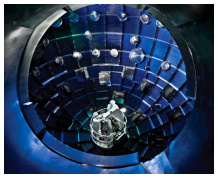
What can "laser" light do for me?



The National Ignition Facility (NIF) is the world's largest laser. NIF's 192 intense laser beams [are] capable of directing nearly two million joules of ultraviolet laser energy in billionth-of-a-second pulses to the target chamber center.
- NIF: https://lasers.llnl.gov/about/nif/about.php

Phys 1010, class 28
Questions?
LASERS: 14.3

Reminders
Check CU Learn scoring!
Review all next week
See new HW appaoch

How do we establish that a scientific explanation is correct?
a. have big scientific conventions and vote.
b. see if it predicts new things, then see if experiments give results matching that prediction?
c. Wieman (Nobel 2001) or some other scientific big shot says its right.
d. see if it is consistent with experiments already done.
e. b and d.

Answer is e.
Start with d., if it explains past experiments, then test with b.
More predictions that hold up to test, more confidence in results.

2

Pick up little plastic diffraction grating !

Today- lasers *(complete with awesome graphics!)*
A) What is different/special about laser light.
B) How does a laser work.
- review atomic discharge streetlight.
- how light interacts with atoms
- how these idea used to make laser.

lasers- 0.001 W laser pointers
10,000 W metal cutters (infrared) *(5 W in lab, hurts!)*
all kinds of colors,
times--continuous down to 0.000 000 000 000 001 sec long pulses.

3

What would make Prof. Finkelstein the MOST WORRIED about his eyesight
a. Shining a laser into his eye because it is a more dangerous color
b. Shining a laser into his eye because it has more power in the beam
c. Shining a laser into his eye because power is concentrated to a much smaller spot and could hurt his retina
d. Shining a flashlight into his eye because it would contract the black of his eye (pupil)
e. Nothing worries the Prof.

c. focuses to much smaller spot, local burn.
Why lasers are good for surgery: can make a spot much smaller than scalpel, get to retina or lens of eye without damaging stuff in front, send down tiny fiber running down artery to get into middle of body with only tiny hole.

laser light is special and useful because:
1) All light exactly the same color
2) Same direction columated
3) In Phase (all waves go up and down together)

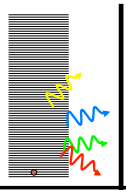
→. **Can be controlled much better,**
focused into smaller spot, sent in more parallel beam etc.

On to how laser works.

4

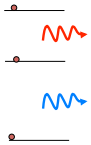
Review of atom discharge lamps-- neon signs.

Energy levels metal, bulb filament, or not stuck in atom (like sun). If hot, jump between all diff. levels. Wiggle around, all colors.

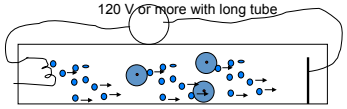


Energy levels in isolated atom.

kick up, only certain wavelengths when come down.



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

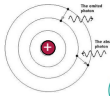


5

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

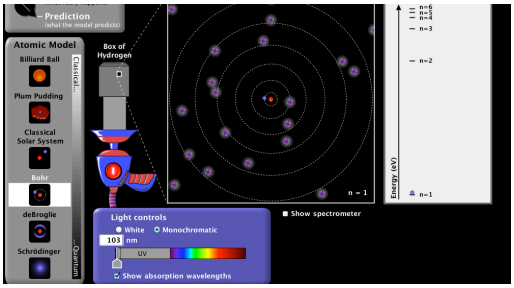


- deBroglie – electron standing waves
  - Why? Explains fixed energy levels
  - Problem: still only works for Hydrogen.

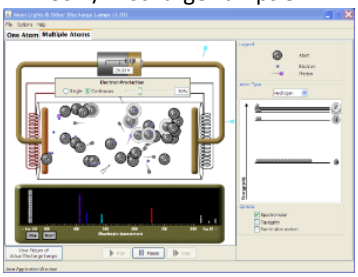
- Schrodinger – quantum wave functions
  - Why? Explains everything!
  - Problem: None (except that it's hard to understand)

6

Atomic Models & Light



Neon / Discharge Lamps Sim

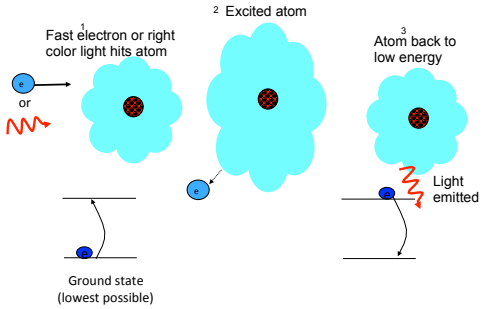


Note: different atoms have different energy levels (orbits for electrons), resulting in different energies of light (colors) coming out

http://phet.colorado.edu/en/simulation/discharge-lamps

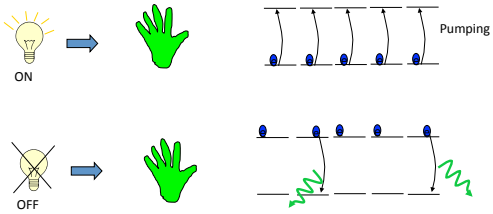
8

atoms lazy- always want to go back to lowest energy state.
Have to get rid of energy, send it off as light.



