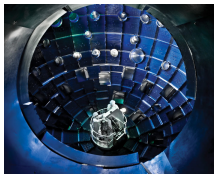
What can "laser" light do for me?



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 1020, Day 15:
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.

2

Pick up little plastic diffraction grating !
(And a hand or a foot)

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.

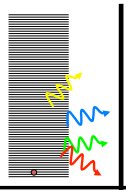
3

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.

4

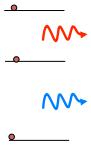
Review of atom discharge lamps-- neon signs.

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



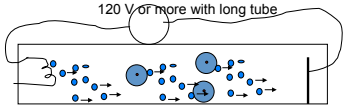
Energy levels in isolated atom.

kick up, only certain wavelengths when come down.



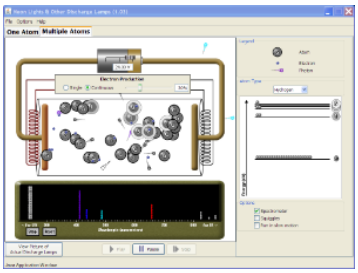
In discharge lamps, lots of electrons given bunch of energy (voltage). Bash into atoms. *("discharge tube")*

120 V or more with long tube



5

Neon / Discharge Lamps Sim



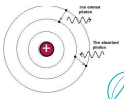
http://phet.colorado.edu/en/simulation/discharge-lamps

6

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

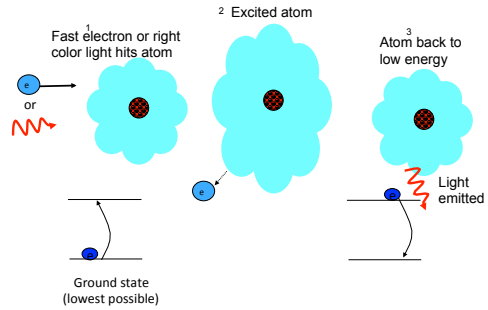


- deBroglie – electron standing waves
  - Why? Explains fixed energy levels
  - Problem: still only works for Hydrogen.

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

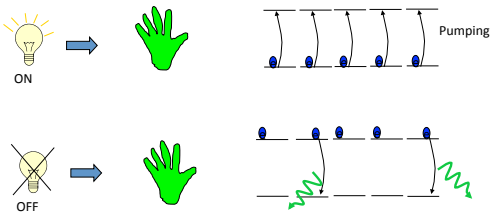
7

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



8

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)

9

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.

10

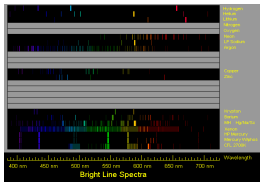
compare flor. light, neon lamp and laser light from pointer.

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.

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.

11

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!

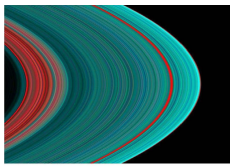
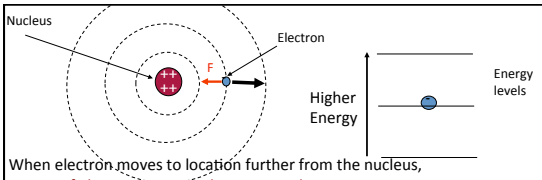


Fig. A false color image of the water content in Saturn's rings. (Taken in UV and not visible). More blue (turquoise) means more water, red means less water. Note the fine structure of the rings.

12



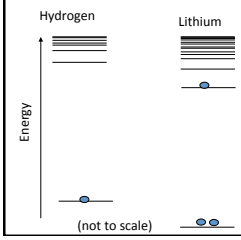
When electron moves to location further from the nucleus, energy of electron increases because it takes energy input to separate positive and negative charges, and there is an increase in the electrostatic potential energy of the electron.

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

13

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.

16

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)

or

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

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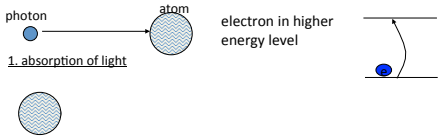
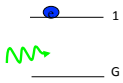
Everything to know about interaction of light and atoms. 3 easy steps.



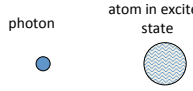
2. Spontaneous emission of light. Electron jumps down from upper level, gives off light. Randomly in any direction.

18

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



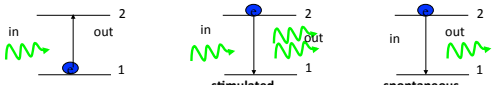
Photon hits atom already in higher energy level.
original photon continues and atom emits second identical one



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

19

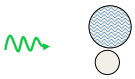
Three processes by which light interacts with atoms



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.

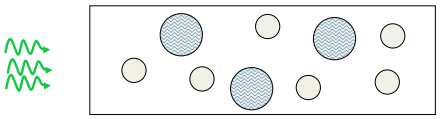
Laser-- just use stimulated emission to clone photon many times (~10^{20} /sec)
Light **A**mplification by **S**timulated **E**mission of **R**adiation

20



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

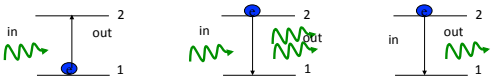


I would expect that
a. more photons will come out right hand end of tube,
b. less come out right,
c. same number as go in,
d. Can't tell.. It's completely random

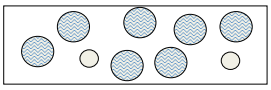
21

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)*



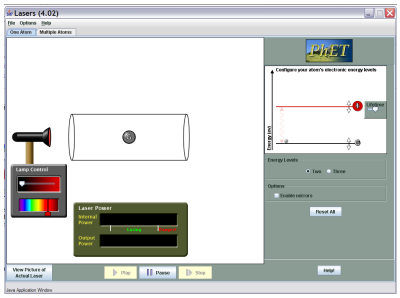
2) Need method of re-cycling photons to clone more times ("feedback") *(mirrors)*

22

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.

