Physics 102 - September 30, 2009

You should be able to find the accompanying audio file (mp3 format) on the class website

- No class next Monday due to what passes as our Fall break

- No recitation Next Monday

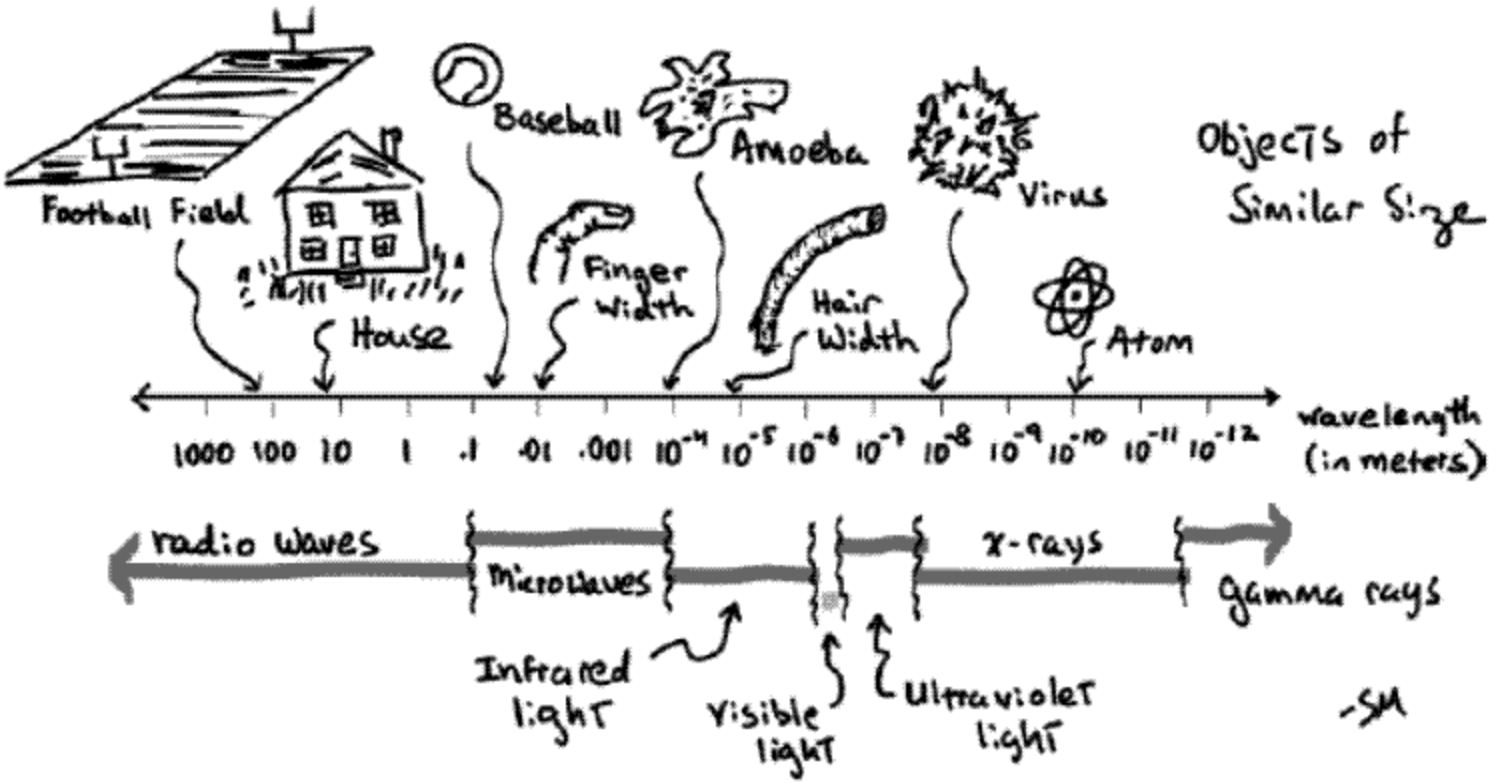
- Next week's Tuesday and Friday recitations will meet. (The new recitation cycle will run Tues, Fri, Mon ...)

