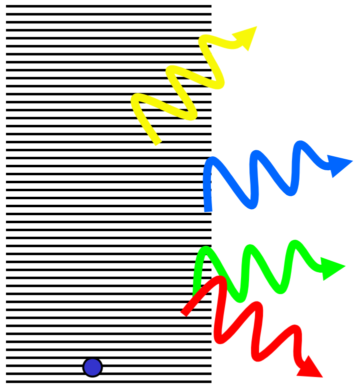

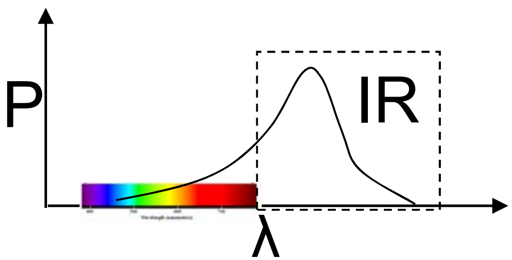

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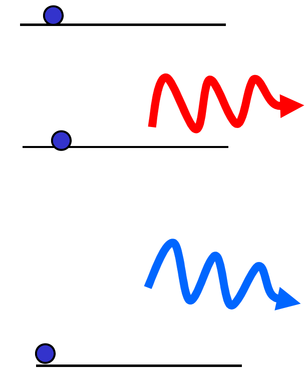

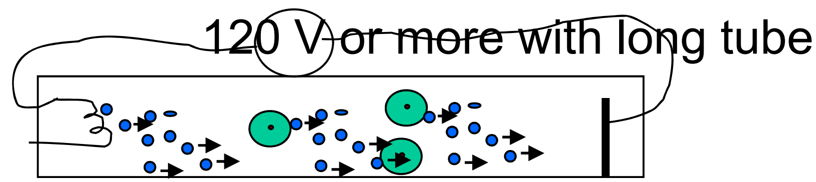

- Light from extended source
- Going different directions
- Range of wavelengths

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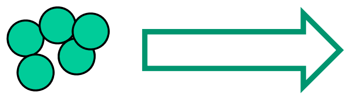
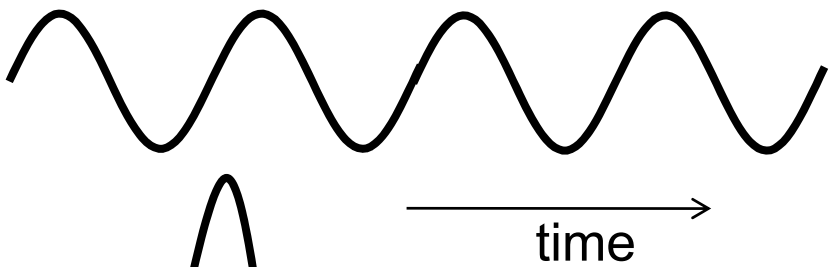
laser light different-- all the same, much better behaved.

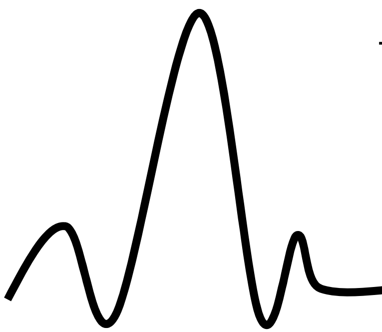
Which accurately describes laser light?

a. 

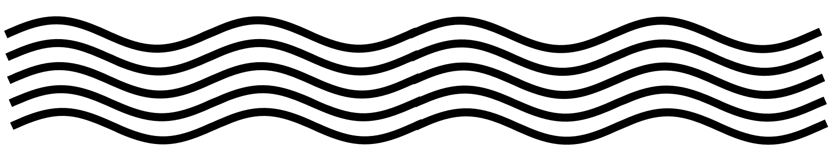
whole bunch of identical photons
(actually on top of each other)

b. 

big electric field
nearly perfect sine wave

c. 

short, very large/intense pulse of electric field

d. 

many small identical E field sine waves that add together

e. more than one of the above

ans e. --a, b. d. all good

Light from a laser all the same ***<u>exact</u>*** color and direction.

light from lasers are much more likely to damage the retina of the eye than light from a bulb because

a. laser is at a more dangerous color.

b. has lots more power in the beam.

c. light is concentrated to a much smaller spot on the retina.

d. light from bulb is turning off and on 60 times per second so light is not as intense.

c. focuses to much smaller spot on retina, local burn.

