

## 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)

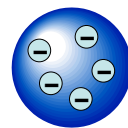
Discharge Lamps & "lasers"

Reminders:

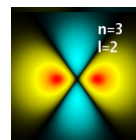
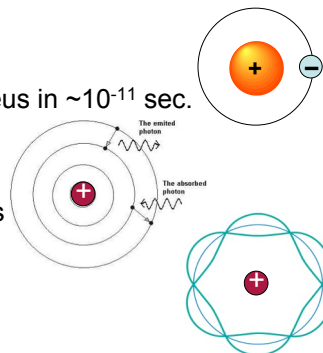
Lasers Bonding and LEDs

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  $\sim 10^{-11}$  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



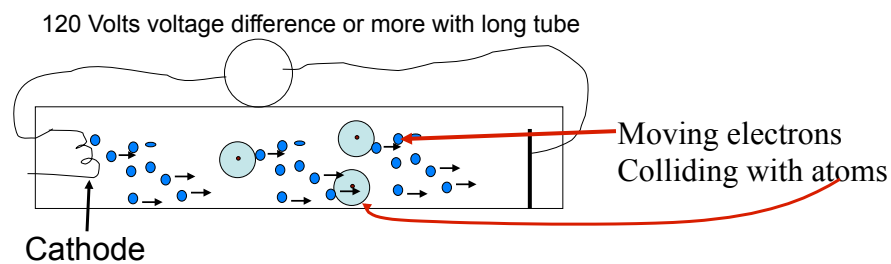
# Learning Goals

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

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*)



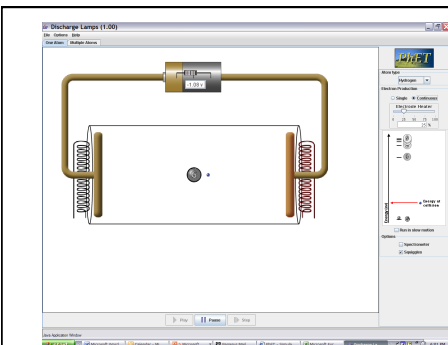
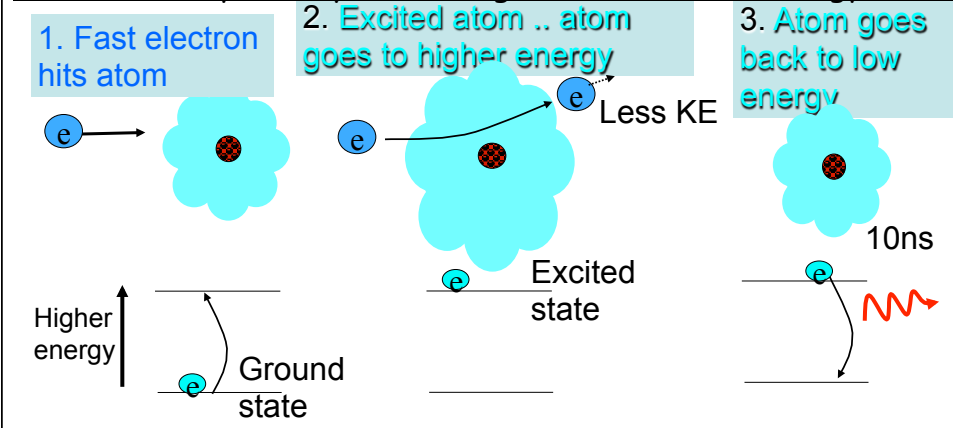
Discussion: Given what we know about light, what does this imply about electrons in atoms?

Atoms only change between very specific energies.

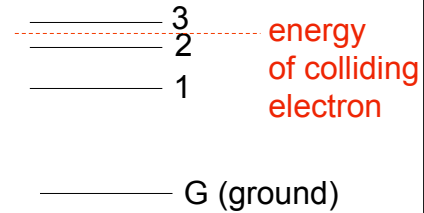
Only way for *individual* atoms to give off energy is as light.

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.