9

Experimenting a little bit with glow-in-the-dark toys
(phosphorescence)



Lifetime of an excited state: the average time electrons spend in the excited state (somewhere between < 10^{-9} s and > 1000 s)

10

look at neon lamp with diffraction gratings.
(much more stuff like this in lab this week)

Hold grating only by edges...oil from hands ruins grating.

Hold close to eye... See rainbow from lights.

Turn so rainbow is horizontal. See lines from neon lamp.

11

compare flor. light, neon lamp and laser light from pointer.

If you look at light from laser pointer, it will look
a) more like from light bulb with a range of colors,
b) like from neon lamp, but with only a single color
c) will not show up at all when you look at it through diffraction grating.
d) will be a single bright color but too intense to look at without discomfort.

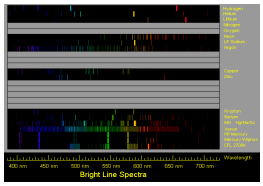
b) It is light of all ***exactly*** the same color, so no spread with grating.

Focus flashlight beam and laser beam with lens.
a) both will focus to same size spot
b) laser will focus to much smaller spot with much more power in it
c) flashlight will focus to smaller spot with more power in it
d) laser will focus to smaller spot but with less total power.

d) flashlight actually has quite a lot more power, but not as intense because spread out over much larger region. All laser light the same so focuses into same spot, (or very nearly)

12

Small detour: Spectra of materials – what it is good for
Every material (atom, molecule) has a characteristic emission spectrum ("fingerprint"). Thus by looking at the spectrum of an unknown material you can figure out its composition (cool!). This is how we knew the rings of Saturn are mostly composed of water ice before we actually sent there a satellite to look closely.



Astronomers learn about the Universe by observing light from distant astronomical objects, like stars or galaxies. Light contains *information,* and since it is much easier to observe a star than it is to travel to one, there is clearly a benefit to being able to understand what the light is telling us!

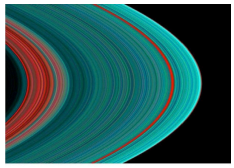
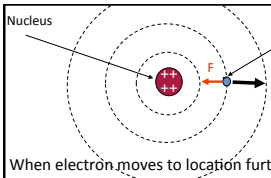
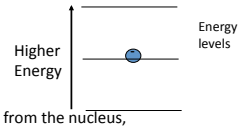


Fig. A false color image of the water content in Saturn's rings. (Taken in UV and not visible). More blue (turquoise) means more water, red means less water. Note the fine structure of the rings.

13





When electron moves to location further from the nucleus, energy of electron increases because it takes energy input to separate positive and negative charges, and there is an increase in the electrostatic potential energy of the electron.

(***Force* on electron is less, but *Potential Energy* is higher!)**

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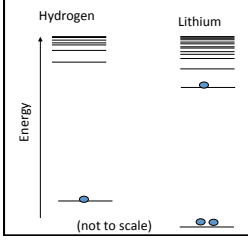
Important Ideas

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.

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Laser-- Light Amplification by Stimulated Emission of Radiation

repeated cloning of photons to produce LOTS of identical photons of light.

Requirements: 1) stimulated emission (always have)
2) population inversion of bunch of atoms (hard)
3) optical feedback (mirror)

photon, little piece of wave,
we often draw as little ball because less work.

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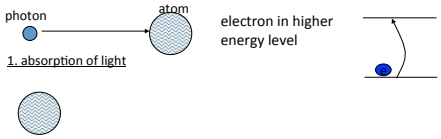
Everything to know about interaction of light and atoms. 3 easy steps.



1. absorption of light

2. Spontaneous emission of light. Electron jumps down from upper level, gives off light. Randomly in any direction.

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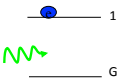
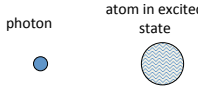
"Stimulated emission" of light. First realized by A. Einstein



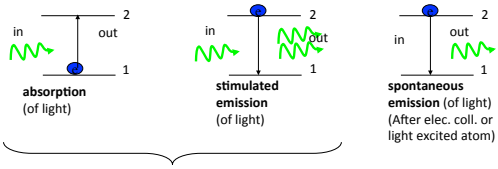
Photon hits atom already in higher energy level.
original photon continues and atom emits second identical one



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

20

Three processes by which light interacts with atoms



absorption (of light)

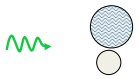
stimulated emission (of light)

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.

