PH300 Modern Physics SP11

"I have one simple request, and that is to have sharks with frickin' laser beams attached to their heads!" – Dr. Evil

**2/24 Day 12:**
Questions?
Finish atomic spectra
Frickin' Lasers!

**Next Week:**
Atomic models (Bohr)
Experiments with atoms

1

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<u>Last time:</u>
- Photons
- Atomic spectra/discharge lamp

<u>Today:</u>
- Finish atomic spectra
- Apply properties of photons and atoms to create lasers

<u>Key concepts for quantum physics.</u>
- Light energy is "quantized".
- Light has both wave-like and particle-like properties.
- Electrons in atoms can only exist at certain energy levels (quantized energy).
- Atom emits (or absorbs) a single photon each time an electron transitions between energy levels.

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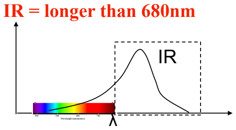
**<u>Incandescent light</u>** (hot filament)
Temperature = 2500-3000K

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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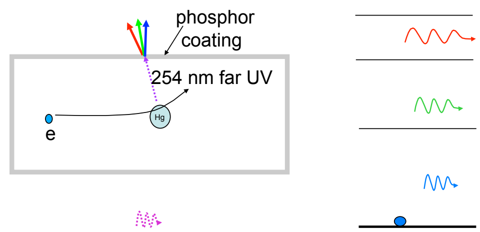
**<u>Florescent Lights.</u>** Similar idea, but little more complicated to get out light that looks white to eye.

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




4

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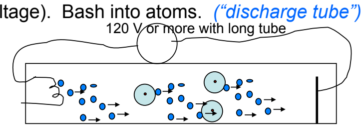
In discharge lamps, lots of electrons given bunch of energy (voltage). Bash into atoms. *("discharge tube")*




*see simulation*

If *proper* pressure and voltage, almost all free electron's energy goes into exciting atom to level that produces visible light.

<u>Why are pressure and voltage important?</u>
a. Voltage needs to be high enough for free electrons to get energy to excite atom to desired level between collisions.
b. Pressure determines distance between collisions.
c. Only voltage matters for electron excitation. Pressure just has to be low enough to keep tube from exploding.
d. Voltage needs to be high enough for free electron to excite atoms.

5

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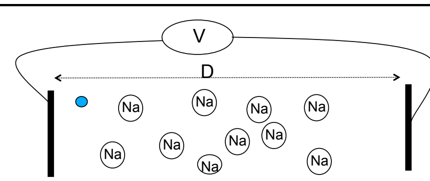



Electron energy = $q\Delta V = q(Ed)$,
E is electric field = V/D,
d is the distance between energy losing collisions.

The higher the pressure, the higher the density,
=> the smaller is d.
d decreases if the collision cross section $\sigma$ ("atom size") increases.
looking at geometry, d = (# atoms/m$^3$ x $\sigma$)$^{-1}$
if $\sigma$ is in m$^2$. $\sigma$ is typically a few x $10^{-20}$ m$^2$

6

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

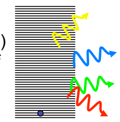
(you'll have to find your own shark)

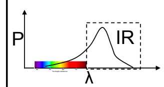
7

sources of light (traditional):

light bulb filament

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



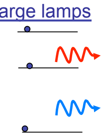


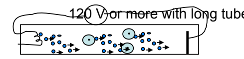

•Light from extended source
•Going different directions
•Range of wavelengths

atom discharge lamps

Electron jumps to lower levels.

Only specific wavelengths.



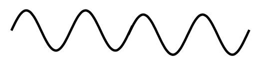



**laser light-- all exactly the same**

photon view

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

wave view



big electric field
nearly perfect sinewave

8

Light from a laser all the same ***exact*** 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.**
**Can be controlled much better.**
**Easy to reach uncertainty principle limit for beam focus and collimation.**

*small spot = high intensity*

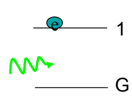
9

How to produce laser light?
- photons exactly same color
- same direction
- in phase

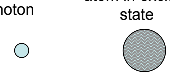
Base on how light interacts with atoms!