Last Time late 1800s Maxwell + others established beyond doubt that light is a wave phenomenon.

Electric + Magnetic fields do the waving.

Leads to a rich spectrum of "electromagnetic waves" (differing in frequency ... color)

The variety of electromagnetic Waves



-SM

All waves exhibit

- Interference
  - Wave Amplitudes Add Together
- Diffraction
  - Waves spread out when going thru small openings
- Refraction
  - Waves bend at interface between substances

java demos – waves

Java applet for waves interfering on string

http://mysite.verizon.net/vzeoacw1/wave_interference.html

Superpostion of two waves – beats, standing waves
http://www.kettering.edu/~drussell/Demos/superposition/superposition.html

Refraction of light at interface
http://www.physics.uoguelph.ca/applets/Intro_physics/refraction/LightRefract.html

Different frequencies bend different Amounts ... called dispersion

Max Planck

(1858 - 1947)

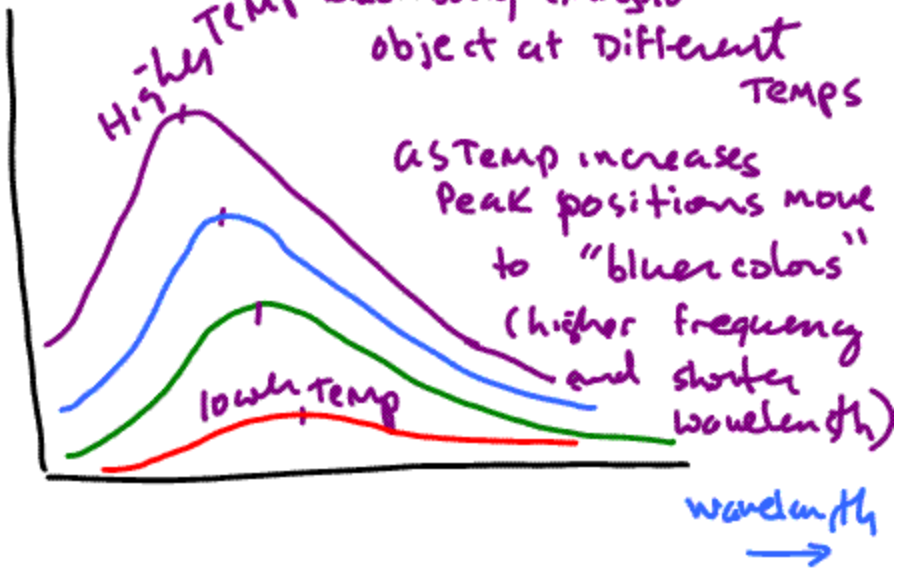
German national

Awarded 1918 Nobel Prize in physics for analysis of blackbody radiation which contributed to rise of quantum Mechanics

http://www-history.mcs.st-andrews.ac.uk/Mathematicians/Planck.html

observer

"Blackbody" radiation (emitted by object)



Blackbody emission from object at Different Temps

as Temp increases Peak positions move to "bluer colors" (higher frequency and shorter wavelength)

Planck succeeded in describing Black body radiation

Light exists in packets of energy

Discrete

Particle

"photons"

Planck's constant

$$E = h\nu$$

Energy

Frequency

Planck's Theory worked perfectly ... but physicists thought it was a fortuitous Accident ... after all, light is a wave.

