An odd world…

(α) source,- He- nucleus
(β) source, - electrons
(γ) source. - photons

You find yourself in some diabolical plot where you are given an alpha (α) source, beta (β) source, and gamma (γ) source. You must eat one, put one in your pocket and hold one in your hand. You …

a) α hand, β pocket, γ eat
b) β hand, γ pocket, α eat
c) γ hand, α pocket, β eat
d) β hand, α pocket, γ eat
e) α hand, γ pocket, β eat

α - very bad, but easy to stop -- your skin / clothes stop it
β - quite bad, hard to stop -- pass into your body -- keep far away
γ- bad, but really hard to stop--- rarely rarely gets absorbed
Me--- I pick (d)---

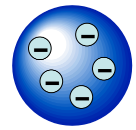
How can I control light? (and rule the world?)

"You know, I have one simple request. And that is to have sharks with frickin' laser beams attached to their heads!"
- Dr. Evil

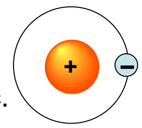
Phys 2130, Day 35
Questions?
Spectra (colors of light)
Discharge Lamps & "lasers"

Reminders:
Lasers Bonding and LEDs
Survey on next week up til tonight

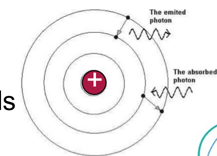
Models of the Atom



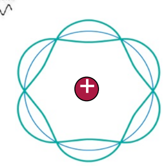
- Thomson – Plum Pudding
  - Why? Known that negative charges can be removed from atom.
  - Problem: just a random guess



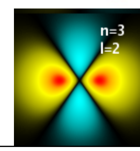
- Rutherford – Solar System
  - Why? Scattering showed hard core.
  - Problem: electrons should spiral into nucleus in ~10^{-11} sec.



- Bohr – fixed energy levels
  - Why? Explains spectral lines.
  - Problem: No reason for fixed energy levels



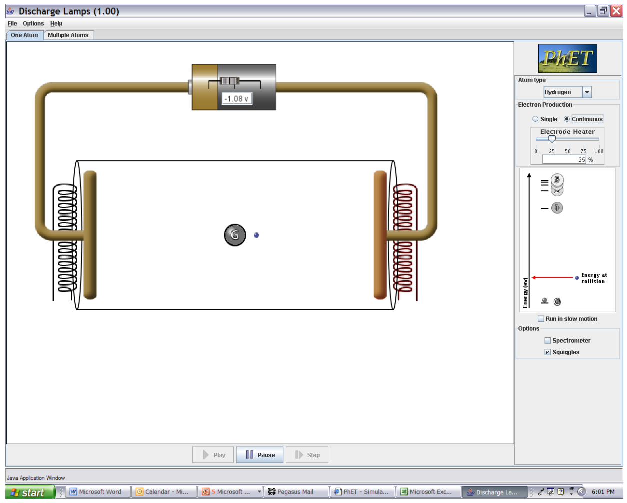
- deBroglie – electron standing waves
  - Why? Explains fixed energy levels
  - Problem: still only works for Hydrogen.
- Schrodinger – saves the day!
  - Why? Explains everything we know
  - Problem: complicated



Learning Goals

1. What one sees if bash atoms with anything, particularly electrons, as in a discharge lamp.
3. What light coming from atoms ("spectra") imply about behavior of electrons in atom.
3. Describe and design how to use atomic structure and interaction with light to make lasers

Observing light, inferring atomic structure

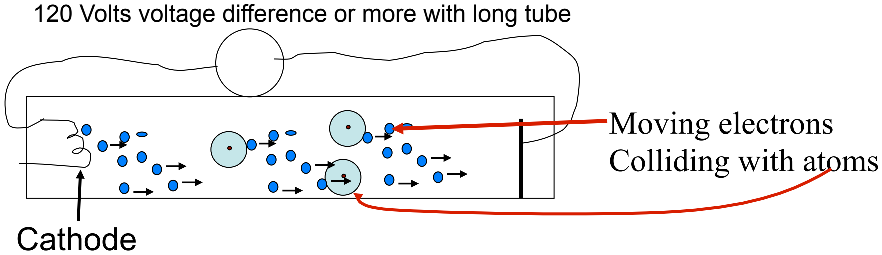


Look at with diffraction gratings and atomic discharge lamps.
Mercury, Sodium, neon

> *Hold grating only by edges...oil from hands ruins grating.*
> *Hold close to eye... See rainbow from lights.*
> *Turn so rainbow is horizontal.*