100 W light bulb no big deal

100 W laser beam cuts through steel like butter

laser light is special and useful because all light exactly the same color and direction.

<u>Can be controlled much better.</u>

<u>Easy to reach uncertainty principle limit for beam focus and collimation.</u>

small spot = high intensity

Reading quiz on laser section

1. “Population inversion” means
a. a larger fraction of the atoms have electrons in a higher energy state than the fraction with electrons in a lower state.
b. a smaller fraction of the atoms have electrons in a higher energy state than the fraction with electrons in a lower state.
c. A sample of atoms in a discharge lamp is emitting more light in the red end of the visible spectrum than is being emitted in the blue end of the spectrum.
d. In a gas discharge lamp more atoms are located are in the top half of the lamp than in the bottom half.

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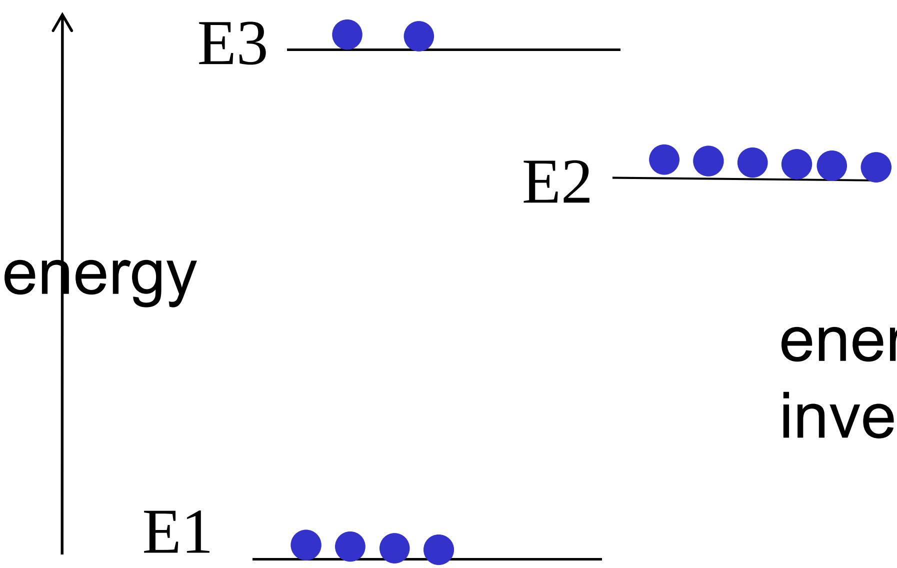


energy level 2 has population inversion relative to level 1.

q2. Stimulated emission means

a. a collision with energetic free electron causes electron in atom to jump to higher energy level.

b. a collision with energetic free electron causes electron in atom to jump to lower energy level.

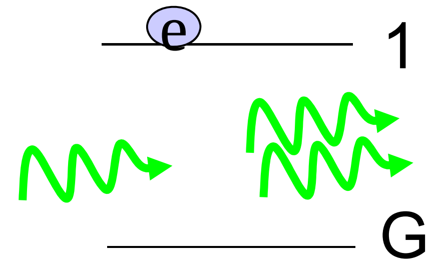
c. a collision with energetic free electron causes two electrons in atom to jump to higher energy levels.

d. a photon causes electron in atom to jump to lower level

e. a photon causes electron in atom to jump to higher level

ans. d--

<u>"Stimulated emission" of light.</u> 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 jumps down.

Cloning photon.

