Phys 301 Classes 15 and 16
The Compton Effect
The Photoelectric Effect

What Have We Learned?

- Young's Double Slit Experiment
  - Light acts like a wave.
- Blackbody Radiation, Planck Function
  - Energy is quantized.
- Compton Scattering and Photoelectric Effect
  - Light acts like a particle.
- Compton Scattering handout

Finish Handout: Compton Effect

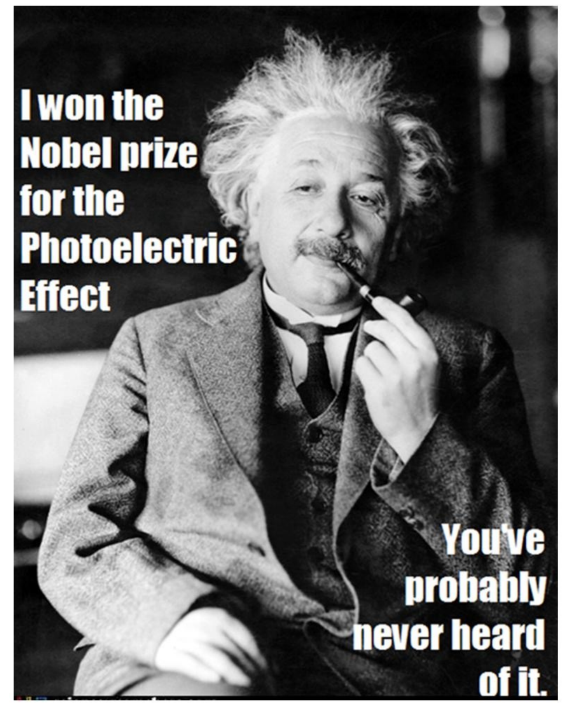
- Goal: Apply the model of a photon as a particle involved in a collision to explain the Compton Effect.
- We will use the fact that for a photon:

$$E = hf = \frac{hc}{\lambda}$$

Start PE Handout: Through Part II

The Photoelectric Effect

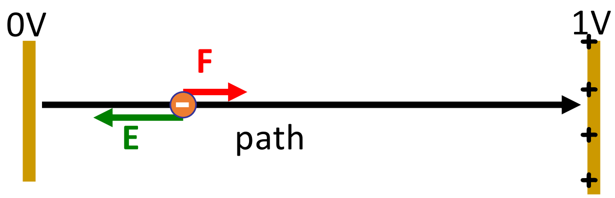
- It is 1905. So, light's just a wave, right?
- Einstein is 26 years old.
- This will earn him the 1921 Nobel Prize.



Hipster Einstein

Energy Units

- Joules: good for macroscopic energy
- New unit: the electron-volt (eV)
  - Kinetic energy gained by an electron when accelerated through 1 volt of potential difference.



$$\begin{aligned}
\Delta K &= -\Delta U \\
&= -q\Delta U \\
&= -(-e)(1\ \mathrm{V}) \\
&= (e)(1\ \mathrm{V}) \\
&= 1.6 \times 10^{-19}\ \mathrm{J} \\
&= 1\ \mathrm{eV}
\end{aligned}$$

Photoelectric Effect Activity

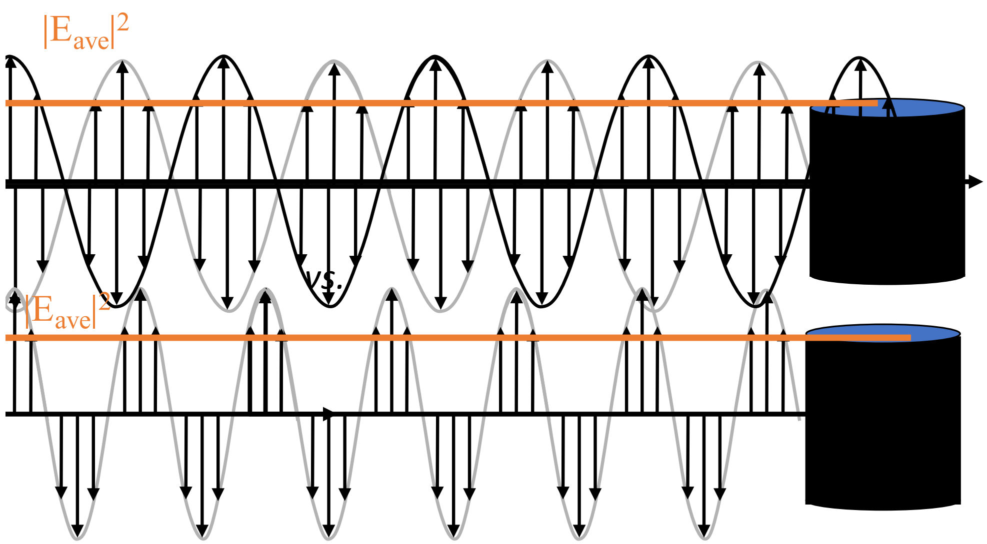
- Goal of handout: understand the properties of the photoelectric effect.
- After the activity: WHY must this be explained by light as a particle? Why can it NOT be explained by light as a wave?