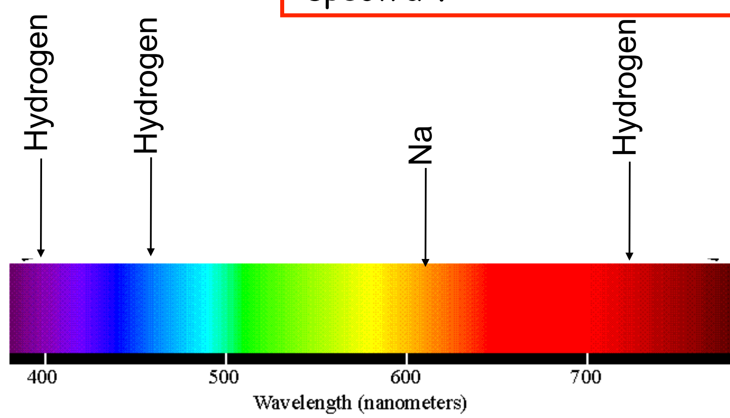
In atomic discharge lamps, lots of electrons given bunch of energy (voltage). Bash into atoms. *("Neon" lights, Mercury street lamps)*

120 Volts voltage difference or more with long tube



What colors from white light?
What colors from hydrogen?
What from sodium?
What from mercury?
What colors from neon?

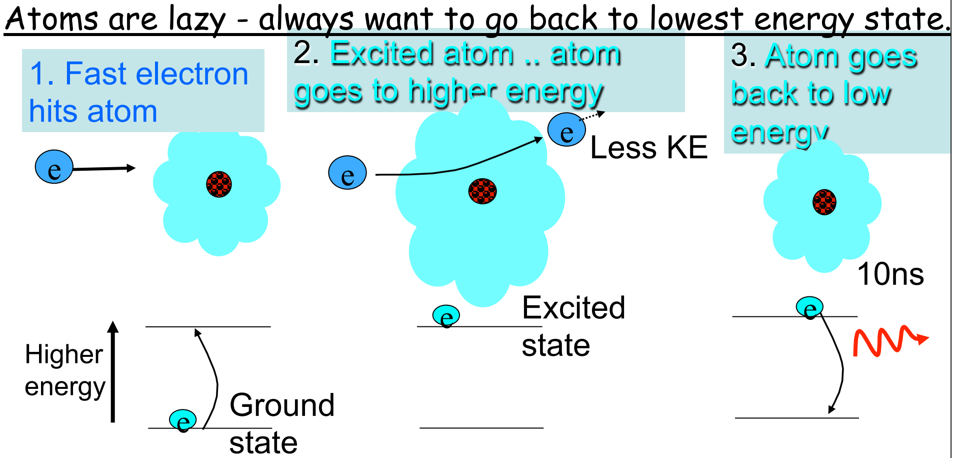
White light = whole spectrum
Each type of atom produces unique set of colors.
Called its "spectrum", plural "spectra".



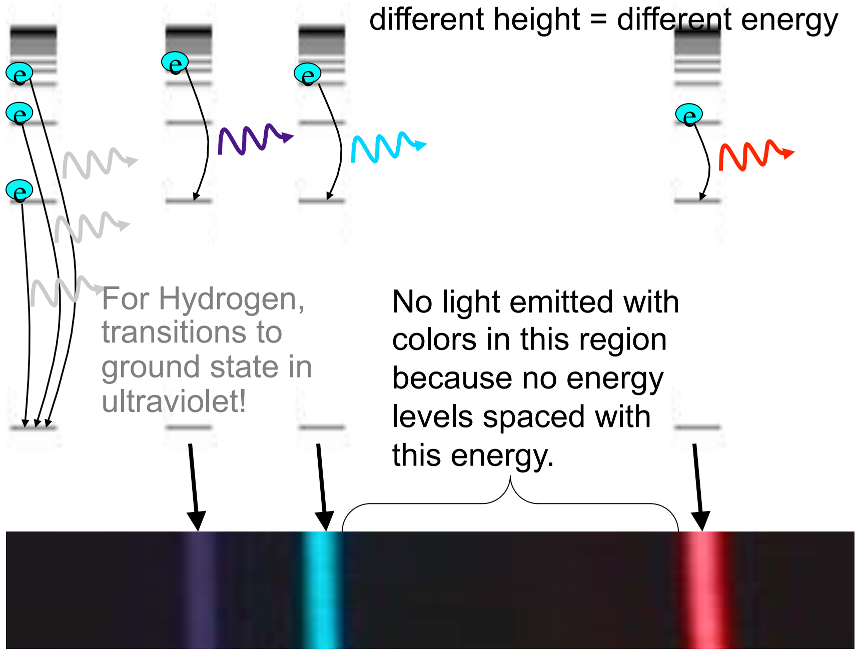
Given Observations of the Spectra of light we know:

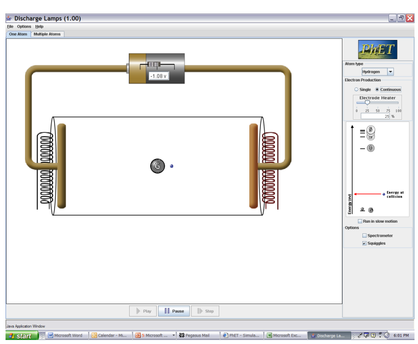
Atoms only change between very specific energies.
Only way for *individual* atoms to give off energy is as light.
Each time a photon is emitted an atom must be changing in energy by that amount (*releasing* energy). (basics, applications)

Atoms are lazy - always want to go back to lowest energy state.

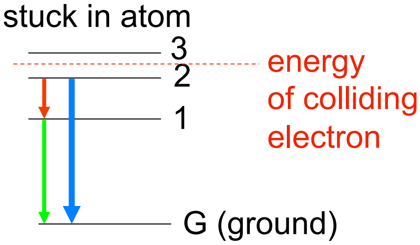


Energy level diagrams- represent energy levels of atom





energy levels of electron stuck in atom



If many colliding electrons have an energy between that of level and level 3 when they hit the atom

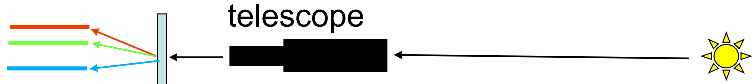
a. no levels will be excited, and so no light will come out.
b. 1 color of light will come out
c. 2 colors of light will come out
d. 3 colors of light will come out
e. 4 colors come out.

ans. d. enough energy to excite level 2, then get **2⇒1** followed by **1⇒G**, but also can go **2⇒G**.

Applications of atomic spectroscopy (how it is useful)

1. Detecting what atoms are in a material.
(excite by putting in discharge lamp or heating in flame to see spectral lines)

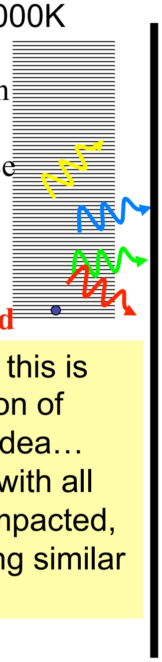
2. Detecting what sun and stars are made of.
Look at light from star with diffraction grating, see what lines there are- match up to atoms on earth.



3. Making much more efficient lights!
Incandescent light bulbs waste 88% of the electrical energy that goes into them! (12% efficient)
Streetlight discharge lamps (Na or Hg) 80% efficient.
Fluorescent lights ~ 40-60% efficent.

Incandescent light (hot filament)
Temperature = 2500-3000K

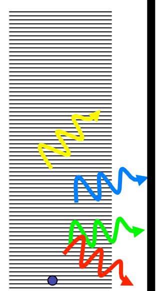
Hot electrons jump between many very closely spaced levels (solid metal). Produce all colors.
Mostly infrared at temp of normal filament.
88% is worthless InfraRed

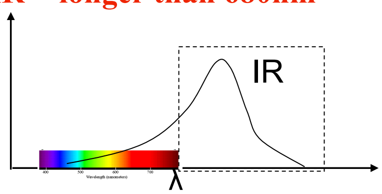


Note: I' ve mentioned this is wiggling (acceleration of electrons) --- Same idea… different perspective: with all these energy levels compacted, wiggling is moving among similar energy levels

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



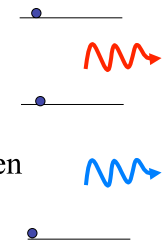


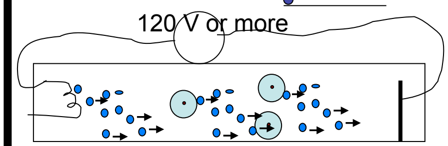
12% of energy is useful visible light

Discharge lamp

Energy levels in isolated atom.

kick up, only certain wavelengths when come down.