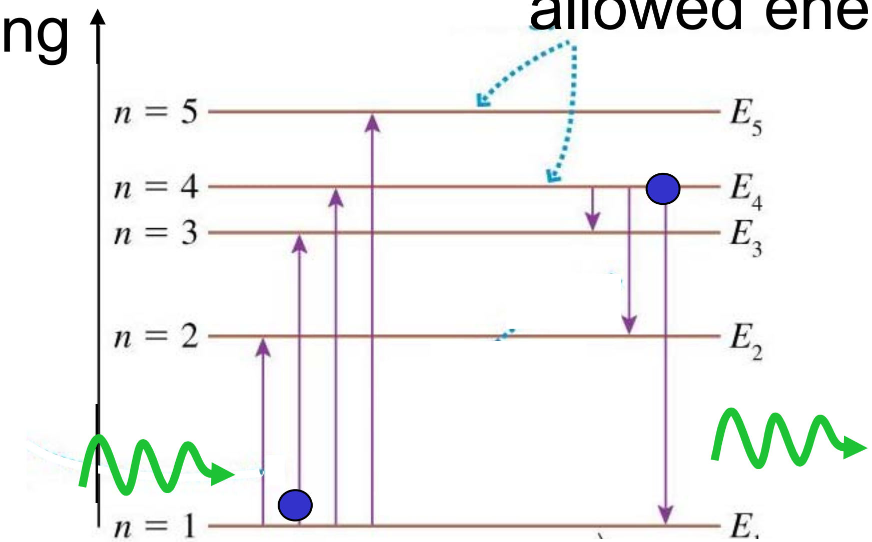
How to produce laser light?

Stimulated emission will clone a photon.

Produce conditions where photon cloned many, many times $\Rightarrow$ laser.

increasing energy

allowed energies



ground state

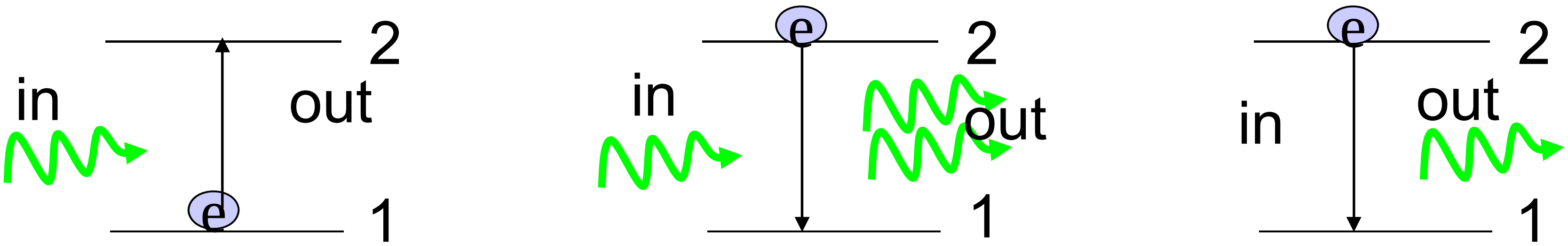
Figure from textbook.

arrows on left represent absorption of light,
arrows on right represent emission.

Weak resonant excitation ⇒ absorption, then spontaneous emission ~0.000 000 01 sec later

what happens if stronger exciting light? go to laser sim

three processes by which light interacts with atoms



absorption (of light)

stimulated emission (of light)

spontaneous emission (of light) (After elec. coll. or light got it up to 2)

Surprising fact. Chance of stimulated emission of excited atom **EXACTLY** the same as chance of absorption by lower state atom. Critical fact for making a laser.

Laser-- just use stimulated emission to clone photon many times (~10^{20} /sec)

Laser-- Light Amplification by Stimulated Emission of Radiation

lots of cloning of photons- LOTS of identical light.