5 Properties of Photoelectric Effect

1. Current linearly proportional to intensity.
2. Current appears with no delay (no lag).
3. Electrons only emitted if frequency exceeds a threshold (cutoff frequency).
4. Maximum kinetic energy of photoelectrons increases linearly with frequency.
    1. How, in “real life,” would you measure maximum K?
    2. Maximum energy = – stopping potential energy
5. Threshold frequency depends on metal.

Predictions of Wave Model

- Intensity



1. Energy could build up over time. (But no lag time!)
2. Higher intensity light provide *more* energy (but energy of electron doesn't depend on intensity!)
3. Energy independent of frequency. (But there's a cut-off frequency!)

The Work Function and Your Models

$$K_{max} = hf - \phi$$

$$h = 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$$
(Planck's Constant, slope)

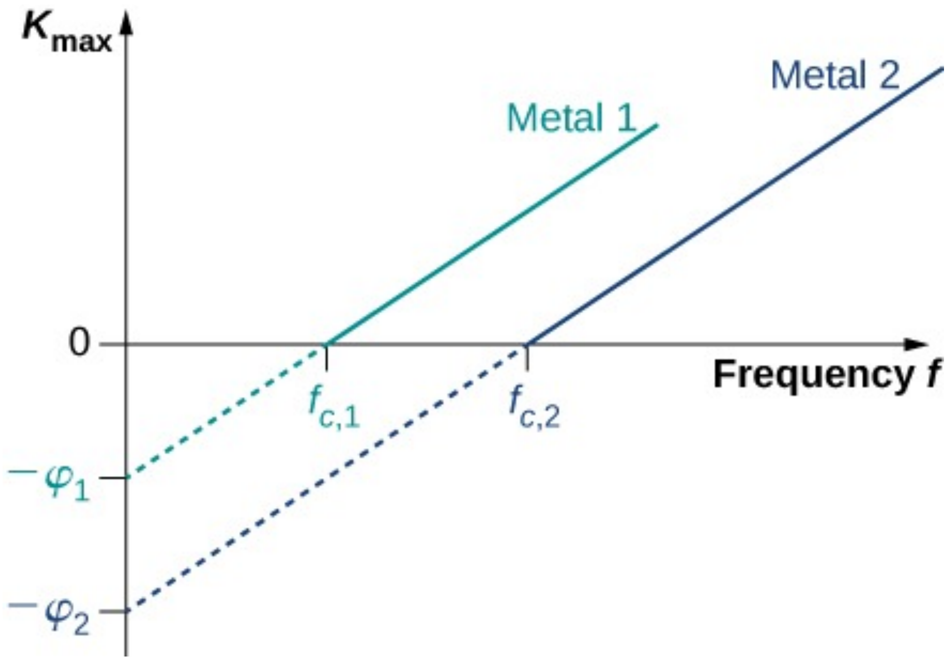
Typical Values of the Work Function for Some Common Metals

Metal	ϕ (eV)
Na	2.46
Al	4.08
Pb	4.14
Zn	4.31
Fe	4.50
Cu	4.70
Ag	4.73
Pt	6.35

Table 6.1

$\phi =$ Work Function (property of metal, intercept)