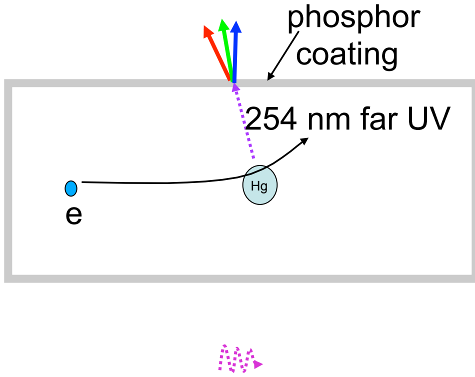


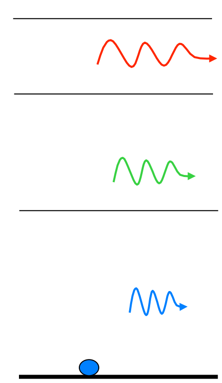
Right atom, right pressure and voltage, mostly visible light.

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

Florescent Lights. Similar idea, but little more complicated to get out light that looks white to eye.

Converting UV light into visible photons with phosphor.
Phosphors block all but UV, converts to visible.





energy of electron in phosphor molecule

Questions on applications of discharge lamps to lighting?

Lasers: ("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

(you'll have to find your own shark)

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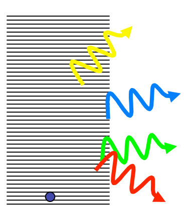
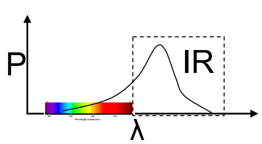
sources of light (traditional):

light bulb filament

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

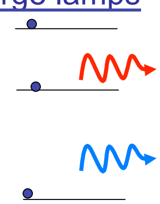


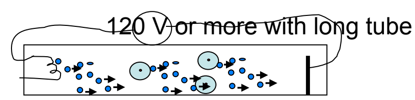


atom discharge lamps

Electron jumps to lower levels.

Only specific wavelengths.





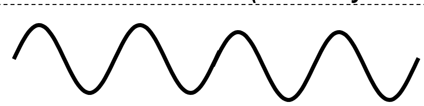
- Light from extended source
- Going different directions
- Range of wavelengths

laser light-- all exactly the same

photon view

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

wave view



big electric field
nearly perfect sinewave

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Light from a laser all the same ***exact*** color and direction.

Light from lasers is 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.

Can be controlled much more precisely.

Easy to reach uncertainty principle limit for beam focus and collimation.

small spot = high intensity

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How to produce laser light?

- photons exactly same color
- same direction
- in phase

Base on how light interacts with atoms!

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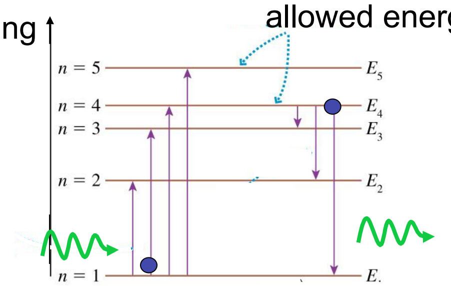
increasing energy

allowed energies



ground state

Figure from textbook.

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

http://phet.colorado.edu/simulations/lasers/lasers.jnlp

Weak resonant excitation ⇒ absorption,
Light ONLY absorbed if it matches ΔE
then spontaneous emission ~0.000 000 01 sec later
what happens if stronger exciting light?

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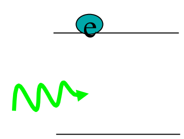
<u>"Stimulated emission" of light.</u> First realized by A. Einstein



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

photon

atom in excited state

second identical photon comes out. Atom jumps down.
Cloning photon.

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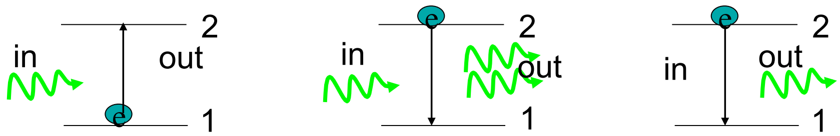
Three processes by which light interacts with atoms



absorption (of light)

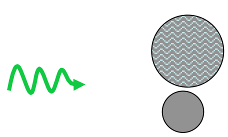
stimulated emission (of light)

spontaneous emission (of light) (After elec. coll. or light excited atom)

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.

