Ch. 7 PHOTONS

What's a wave?
What's a matter?

All "stuff" has both wave and matter properties. Both.

The most wavelike things we know of---that has zero rest mass--has particle properties. We have accepted the notion of "photons" for a while, but let's take a look back historically.

This "light" stuff---had only recently been shown to be electromagnetic in origin, that the EM waves travel at the speed of light, seem to travel through ---no medium whatsoever, and now---experiments show that they are particles.

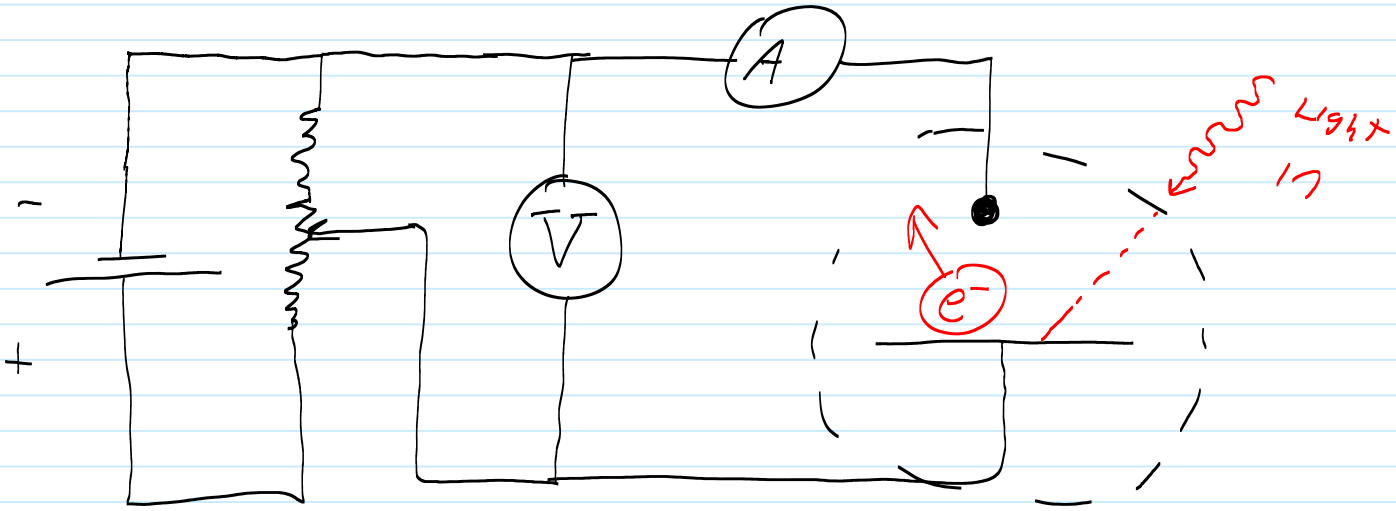
And this kind of leap---leads to ideals like quantum entanglement, spooky action at a distance (Einstein's phrase).

7.1 The photoelectric effect.

Planck suggested in the derivation of Blackbody radiation that the energy levels of the oscillators (the things exchanging energy with the cavity---the thermalizers) -- WERE QUANTIZED.

- The energy levels are quantized.
- So the radiation should only be emitted/absorbed in "lumps" also---since the energy levels can only make quantized transitions.
- Light itself carries the quantization property---- detections/emissions/interactions of any kind---occur with the "lumpiness" inherent (if we look for it).

The experiment---and a lengthy discussion.



Send in Light of ν
get out e^- with some K.E. (a spread)
Vary the Voltage divider until
Photocurrent → 0

The experiment is seemingly simple.
Send in the light--hit surface--get out electrons

- We should have a wide range of light energies---and for many materials reaching into energies of x-rays would be really ideal
  - Remember that visible light is about 2.00eV---x rays--thousands.
  - Going to higher energy light ---can be hazardous ---and may require vacuum for the metal surface and detector (some light don't get through glass).
- We should try many different materials
- Note that measuring max KE (once set up) is relatively easy

https://phet.colorado.edu/sims/cheerpj/photoelectric/latest/photoelectric.html?simulation=photoelectric

Observations ---for a given material---we change the potential V, and measure the photocurrent I.