The cutoff frequency

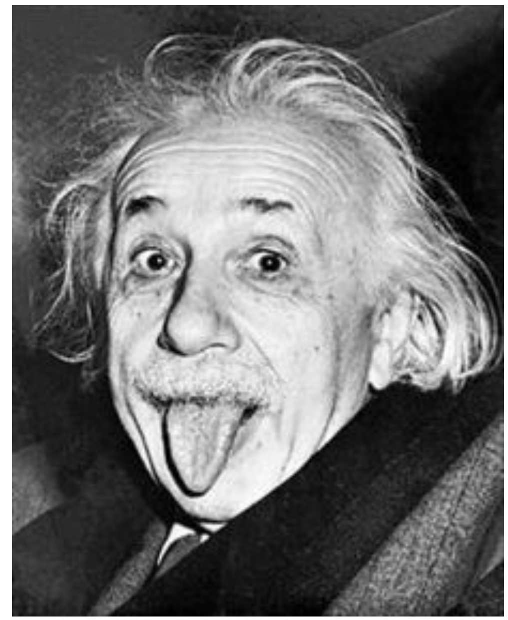


$$0 = hf_c - \phi$$

$$f_c = \frac{\phi}{h}$$

What's the Explanation?

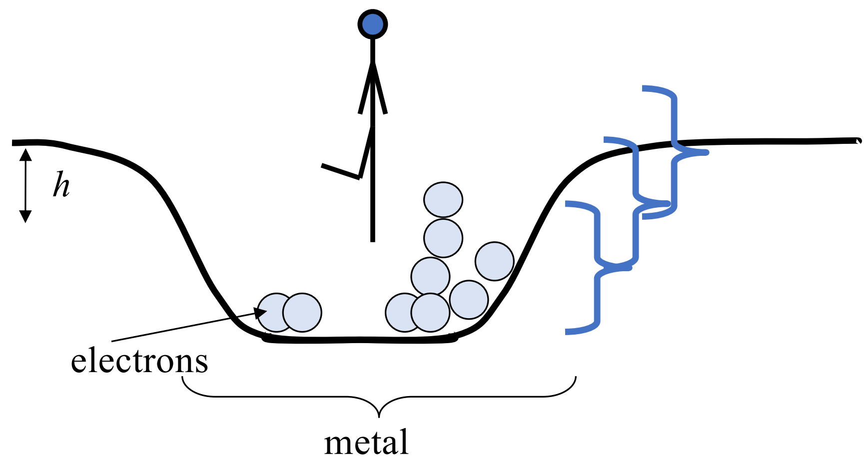
- A *photon* is a particle of light…
- ...moving at the speed of light...
- … with energy $E_f = hf$.



The Kicker Analogy

Credit to Noah Finkelstein's Physics 2130 class materials at CU Boulder.

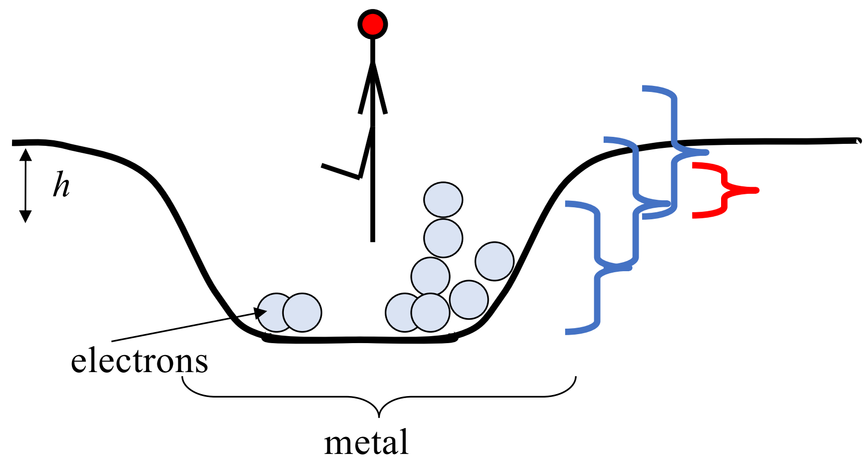
- Balls (electrons) in a pit.
- Kicker (photon) puts energy into ball.
- Kick only one ball with all kick energy.
- Blue kicker kicks the same and harder than red kicker always kicks.
- Ball emerges with
  - $K = \text{Kick Energy} - mgh$
  - mgh = energy needed to make it up and out of the pit.