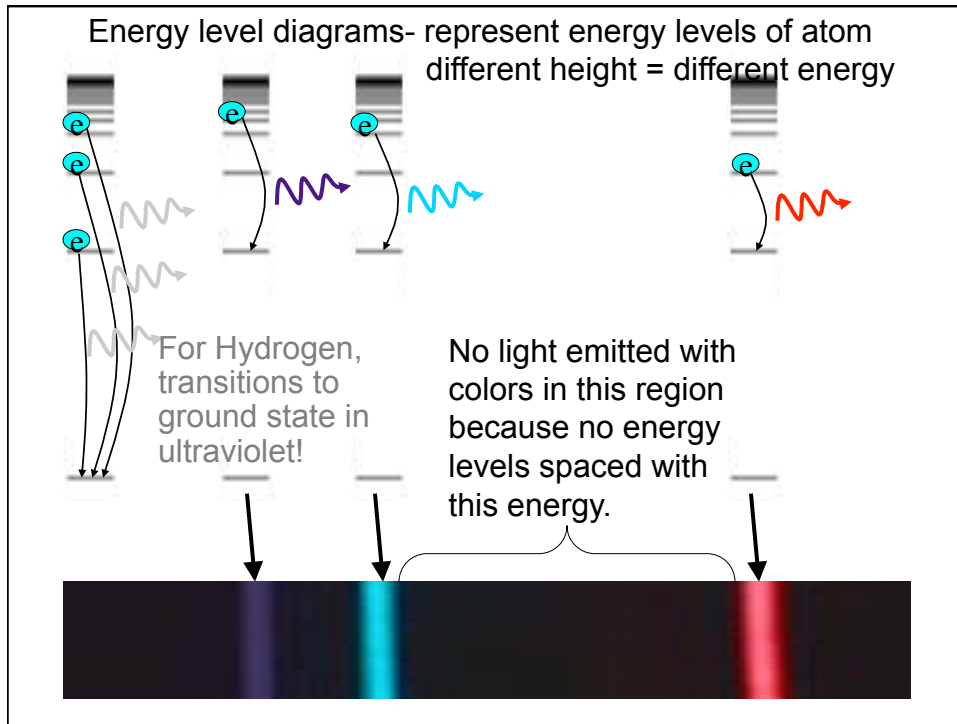


energy levels of electron stuck in atom



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.



In discharge lamps, one electron bashes into an atom.

If atom fixed at this point in tube,  
list all the possible energy photons (colors) that you might see?

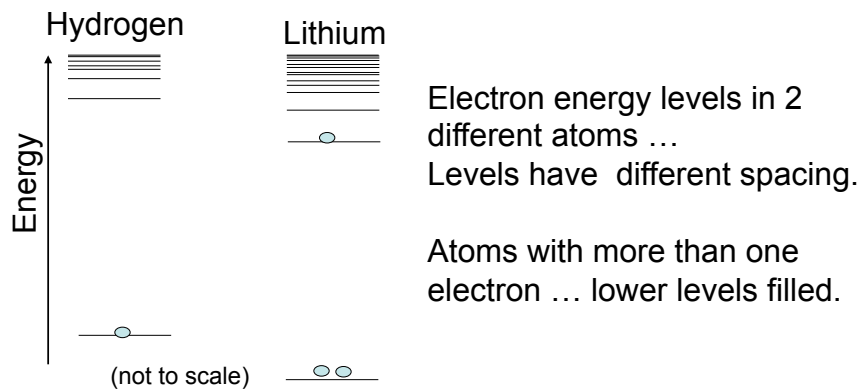
A. 1eV, 2eV, 3eV, 4eV, 7eV, 8eV  
 B. 4eV, 7eV, 8eV  
 C. 1eV, 3eV, 4eV  
 D. 4eV **Answer is D. Electron only gains about 5eV!**  
 E. Impossible to tell.

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Electron energy =  $q\Delta V = e(Ed)$ ,  
 where  $E$  is the electric field = (battery  $V$ )/(total distance  $D$ ),  
 and  $d$  is the distance it goes before a collision.

