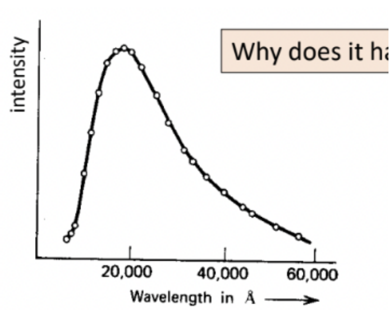
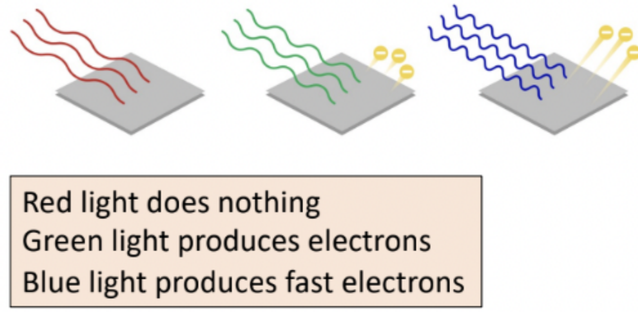
CAS PY 106

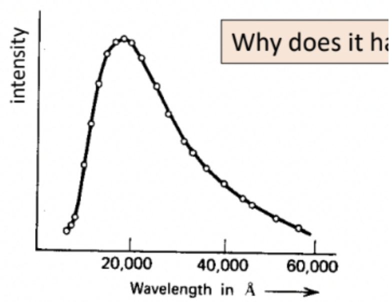
InClass Note 34

1. Laying the groundwork for quantum theory
    a. Quantum theory describes: How our universe works down at the level of individual atomic and subatomic particles
    b. Manipulation of quantum states potential to open new frontiers in
        - Information storage
        - Cryptography
        - Computing
        - medicine
2. A few holes in physics (around 1870)
    a. Problem of Black-body radiation
        - Amount of heat (EM waves) from radiator is different for different wavelengths
        - In 1870s, this group could not be explained
        - 

    b. Problem of photoelectric effect
        - Light hitting metal produces electrons but not for red light

- 

3. Black-body radiation problem

    a. 

    b. Everything at T > 0 K emits EM waves; and black objects radiate more heat than shiny objects

    c. Experiments revealed that at a given temperature of a black-body, there is a peak energy intensity at a particular wavelength that falls off at smaller wavelengths

    d. The classical theory of light as waves predicted that a black-body radiates an infinite amount of energy at small wavelengths of light

    e. This problem became known as the “ultraviolet catastrophe” because it violated the first law of thermodynamics (energy conservation)

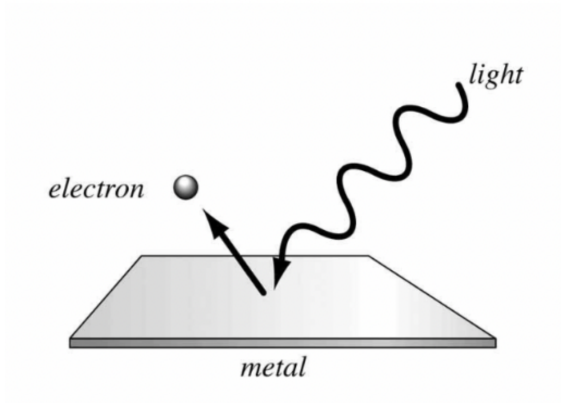
    f. One “small batch of energy” is called one “quantum of energy”

    g. In case of light, one quantum is called a “photon”

    h. Energy of a single photon

        - E = hf with Planck’s constant h = 6.626 * 10^-34

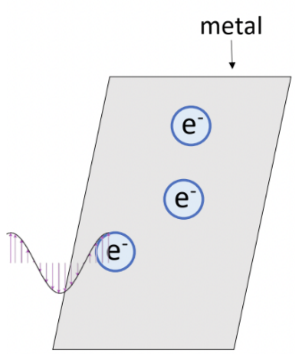
4. Photoelectric Effect (aka, the other hole in physics)

a. 