- When V=0 a current is detected
  - The photocurrent depends on material, the geometry and the intensity of light.
- When V= + (positive)---then all the emitted photoelectrons are collected. The photocurrent saturates---electrons attracted to positive plate.
- When V=- (negative)----
  - The photocurrent reduces
  - The photocurrent reduces until a stopping potential (maximum potential) (retarding potential)---whatever you call it---- negative potential of magnitude V_o
  - At this potential the electrons do not make it to the Anode (negative plate).
- Interpretation---the electrons are emitted from the "photoelectric plate that light hits" (the cathode) with a range of kinetic energies.
  - The maximum kinetic energy is apparently $|e V_o| = KE_{max}$
  - Once this V_o is reached---electrons don't have enough KE to make it to the Anode---zero photocurrent.

Classical problems with all this:

- Given a constant frequency ν the observed V_o does not depend on the intensity of light.
  - *classically it was understood that more intensity meant more overall energy going in (cranked up the fire hose) so more energetic electrons should come out. That would mean that* $V_o \alpha Ke_{max}$
  - *Recall---that we know---there are two ways to increase energy in a wave----1) shake the slinky faster (more work) --higher freqency or 2) shake it with higher amplitude (louder/brighter/more intensity).*
- Even at very low intensity there is some photo current----AND IT HAPPENS RIGHT AWAY (SPOOKY)--NO TIME FOR "BUILDUP OF ENERGY" LIKE PUSHING A KID ON A SWING.
  - *The classical understanding is that it should take some time to build up enough back/forth energy at low intensity---so there must be a delay.*

Continue

- Delay not there
  - *The Non-Delay is so pronounced it is like if you knew the entire next sentence by reading only the first letter. B……*
  - *So you got that last sentence ---right?*
- For a given frequency ν and a fixed V, when the intensity of light is increased (I), so does the photocurrent (i). Big I, Little i, i,i,i……
  - This is in agreement with classical.
- The maximum KE_{max} is proportional to ν AND
  - FOR FREQUENCIES BELOW A MINIMUM VALUE ν_{min} THERE IS NO PHOTOCURRENT (SPOON?)
  - *There is no classical explanation for this---classically eventually at any frequency of light there should be enough energy built up after a time ---to emit photoelectrons.*
- So what gives?????????????

We need an explanation for all this.

7.2 Photoelectric effect theory---don't worry--not like blackbody. This is easy one or two lines.

Planck suggested some kind of quantization--but Einstein put the whole thing together.

Quantization of light--in packets called photons

$h = 6.63 \times 10^{-34}\ J \cdot s$

$$E = h\nu$$

If this is true for photons, and $c=\nu\lambda$ then

$$E_{photon} = h\frac{c}{\lambda} = \frac{1.240\ eV\ \mu m}{\lambda \text{ in } \mu m}$$

Einstein suggested that the Photo Electric effect was all or nothing---

That the electron picks up the entire energy lump $h\nu$ all at once, or nothing.

Let's go with this ---even though it sounds preposterous---(why ---you ask why). Once the electron has energy, it now must separate from the material in order to be free---and then detected as part of photocurrent. It takes some Energy to break the bond with matter. The energy is called the work function ϕ and depends on the specific material.

So an ejected electron will have a maximum Ke_{max}

$$KE_{max} = h\nu - \phi$$

Photoelectrons may have less energy than this---due to geometry---coming from a layer below the surface a little bit, or sliding out at an indirect angle. But this is the maximum energy available.

Quick discussion of the experiment

Select a material.

Send light in at several different frequencies.

Dial up the retarding Voltage until V_o is observed

V_o is the number recorded when you observe ZERO photocurrent

Any other photocurrents (which do happen) are irrelevant data--

So we have Ke_{max} vs $h\nu$ (or just frequency)