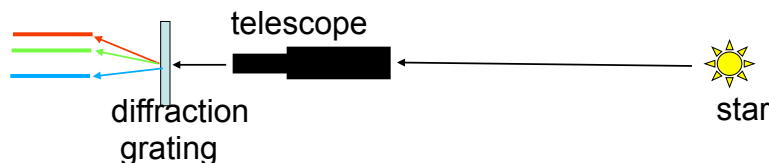
### Important Ideas

- 1) Atoms have specific, fixed energy levels
- 2) Different set of energy levels for different atoms
- 3) 1 photon emitted per electron jump down between energy levels. Photon color determined by energy difference.
- 4) atom spends very little time ( $10^{-8}$  s) in excited state before hopping back down to lowest unfilled level.
- 5) If electron not stuck in atom, it can have any energy.



### 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.



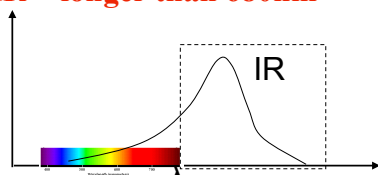
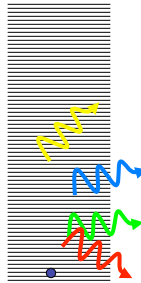
3. Making much more efficient lights!  
**Incandescent light bulbs** waste 88% of the electrical energy that goes into them! (12% efficient)  
**Streetlight discharge lamps** (Na or Hg) 80% efficient.  
**Fluorescent lights** ~ 40-60% efficient.

**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**

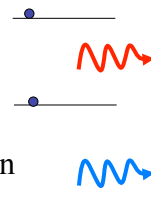


12% of energy is useful visible light

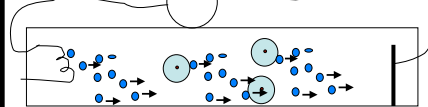
**Discharge lamp**

Energy levels in isolated atom.

kick up, only certain wavelengths when come down.



120V or more

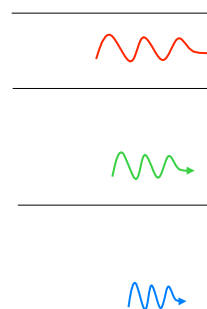
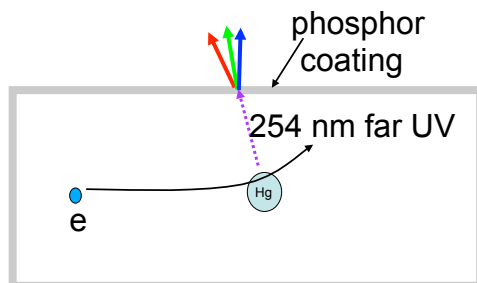


Right atom, right pressure and voltage, mostly visible light.

**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.



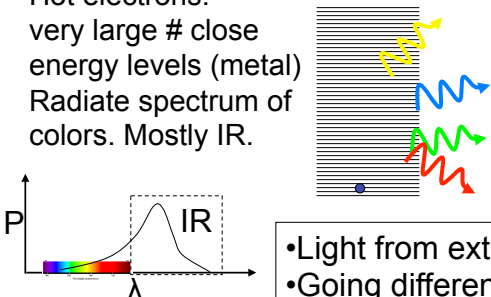
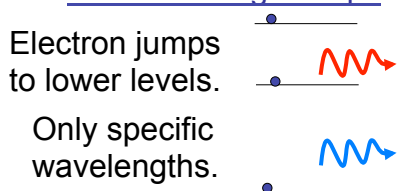
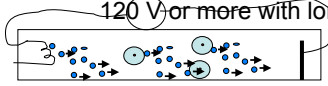
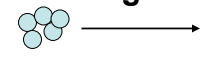

energy of electron in phosphor molecule

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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<p style="text-align: center;"><u>sources of light (traditional):</u></p> <p style="text-align: center;"><u>light bulb filament</u></p> <p>Hot electrons. very large # close energy levels (metal) Radiate spectrum of colors. Mostly IR.</p> 	<p style="text-align: center;"><u>atom discharge lamps</u></p> <p>Electron jumps to lower levels.</p> <p>Only specific wavelengths.</p>  <p style="text-align: center;">120 V or more with long tube</p> 	
<p><b>laser light-- all exactly the same</b></p>		
<p>photon view</p>	 <p>whole bunch of identical photons (<i>actually on top of each other</i>)</p>	<p>big electric field nearly perfect sine wave</p>
<p>wave view</p>		

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.