The Kicker Analogy

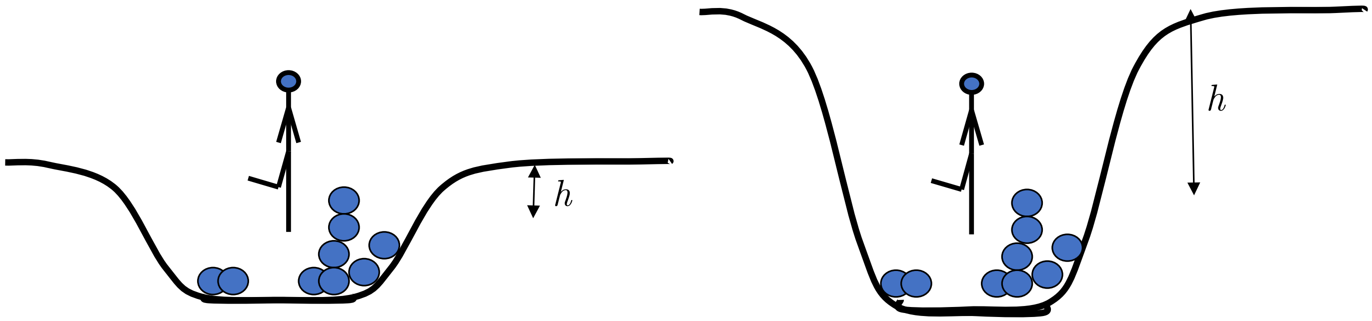
Credit to Noah Finkelstein's Physics 2130 class materials at CU Boulder.

- Balls (electrons) in a pit.
- Kicker (photon) puts energy into ball.
- Kick only one ball with all kick energy.
- Blue kicker kicks the same and harder than red kicker always kicks.
- Ball emerges with
  - $K = Kick\ Energy\ - mgh$
  - mgh = energy needed to make it up and out of the pit.



The Kicker Analogy

- Work function (ϕ): energy needed to get the most loosely bound electron out of the "pit" (being bound to atom).



Sodium- easy to kick out
small work function ⇔ shallow pit

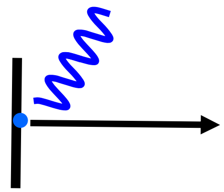
Platinum, hard to kick out
large work function ⇔ deep pit

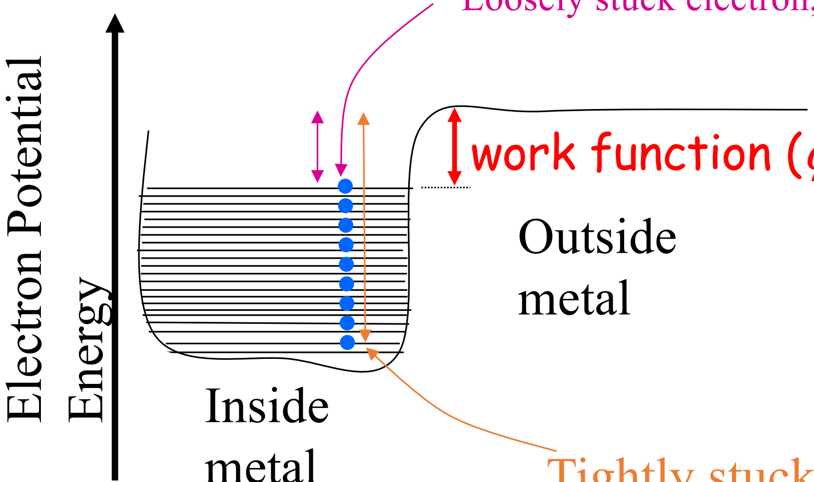
$$\text{Initial } K \text{ of electron as it comes out of the metal} = E_{\text{photon}} - \text{energy needed to kick electron out of the metal}$$

Depends on the type of metal.