b. Emission of electrons from a metal caused by light shining on the metal

c. Light can hit a metal and impart energy to the electrons

d. It can even knock the electrons off the metal. These are called photo electrons

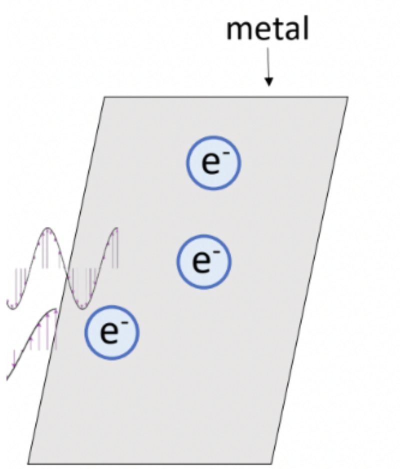
e. 

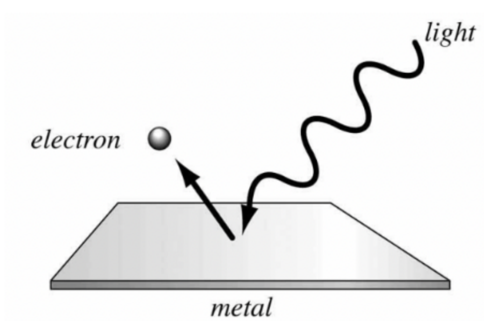
f. We can measure the kinetic energy of these photoelectrons

g. The theory that light is a wave makes two predictions for this phenomenon:

   - High intensity light produces higher kinetic energy photoelectrons
   - Shining of dim light should result in a time lag between light and ejection of photoelectrons

h. This is not what we observe…What do we observe?

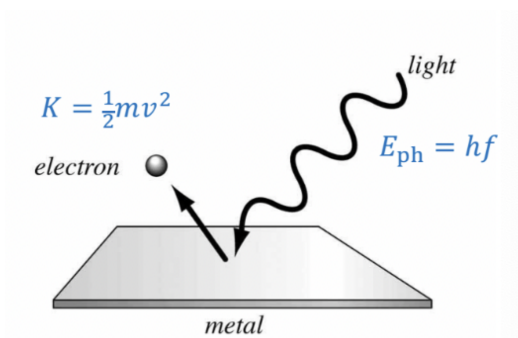
- Photoelectrons are only produced when incoming light reaches a critical frequency
- Higher intensity light produces more photoelectrons, not photoelectrons of higher kinetic energy
- Kinetic energy is proportional to light frequency
- 

i. New unit for energy: "electronvolt" or eV
j. The amount of kinetic energy gained or lost by a single electron accelerating from rest through an electric potential difference of 1 Volt in vacuum
k. 

l. 1eV = 1V * 1.6 * 10^-19 C = 1.6 * 10^-19 Joules

5. Photoelectric Effect Problem

a. Why are no electrons coming out of the metal below a certain frequency threshold?

6. Photoelectric Effect Explained by Einstein
    a. The electron is bound to the metal
    b. Electron needs to gain energy W to escape
    c. Light = photons (small batches of energy)
    d. Red light photon has low energy: $hf_{red} < W$ so no electrons escape
    e. Green light photon has enough energy: $hf_{green} > W$ and electrons escape
    f. Blue light photon has lots of energy: $hf_{blue} >> W$ and electron escape with high speed (high kinetic energy)
7. Kinetic energy of electrons that escaped
    a. Minimum amount of energy needed for photoelectric effect: $hf = W$
    b. Any energy "left over" becomes kinetic energy for electron
    c. 

8. The photoelectric effect - a graph
    a. A graph of K_{max} vs photon frequency gives a line with a slope of Planck's constant, a y-intercept equal to the negative of the work function, and an x-intercept of the threshold frequency
    b. $K_{max} = hf - W$

c.