10

"Stimulated emission" of light. First realized by A. Einstein



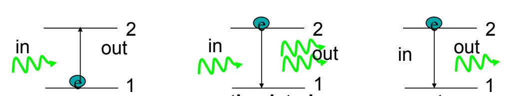

Photon hits atom already in higher energy level.
original photon continues and atom emits second identical one




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

11

Three processes by which light interacts with atoms




**absorption** (of light)

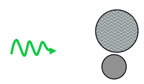
**stimulated emission** (of light)

**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.

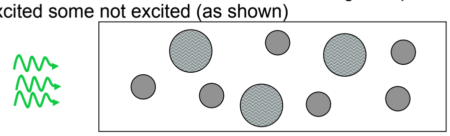
Laser-- just use stimulated emission to clone photon many times ($\sim 10^{20}$ /sec)
**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation

12



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

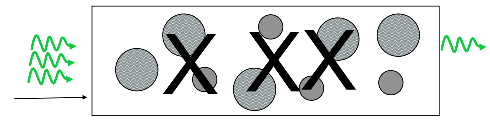
Glass tube below, full of atoms, like discharge lamp. Some excited some not excited (as shown)



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.

13




b. less come out right

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

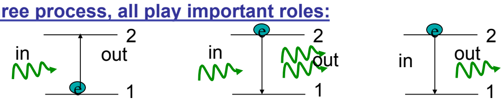
**Think about statistics / probabilities**

14

LASER - Light Amplification by Stimulated Emission of Radiation

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

**Three process, all play important roles:**



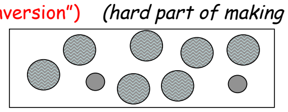

absorption

stimulated emission

spontaneous emission

**Basic requirements for laser:**

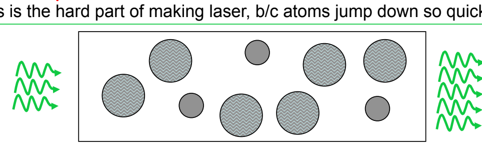
1) Need more atoms in an upper level than a lower one ("Population Inversion") *(hard part of making laser)*



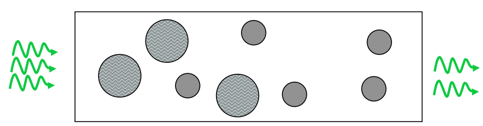
2) Need method of re-cycling photons to clone more times ("feedback") *(mirrors)*

15

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.)



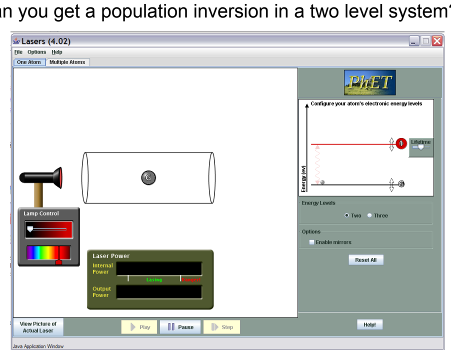
$N_{upper} > N_{lower}$, (more reproduced than eaten)



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

16

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

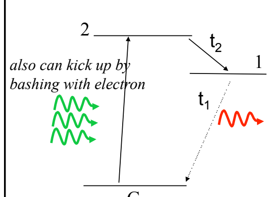



http://phet.colorado.edu/simulations/lasers/lasers.jnlp

17

## 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)




"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

18

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

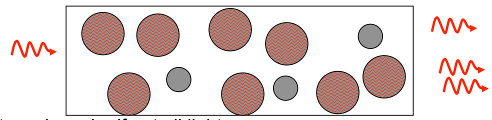
Requires
1) more atoms in an upper level than a lower one
("population inversion")
*(hard part of making laser)*

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

19

## Amplifying light:

Population inversion: gives 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?

20

# 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)

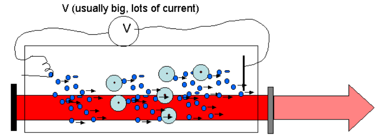
May be bad for human population. Good for photon population.

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. 21

Two types of lasers: He-Ne and Diode



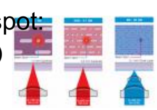

Gas laser like Helium Neon.
Just like neon sign with helium and neon mixture in it and mirrors on end.

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

22

# **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….

23

**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:**

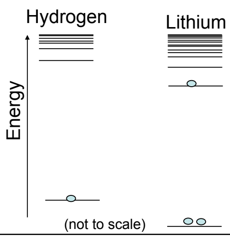
**Why?**

Start with characterizing Hydrogen spectra (Balmer)
then try to explain (Bohr model → Schrodinger)

24

## Important Ideas

1) Electrons in atoms only found in specific 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) electron 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, can have any energy.




Electron energy levels in 2 different atoms …
Levels have different spacing.

Atoms with more than one electron … lower levels filled.

25