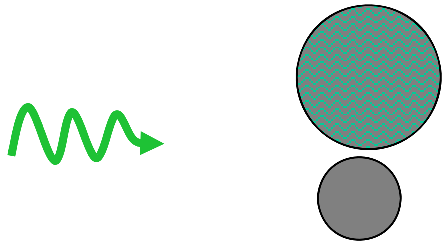
now see how to figure out conditions needed to achieve, important roles all played by:

- absorption (enemy of laser light!)
- stimulated emission
- spontaneous emission (enemy of population inversion)

requires

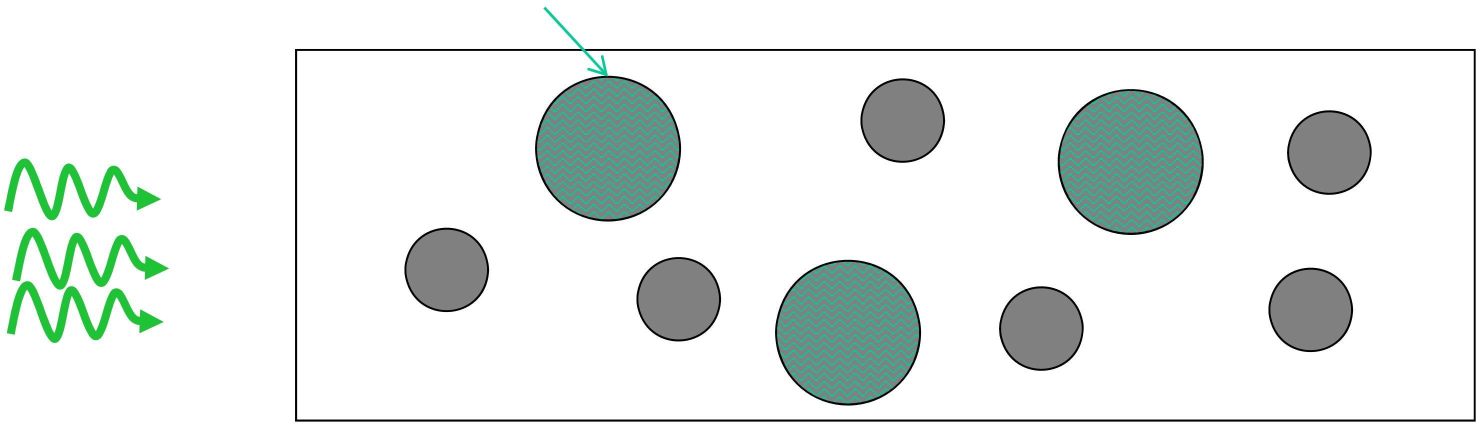
1) more atoms in an upper level than a lower one ("population inversion") *(hard part of making laser)*