Another phenomenon that was NOT understood

Photoelectric effect

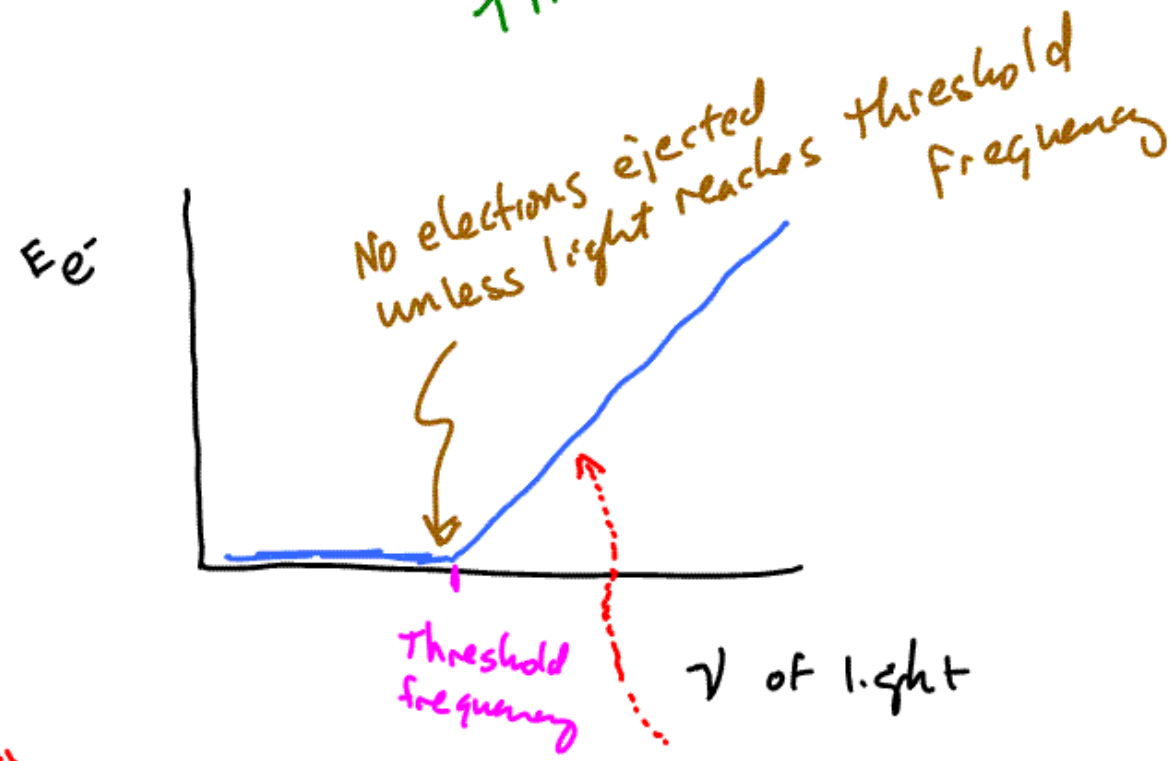
Study electric current depends on Intensity + color of light

Einstein in 1905

$E = h\nu$

- Einstein able to explain photoelectric effect
  Assuming light to come in little packets
  with energy $E = h\nu$
- Light as wave theory could not account for data
- Suddenly world has to face fact that light is both a wave and a particle
  ... Sounds crazy ... but that's what nature tells us.

Photoelectric effect



CONSTANT "h" Found from data (slope of line) – independently found from blackbody radiation experiments ⇒ SAME h !!!

This is telling us something!

[redacted]

Maxwell's equations
interference
diffraction
Refraction
dispersion
⋮

→ **light is a wave!**

Planck

Blackbody Radiation

Einstein

Photoelectric effect

1905

→ light comes in little packets with energy $E = h\nu$

→ **light is a particle!**

As strange as it seems ...

light has both wave and particle properties

wave

$V = \lambda \nu$

particle

$E = h\nu$

The "packet" of energy called the "photon"