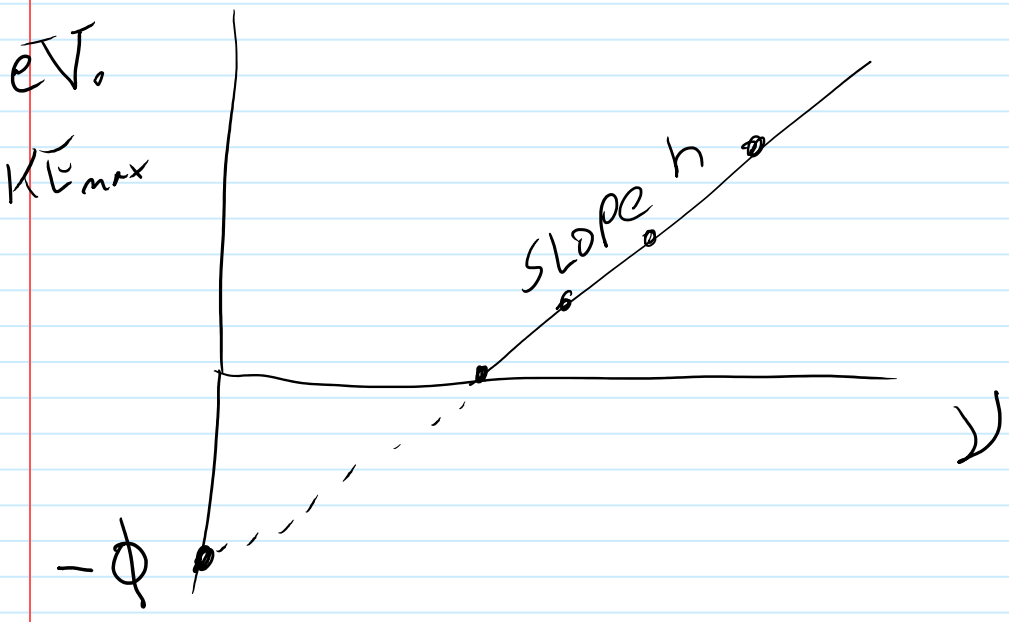
Results

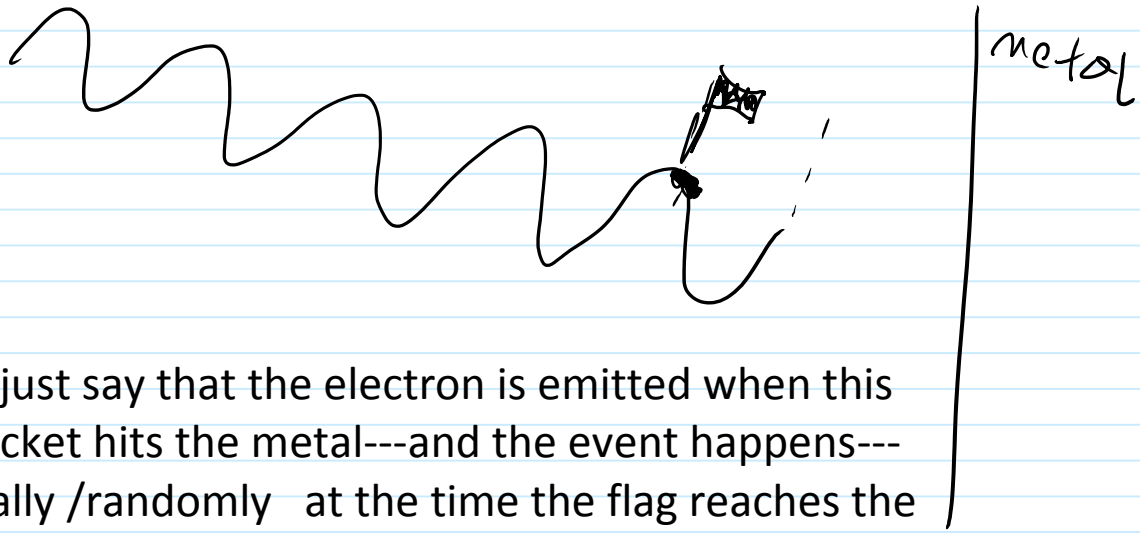
- For given ν and material----KE_{max} or V_o don't depend on the incident intensity.
  - All of the energy of "one photon" appears to be given up to one electron
  - This validates the particle property of light.
  - More photons mean more photocurrent "i" but not a different Ke_{max}
- The transfer of energy happens---apparently without delay, instantaneously when it does occur.
  - The electron is emitted---and the photon has disappeared ---poof ----like Andy Dufresne ---Back to this in a moment
- I is proportional to i
- and

$$KE_{max} = h\nu - \phi$$

$$|eV_o|$$

$$y = mx + b$$





So, let's just say that the electron is emitted when this wave packet hits the metal---and the event happens---statistically /randomly at the time the flag reaches the metal. (it could be earlier or later).

At that time---the entire wavepacket---I mean--the PHOTON disappears entirely. The energy has been transferred. The photon is gone instantly---even the parts that cannot possibly have received the information yet regarding emission--even at the speed of light. Poof---gone---spooky.

Experiment---you will almost certainly be given data--from which you must pick the correct numbers to plot and find a work function, and Plancks constant---YOU MUST KNOW TO IGNORE THE IRRELEVANT--AND YOU MUST SELECT THE BEST DATA (if you are given a bunch of real data points to determine a line---and told to pick TWO, which TWO must you pick).

Be able to find slope and intercept with the RIGHT data.