Photoelectric Effect: Review

Energy of photon = energy needed to kick electron out of the metal + Initial K of electron as it exits the metal





Warning!!
This is not deeper in metal
It is more tightly bound!

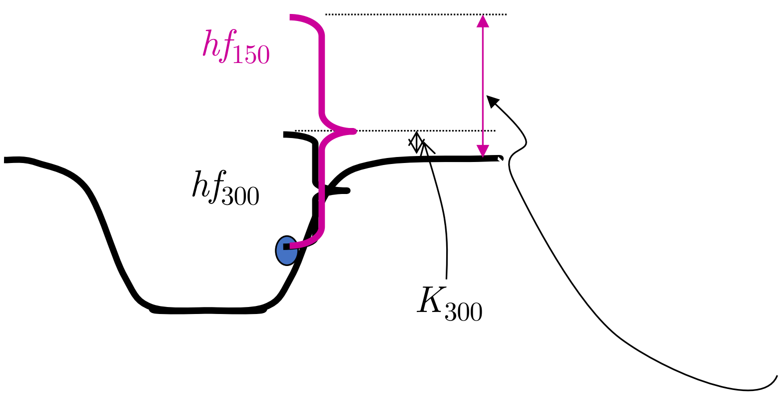
A photon at 300 nm will kick out an electron with an amount of kinetic energy, K_{300}. If the wavelength is halved and it hits an electron in the metal with same energy as the previous electron, the kinetic energy of the electron coming out is:

a. less than ½K_{300}.
b. ½K_{300}
c. $2K_{300}$
d. more than $2K_{300}$

(*remember kicker and hill analogy, draw pictures to reason out answer, don't just pick answer without careful reasoning*)

A photon at 300 nm will kick out an electron with an amount of kinetic energy, K_{300}. If the wavelength is halved and it hits an electron in the metal with same energy as the previous electron, the kinetic energy of the electron coming out is

d. more than $2K_{300}$



K = photon energy – work function

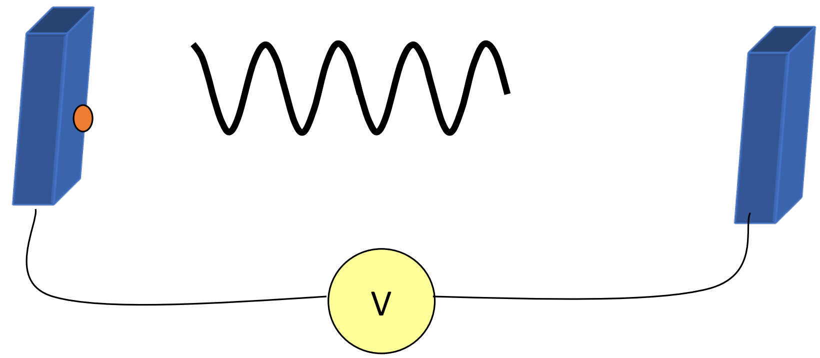
$= hf - \phi$

if λ is ½ then, f twice as big, $E_{phot} = 2hf_{300}$

so have new $K_{new} = 2hf_{300} - \phi$

compared with $K_{300} = hf_{300} - \phi$

so K_{new} is more than twice as big.



Shine in light of 300 nm. The most energetic electrons come out with kinetic energy, K_{300}. A potential diff. of 1.8 V is required to stop these electrons. What is the work function ϕ for this plate? (*e.g.*, the minimum amount of energy needed to kick electron out of metal?)

Recall definition of eV…

Shine in light of 300 nm, most energetic electrons come out with kinetic energy, K_{300}. A potential diff. of 1.8 V is required to stop these electrons. What is the work function ϕ for this plate? (*e.g.*, the minimum amount of energy needed to kick electron out of metal?)

Energy is conserved so:
the energy at the start (E_{phot}) = energy at end
$\Rightarrow E_{phot}$= kinetic energy of the electron + energy to escape metal, ϕ

so $\phi = E_{phot}$ - electron energy
Electron kinetic energy all converted to potential= (e)(1.8V) = 1.8 eV,
E_{phot} = 1240 eV nm/300 nm = 4.1 eV.

So ϕ = 4.1eV - 1.8 eV = 2.3 eV