↑ Gilbert Lewis, 1926

Slight detour to talk about particle mass & Energy units

meter-Kilogram-Second

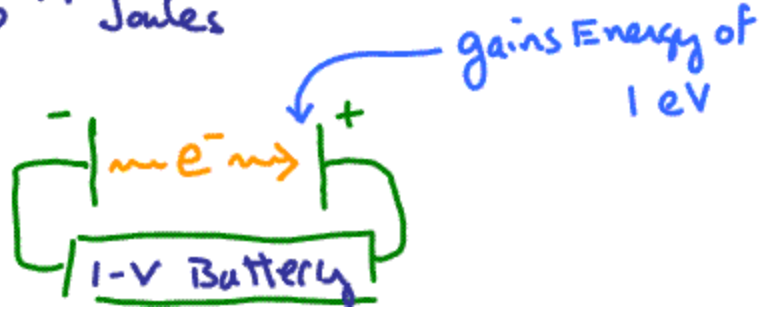
Joule ≡ mks metric unit of energy

good for "normal" Things

eV ≡ electron-volt Energy of electron accelerated by a 1-volt battery

good for atomic and subatomic things

$1\ eV = 1.6 \times 10^{-19}$ Joules



Units of energy commonly used in physics of atoms and particles

eV	
KeV	Thousand of eV
MeV	Millions of eV
GeV	Billion of eV
TeV	Thousands of Billion eV

Energy + Mass related by (A)

$$E = mc^2$$

eV

Mass of particle ~ $\frac{eV}{c^2}$

0.511 MeV/c^2 = electron Mass

Common to ignore the c^2 and refer to masses in terms of eV or MeV

mid-1920's

de Broglie hypothesized matter can have wave characteristics with a wavelength given by

So-called de Broglie Wavelength

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad (H)$$

From special relativity ← form of "$E = mc^2$" when particle moving

$$E = \sqrt{p^2c^2 + m^2c^4} \quad (A)$$

For photon, $m = 0$

$$E = pc \text{ or } p = \frac{E}{c} \quad (B), (C)$$

From Blackbody + Photoelectric

$$E = h\nu \quad (D)$$

$$\nu = \lambda\nu \quad (E)$$

$$E = \frac{hc}{\lambda} \quad (F)$$

$$\frac{h}{\lambda} = \frac{E}{c}$$

$$\lambda = \frac{h}{p} \text{ for photon} \quad (G)$$

de Broglie: Perhaps Also true for Particle with Mass

$\lambda = \frac{h}{p}$

baseball at 92 mph

Mass 142 g

41 m/s

p of baseball = mv

$p = 5.7 \text{ kg m/s}$

$$\lambda_{\substack{92 \text{ mph} \\ \text{baseball}}} = \frac{6.6 \times 10^{-34} \text{ J·s}}{5.7 \text{ kg m/s}}$$

($h = 6.6 \times 10^{-34}$ J·s)

$$\lambda = 1. \times 10^{-34} \text{ m}$$

incredibly small wavelength — not noticeable to us.

1 eV electron

energy of 1.6×10^{-19} J (A)

$= \frac{1}{2} m v^2 \rightarrow v = 596 \text{ m/s}$

$p = (9 \times 10^{-31} \text{ kg})(596) = 5 \times 10^{-28} \text{ kg m/s}$

$$\lambda_{e^-} = \frac{6.6 \times 10^{-34}}{5 \times 10^{-28}} = 1.3 \times 10^{-6} \text{ m}$$

$\sim 1 \mu m$

Not so incredibly small

careful experiments can see wave effects like diffraction and interference of electrons

Electron Microscope

Can use electron waves to image very small objects because electron wavelength is smaller than wavelength of visible light

$\lambda = h/p$

higher Energy of p → smaller λ of electron

Niels Bohr

(1885 - 1962) (Denmark)