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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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Figure from textbook.

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

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

Weak resonant excitation  $\Rightarrow$  absorption,  
 Light ONLY absorbed if it matches  $\Delta E$   
 then spontaneous emission  $\sim 0.000\ 000\ 01$  sec later  
 what happens if stronger exciting light?

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“Stimulated emission” of light. First realized by A. Einstein

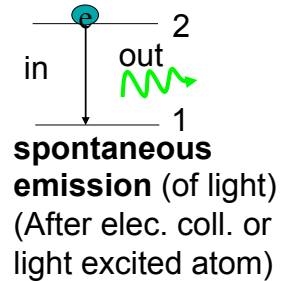
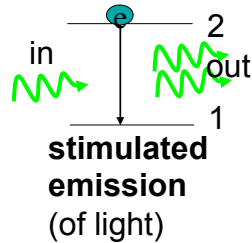
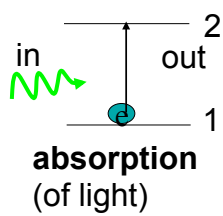
Photon hits atom already in higher energy level.  
 original photon continues and atom emits second identical one

photon                  atom in excited state

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

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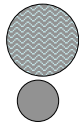
### Three processes by which light interacts with atoms



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.

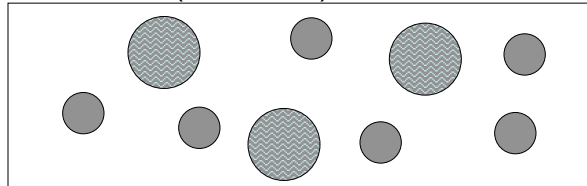
Laser-- just use stimulated emission to clone photon many times (~ $10^{20}$  /sec)

Light **A**mplification by **S**timulated **E**mission of **R**adiation<sub>9</sub>



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?

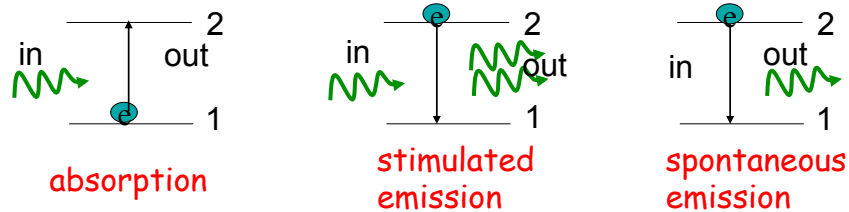
- More photons will come out right hand end of tube,
- Fewer photons will come out right hand end of tube
- Same number as go in,
- None will come out.

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LASER - Light Amplification by Stimulated Emission of Radiation

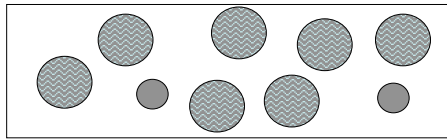
Need to clone lots of photons → LOTS of identical light.

Three process, all play important roles:



Basic requirements for laser:

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



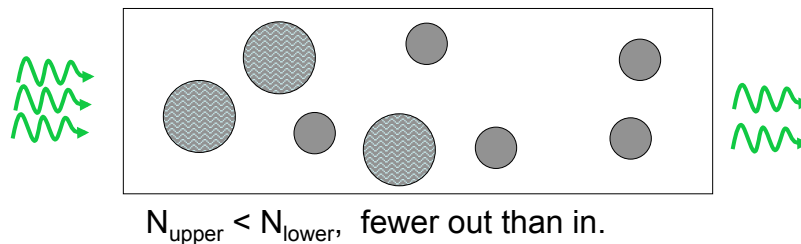
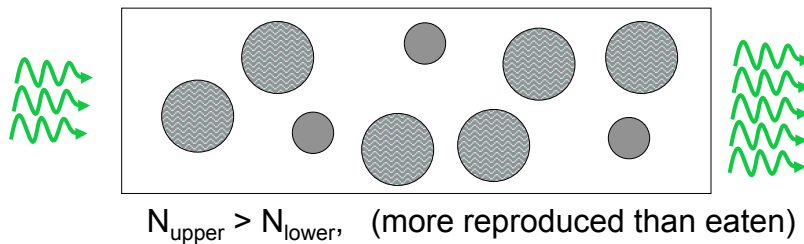
- 2) Need method of re-cycling photons to clone more times ("feedback") (*mirrors*)