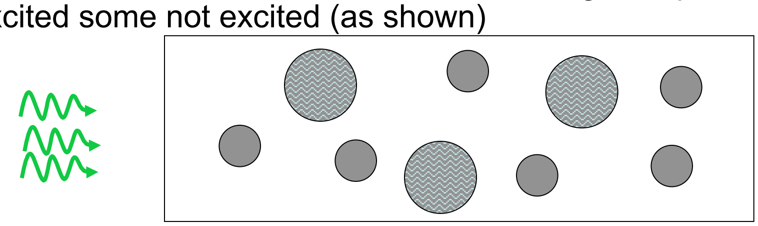
Laser-- just use stimulated emission to clone photon many times ($\sim 10^{20}$ /sec)

Light **A**mplification by **S**timulated **E**mission of **R**adiation



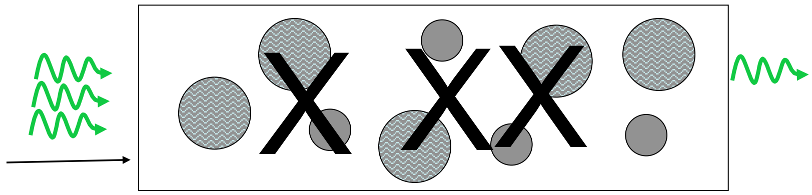
Chance of stimulated emission of excited atom **EXACTLY** the same as chance of absorption by ground state atom.

Glass tube below, full of atoms, like discharge lamp. Some excited some not excited (as shown)



For the condition above: what do you expect?

a. More photons will come out right hand end of tube,
b. Fewer photons will come out right hand end of tube
c. Same number as go in,
d. None will come out.



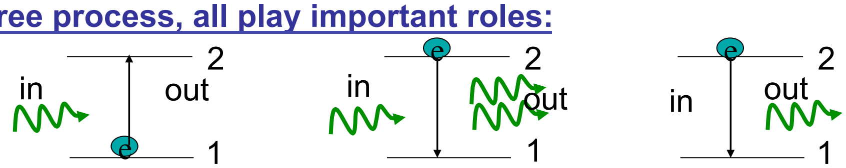
b. less come out right

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

Think about statistics / probabilities

LASER - Light Amplification by Stimulated Emission of Radiation
Need to clone lots of photons → LOTS of identical light.

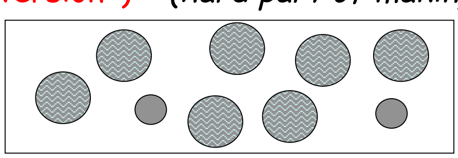
Three process, all play important roles:



absorption | stimulated emission | spontaneous emission

Basic requirements for laser:

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

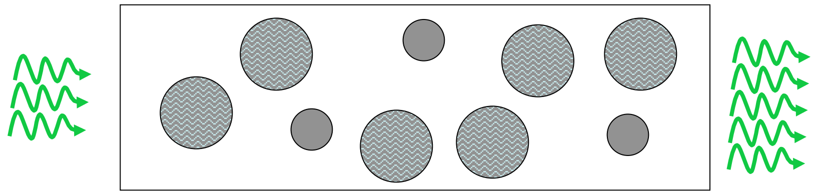


2) Need method of re-cycling photons to clone more times
("feedback") *(mirrors)*

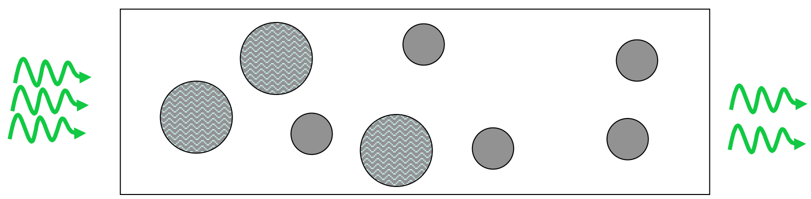
To increase number of photons after going through the atoms need more in upper energy level than in lower.

Need a "Population inversion"

(This is the hard part of making laser, b/c atoms jump down so quickly.)