1922 Nobel Prize in Physics

Atomic (planetary) model with fixed orbits

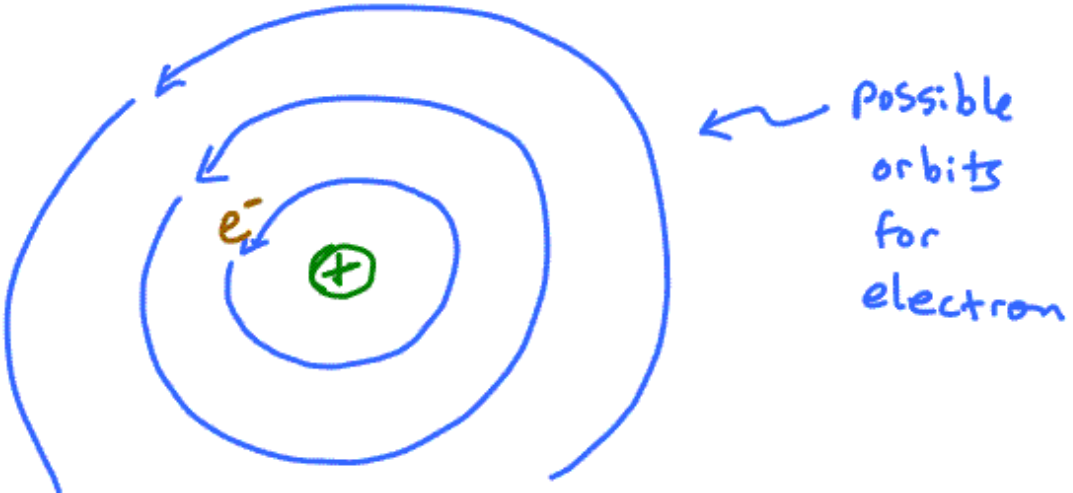
nicely motivated by de Broglie's matter waves in 1924

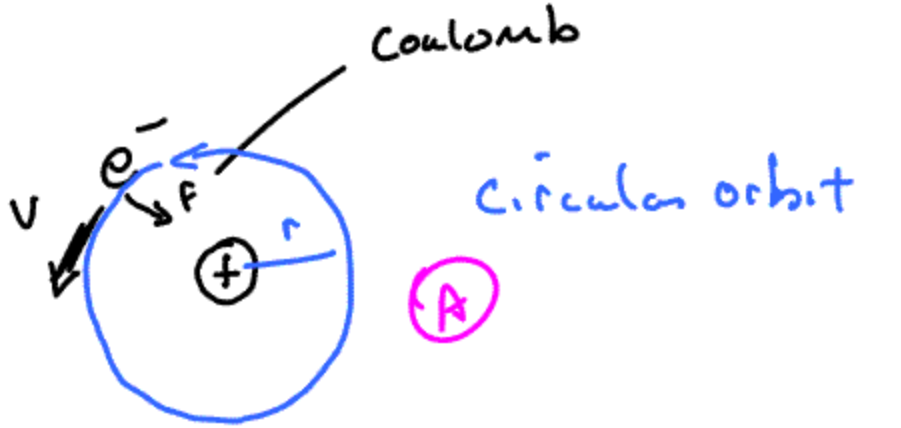
Bohr model of the atom

- positive Nucleus
- electrons orbit in circles
- only particular "discrete" orbits allowed

  ↑ known as quantization

- electric (Coulomb) Force holds electron on Circle as it orbits ... attracts electron toward Nucleus





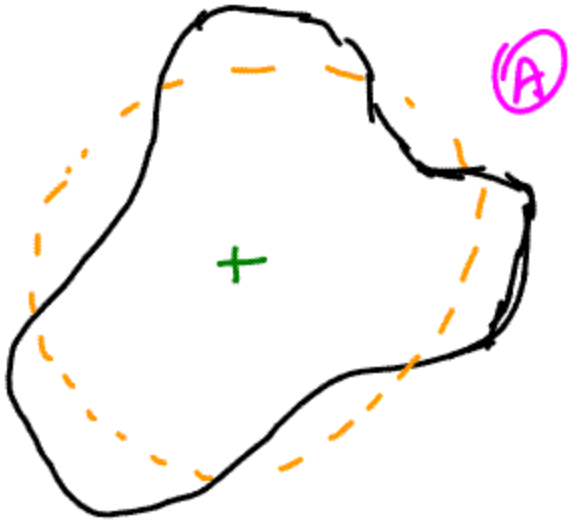
circular orbit

A

B

Recall "standing waves" on a string demo. Waves travel down string and reflect. Waves travel down string and interfere w/ reflected waves travelling back

only get "resonance" or stable system when wave and reflected wave interfere constructively