2) Method of re-cycling photons to clone more times ("feedback") *(mirrors)*

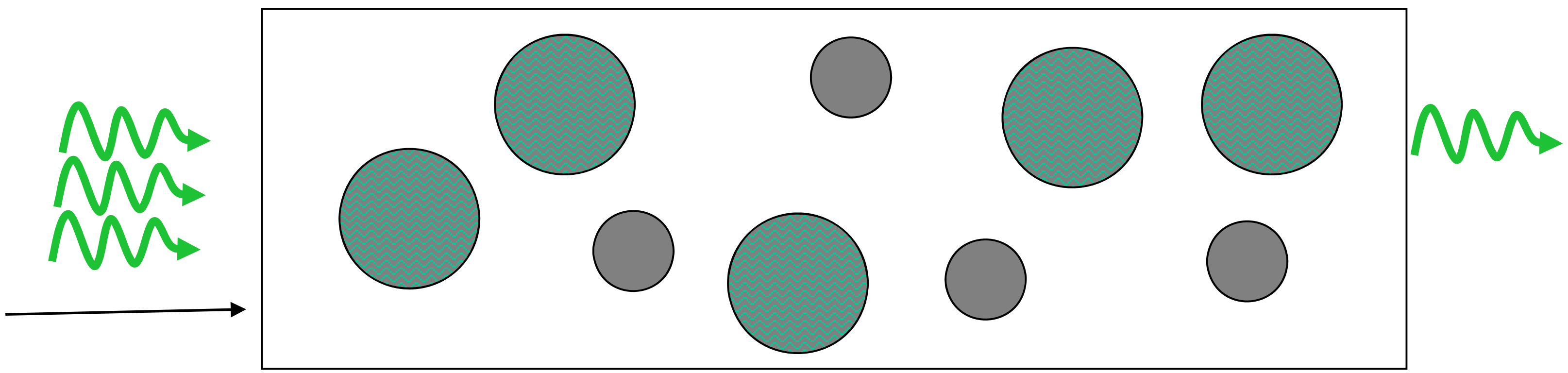


Chance of stimulated emission of excited atom **EXACTLY** the same as chance of absorption by ground state atom.

glass tube full of atoms, discharge lamp
some atoms excited



Expect that on average the photons from left will be a. increased in number, b. decreased in number, c. will be unchanged, d. none will come out.



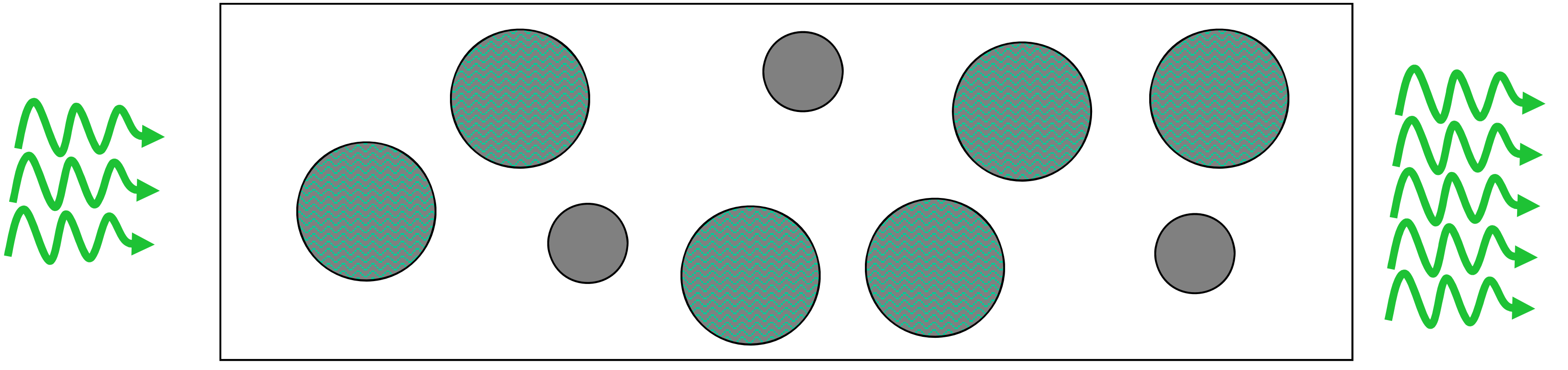
b. less come out right

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

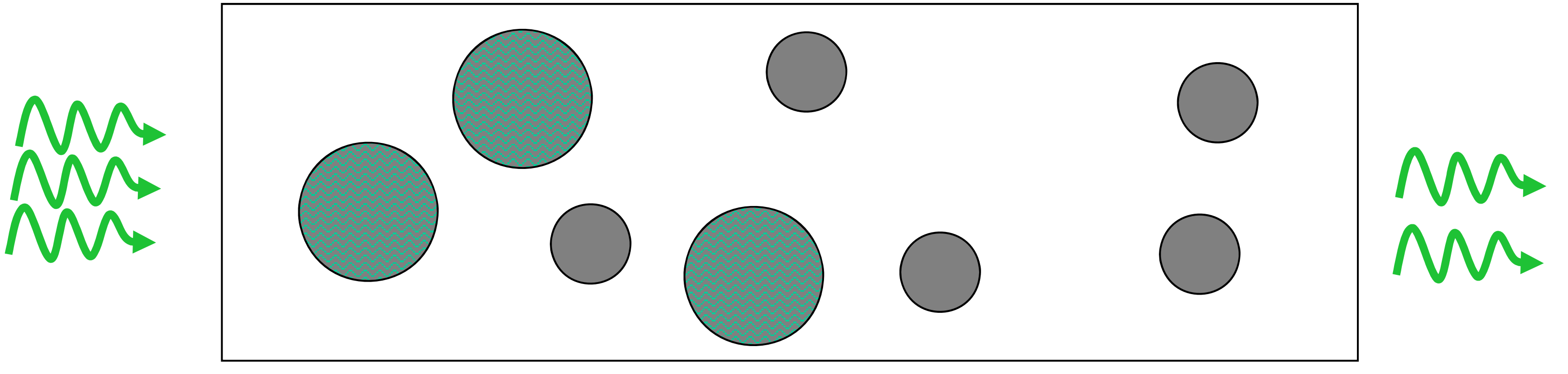
To increase number of photons after going through the atoms need more in upper energy level than in lower.