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

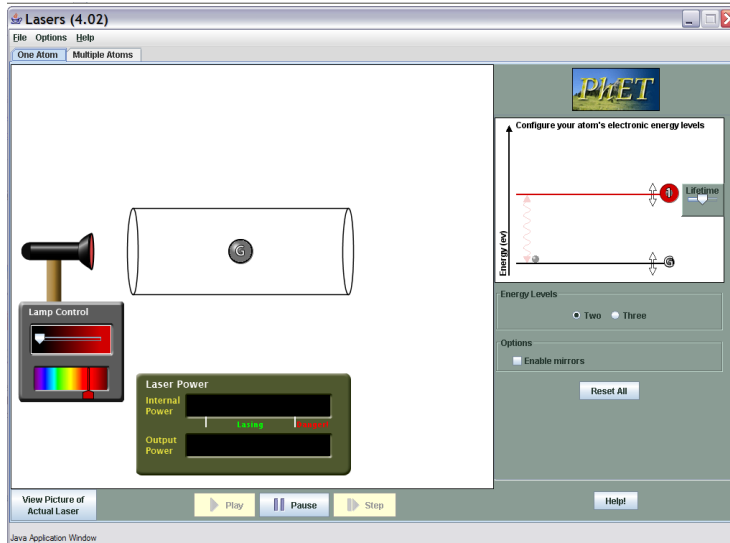
Need a "Population inversion"

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



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



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

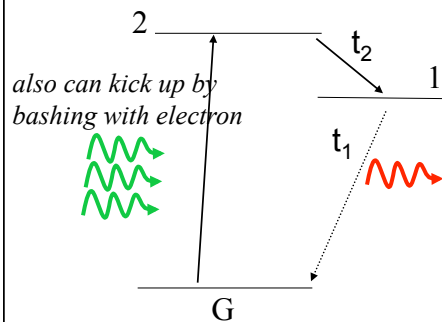
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## Getting a population inversion

**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:

- 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.
- $t_1 = t_2$
- $t_2$  short,  $t_1$  long
- does not matter

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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

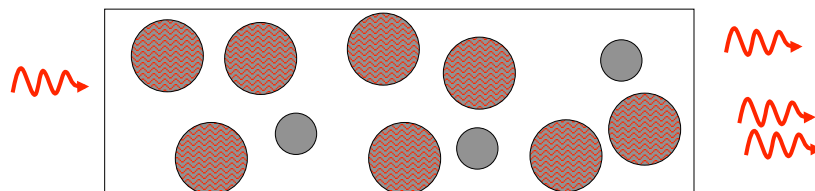
1) more atoms in an upper level than a lower one  
("population inversion")  
*(hard part of making laser)*

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

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## Amplifying light:

Population inversion  $\Rightarrow$  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 AI 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.

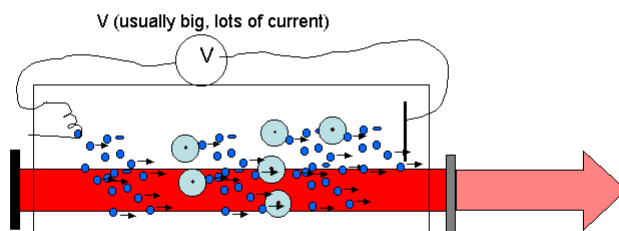
Number of photons between the mirrors,  $n = n_0 e^{Gt}$

“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. 27

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-

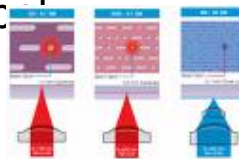
Same basic idea, but light from diode at P-N diode junction.

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 spot
  - (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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