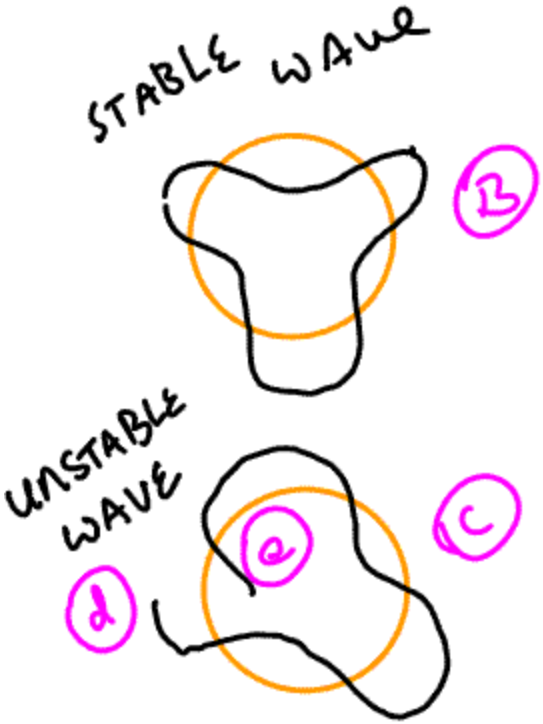


Imagine attaching one end of string to the other in a circle

If electron is a wave in Bohr model circular orbit, Electron can only exist in orbits where the electron wave interferes constructively with itself as you go around the circle.

⇒ only particular circumferences and circle sizes (radii) will work

Leads to quantization



$$F_{center} = \frac{mv^2}{R}$$

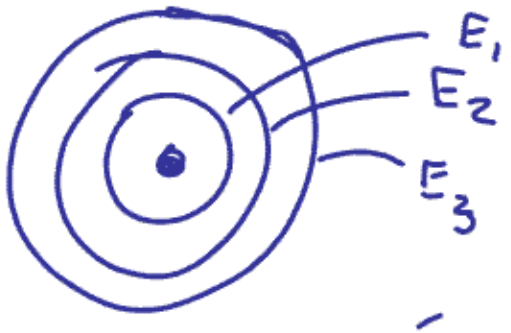
condition for Circular Motion

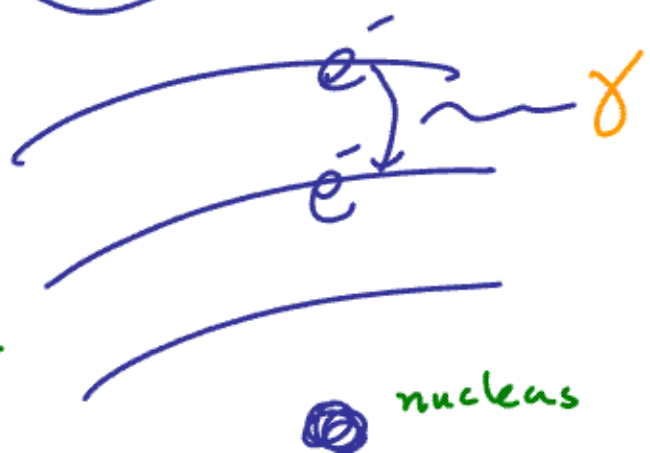
quantized orbits lead to quantized electron energies