Need a "Population inversion"

Hard part of making laser, since atoms jump down so quickly.



$N_{upper} > N_{lower}$, (more reproduced than eaten)

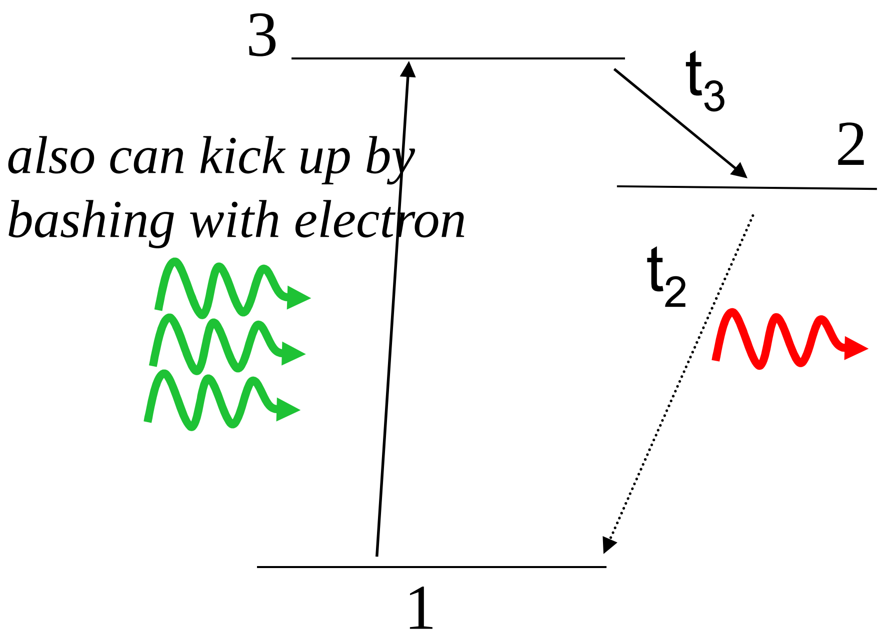


$N_{upper} < N_{lower}$, fewer out than in.

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

(figure out why cannot do with just two levels as HW problem)

show laser sim, multi atom 3 levels



"pumping" process to produce population inversion

To create population inversion between 1 and level 2 would need:

a. time spent in level 3 (t_3) before spontaneously jumping to 2 is long, and time spent in level 2 (t_2) before jumping to G is short.