23

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

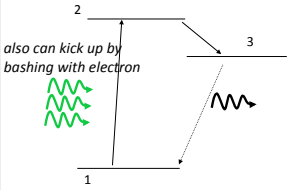


http://phet.colorado.edu/simulations/lasers/lasers.jnlp

27

To get population inversion, need at least 3 energy levels involved.
Need rate into 3 faster than rate out.

What color light could come out on 3 to 1 transition?
a. green, b. blue, c. red , d. a and b., e. a and c

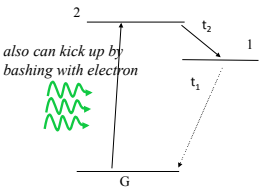


"pumping process to produce population inversion"

28

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.

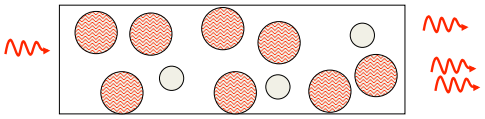
b. $t_1=t_2$

c. t_2 short, t_1 long

d. does not matter

29

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

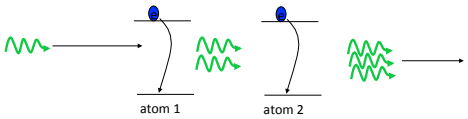


PhET Simulation

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

30

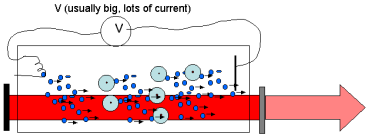
what will come out on the right? Think before you pick…
a. 1 photon, b. 2 photons, c. 3 photons, d. 4 photons, e. 8



31

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.

32

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)

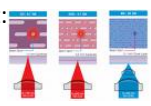
3) How glow in the dark toys work

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

33

Many applications of lasers

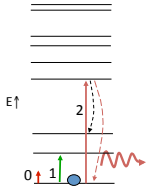
- High energy small area:
  - Cutting: surgery, laser welding
  - "communication" (and weapons)
- Focus light into extremely small spot:
  - (diffraction limit, because in phase!)
  - CDs, DVDs, …
- Collimated beam
  - Tracking, leveling,
- Pure color
  - LIDAR….



34

Why do we care about photons?
Interaction of Electromagnetic Radiation and Matter:
Photon Energy is what counts!
Energy = h x f = Planck's Constant x Frequency

Application: Interaction of EM radiation with molecules in our skin cells. Many energy levels in molecules.



Radio waves (0) → really long wavelength, really low energy photon, no levels that close in energy, no effect.

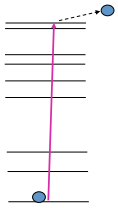
Microwave, infrared waves (1) → low energy photon, electron hops up small level, turns into atom motion as goes back down, heat.

Visible light (2) → Medium energy photon, electron jumps to medium level, energy sometimes turns into heat or chemistry or sometimes back out as light.
(Example: sunlight on plant, red and blue into chemical changes and heat, "light absorbed", green spit back out as light in all directions "scattered".)

35

What happens if energy is greater than visible light… UV light?

Electrons in molecules in skin cells. Many energy levels.



Send in EM radiation of different wavelengths.

UV light (3) → Higher energy- jumps up to such high level, electron has enough energy to fly out of molecule, break it up.

Result is damage to these molecules!!
These molecules are DNA. Cause of SUNBURN

36

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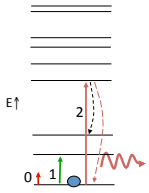

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37

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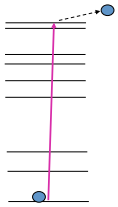

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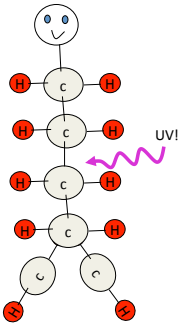
38

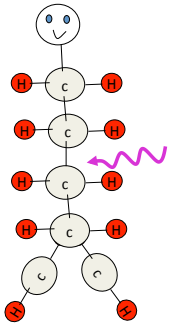
typical biomolecule in skin cell



before UV hits it

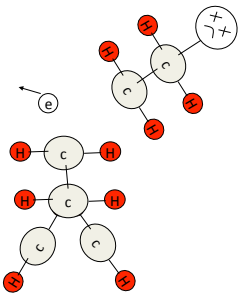
39

typical biomolecule in skin cell



before UV hits it

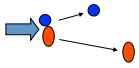
after exposure to UV



red and heat of sunburn is body working on cleaning out and replacing dead cells.

40

UV light-- lots of energy, break apart molecules in skin and damage it.



Skin cancer. Same thing but damage DNA molecule without enough damage to kill cell.
"Maimed" DNA- turns cancerous- skin cancer.

Which would give the worst sunburn?
a. 1000 photons of green light (Total E =3.2 x 10^-24 J)
b. 2 photons of UV light (Total E = 8 x 10^-27 J)
c. 100,000 photons of radio waves

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