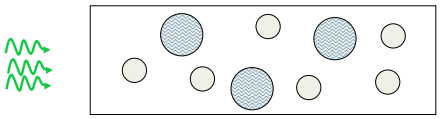
Laser-- just use stimulated emission to clone photon many times (~10^{20} /sec)
Light **A**mplification by **S**timulated **E**mission of **R**adiation

21



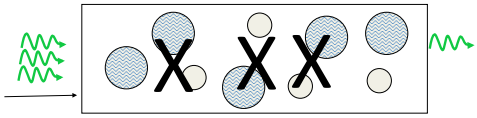
Surprising fact. Chance of stimulated emission of excited atom **EXACTLY** the same as chance of absorption by ground state atom. Equal chance bottom atom will absorb photon leaving no photon, as top atom will jump down and so have two photons.

glass tube full of atoms, discharge lamp



I would expect that
a. more photons will come out right hand end of tube,
b. less come out right,
c. same number as go in,
d. Can't tell.. It's completely random

22



b. less come out right

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

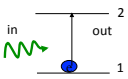
Think about statistics / probabilities

A matter of chance, sometimes could be 0, sometimes 1, sometimes 2 or 3, and 3,2,1 or 0 photons make it through. Depends on number of atoms and how close they are together. But most of the time will be less photons coming out because more lower level atoms than upper.
ON AVERAGE … will get one out!

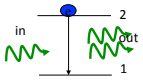
23

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

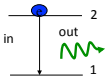
Three process, all play important roles:



absorption

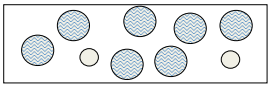


stimulated emission



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)*

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To amplify number of photons going through the atoms I need
a. more atoms in lower energy level,
b. half in lower, half upper,
c. more in upper energy level,
d. a sufficient number in upper level and it does not matter how many are in the lower.

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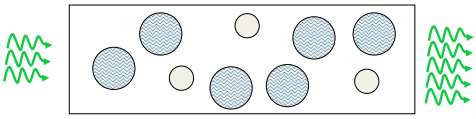
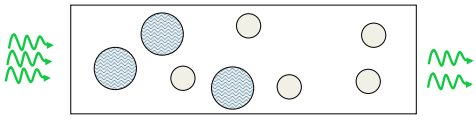
To amplify number of photons going through the atoms I need
c. more in upper energy level than in lower. Lower eats them up, upper clones them (adds energy). Equal prob. so amplification or loss is just N_{upper}-N_{lower}.



$N_{upper} > N_{lower}$, more out than in. (atoms change)

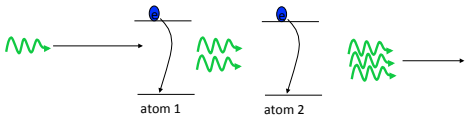


$N_{upper} < N_{lower}$, fewer out than in. (and atoms change)

26

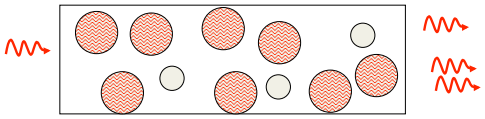
what will come out on the right? Think before you pick…
a. 1 photon, b. 2 photons, c. 3 photons, d. 4 photons, e. 8

c. 3 Double at first atom, then both hit second but atom only has enough energy to give off one more photon.



33

so now see how to get population inversion, will give amplification of red light. If enough atoms in upper, will lase.



PhET Simulation

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

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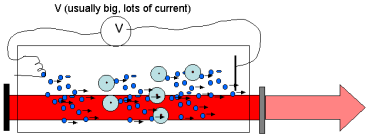
can get amplification, but to really build up to nice high power beam need feedback of mirrors.

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



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

Diode laser- same basic idea, but light produced like in light emitting diode at P-N diode junction.

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What have we learned in this section:

1) Lasers (pump up to population inversion, put mirrors around it, stimulated emission will take care of the rest)

2) For operation, lasers need at least 3 energy levels (ground state and 2 excited states). It helps if the middle level has a long lifetime ("metastable)

3) How glow in the dark toys work

4) Lots of cool demonstrations. Looked at emission spectra. Disassembled a working laser.

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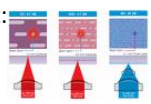
Many applications of lasers

- 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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