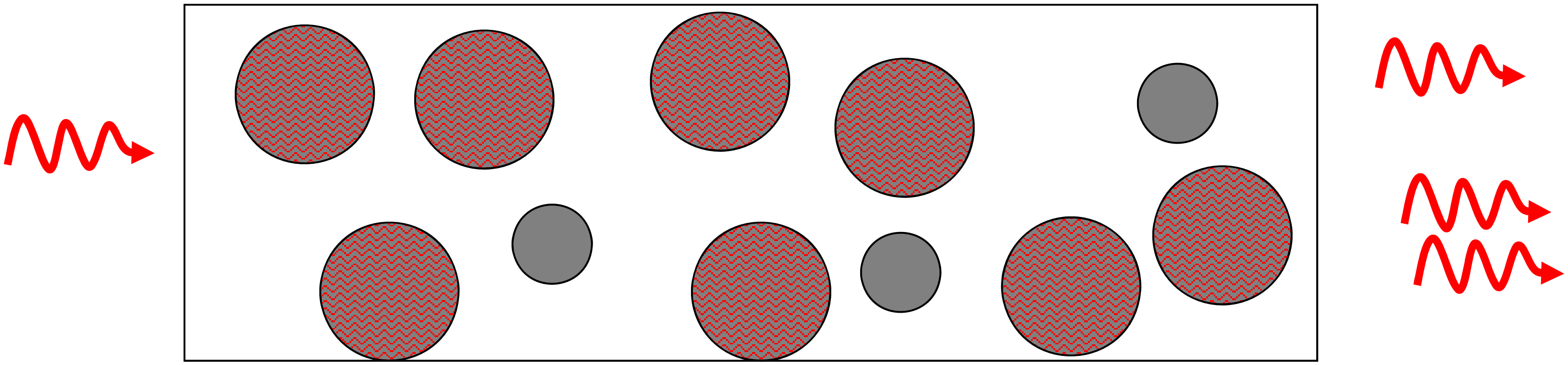
b. $t_3=t_2$

c. t_3 short, t_2 long

d. does not matter

ans. c. show on sim

Population inversion$\Rightarrow$ give amplification of photons from left.



But much easier if not let light all escape. Reuse. mirror to reflect the light. (sim)

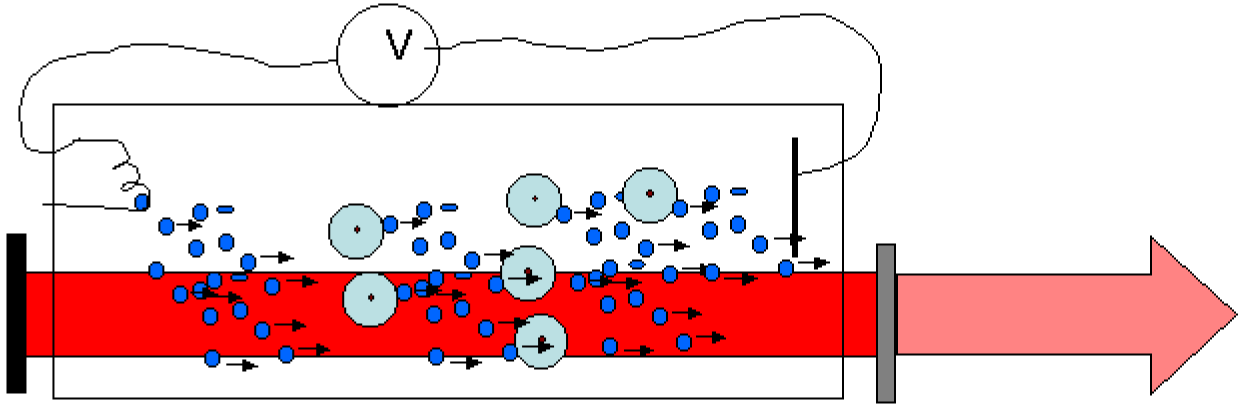
number of photons between the mirrors, $n = n_0 e^{Gt}$

"gain" G >0 exponential increase.

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

can get amplification, but to really build up to nice high power beam need feedback of mirrors.

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



gas laser like Helium Neon. Just like neon sign with helium and neon mixture in it and mirrors on end.

Diode laser- same basic idea, but light from diode at P-N diode junction. Mirrors on it.

questions on lasers?

Bohr model of atom--
reconcile Rutherford observations with atomic spectra, Balmer series relating different colors from hydrogen atoms.

Made bunch of assumptions. Most important was that laws of E&M changed at atomic size scale.
He knew they were arbitrary, only justified, **because** model matched the data.

Never thought to be final answer.