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



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

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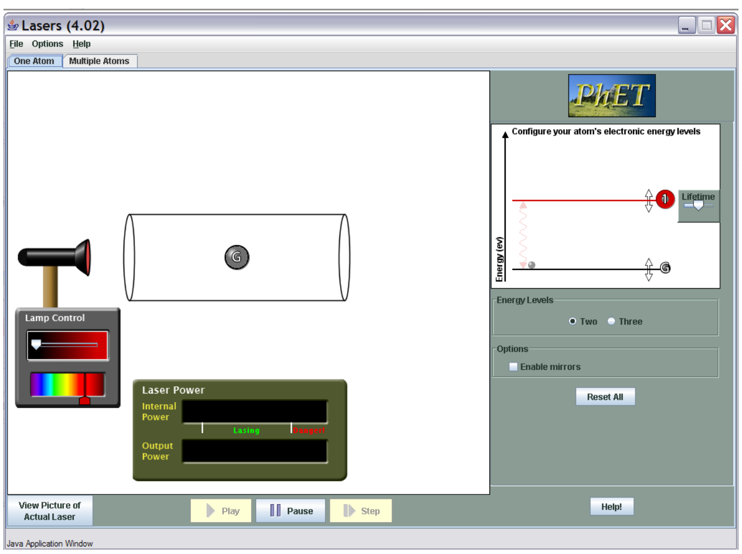
Can you get a population inversion in a two level system?



http://phet.colorado.edu/en/simulation/lasers

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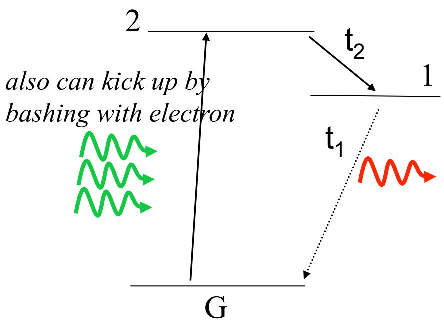
Getting a population inversion

need at least one more energy level involved.
Trick: use a second color of light
(why two levels (one color) won't work as HW problem (maybe))



"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

ans. c. show on sim

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Laser-- Light Amplification by Stimulated Emission of Radiation
lots of cloning of photons- LOTS of identical light.

Figure out conditions for l.a.s.e.r.
Important roles all played by:
- absorption
- stimulated emission
- spontaneous emission

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)

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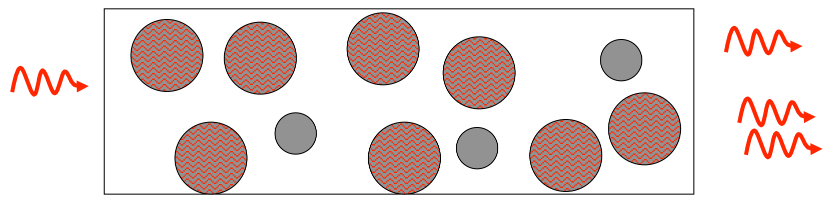
Amplifying light:

Population inversion⇒ give amplification of photons from left.



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

If 3 in becomes 6 at end, What does 6 become?

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Laser Gain

One photon becomes two,
2 becomes 4,
4 becomes 8,
8 sixteen.. Etc…

Do you know the words of Al Bartlett? (the lack of understanding the exponential function is the great failure of the human race)

May be bad for human population. Good for photon population.

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. Use *partially* reflective mirror on one end.
Let some of laser light inside leak out --- that's what we see.

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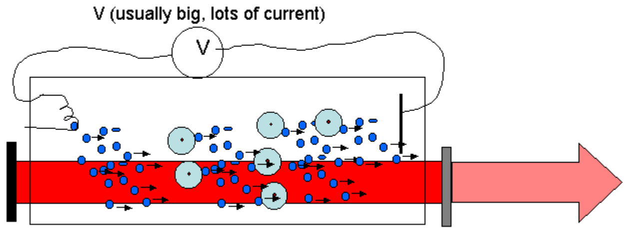
Two types of lasers: He-Ne and Diode



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.

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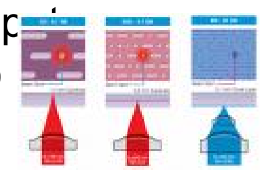
Many applications of lasers

- High energy small area:
  - Cutting: surgery, laser welding
  - “communication” (and weapons)
- Focus light into extremely small sp



  - (diffraction limit, because in phase!)
  - CDs, DVDs, …
- Collimated beam
  - Tracking, leveling,
- Pure color
  - LIDAR….

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End of general atomic spectra.

- Understanding of what has been observed, how implies electrons in atoms only in certain energy levels.
- When hop from higher to lower give off light.
- Applications: neon lights, lasers

Questions?

Next:

Band structure / LEDs

Build from single atom / energy levels to more complex
what happens to energy levels
when atoms interact

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