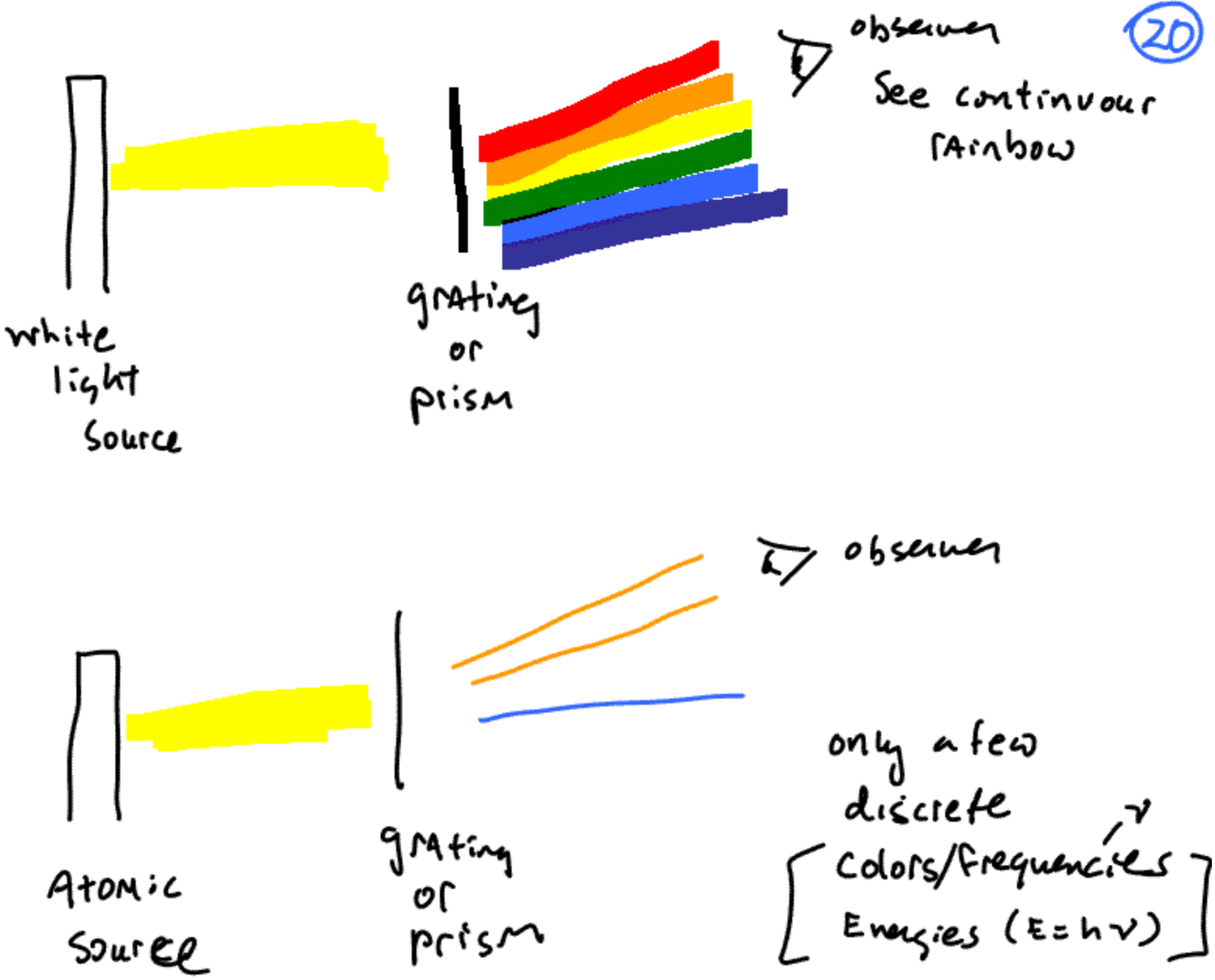
light absorbed and emitted as electron jumps from one orbit w/ fixed energy to another.

→ leads to discrete Atomic spectra

given R → fixed energy






observer
See continuous rainbow
white light source
grating or prism
observer
Atomic source
grating or prism
only a few discrete colors/frequencies (ν)
Energies (E = hν)
emitted
(Neon gas for example)

Bohr model of atom

- Worked with "quantized" nature of light
- Explained discrete spectra for simple ($1\ e^-$) atoms
- Provides decent starting place for visualizing the atom