Announcements

Homework 2 due on Feb 1 (this Wednesday).

Homework 3 due on Feb 8 (next Wednesday).

Today's class

Photoelectric effect

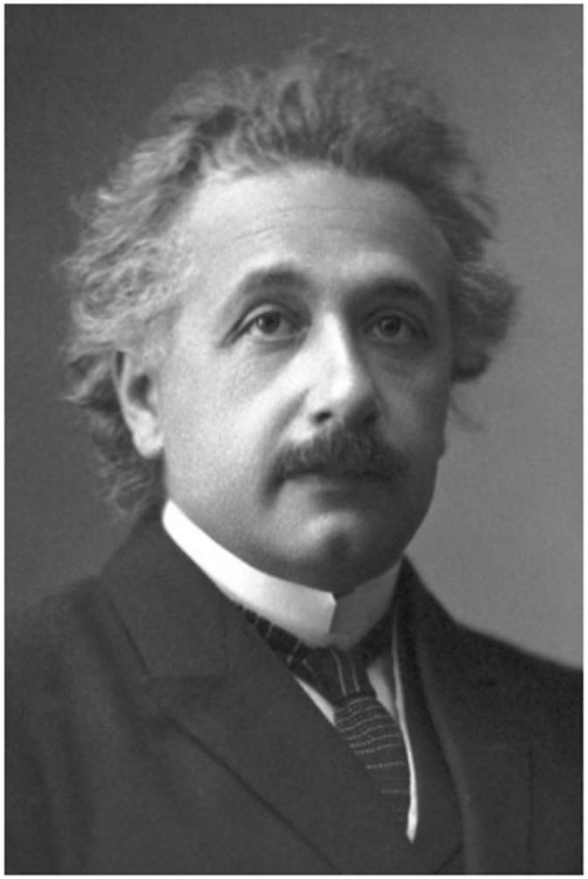


Photo from the Nobel Foundation archive.

Albert Einstein

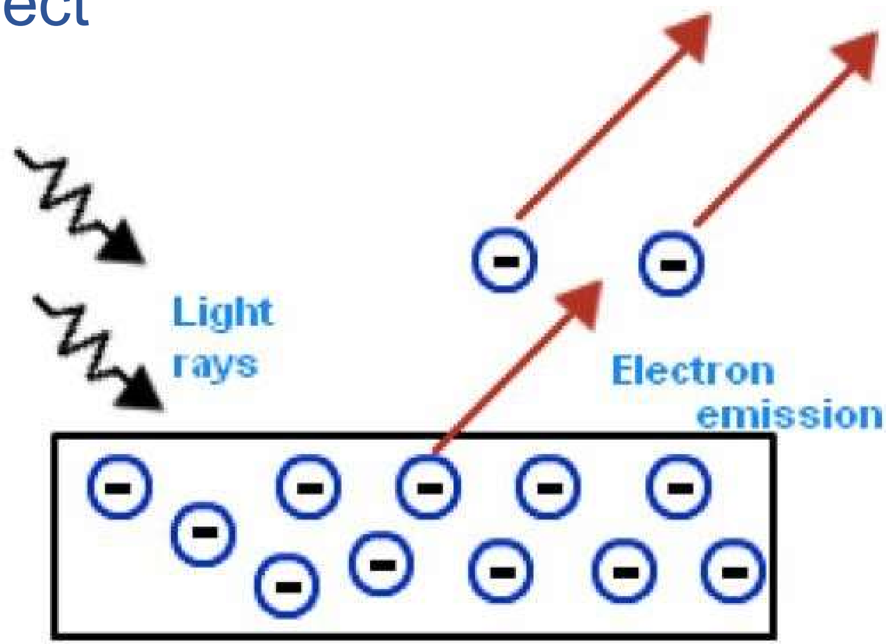
The Nobel Prize in Physics 1921 was awarded to Albert Einstein "for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect."

Photo from the Nobel Foundation archive.

Robert Andrews Millikan

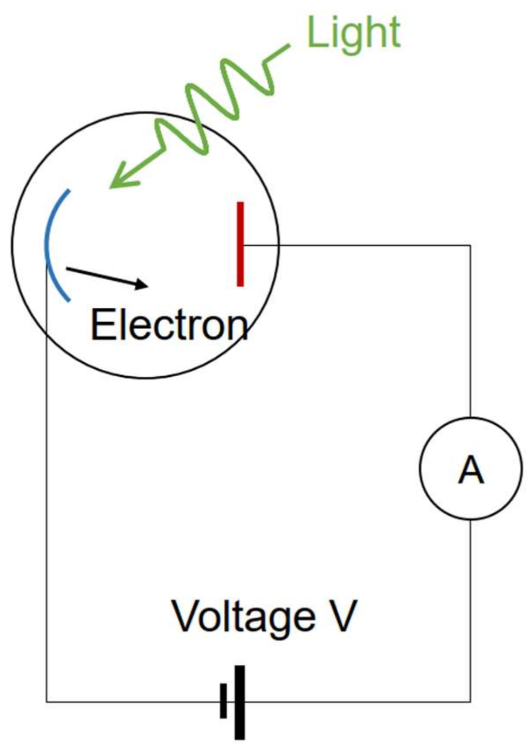
The Nobel Prize in Physics 1923 was awarded to Robert Andrews Millikan "for his work on the elementary charge of electricity and on the photoelectric effect."

Photoelectric effect



- Materials absorbs light and can emit electrons (photoelectrons)
- Light can “kick out” electrons

A way to measure photoelectric effect

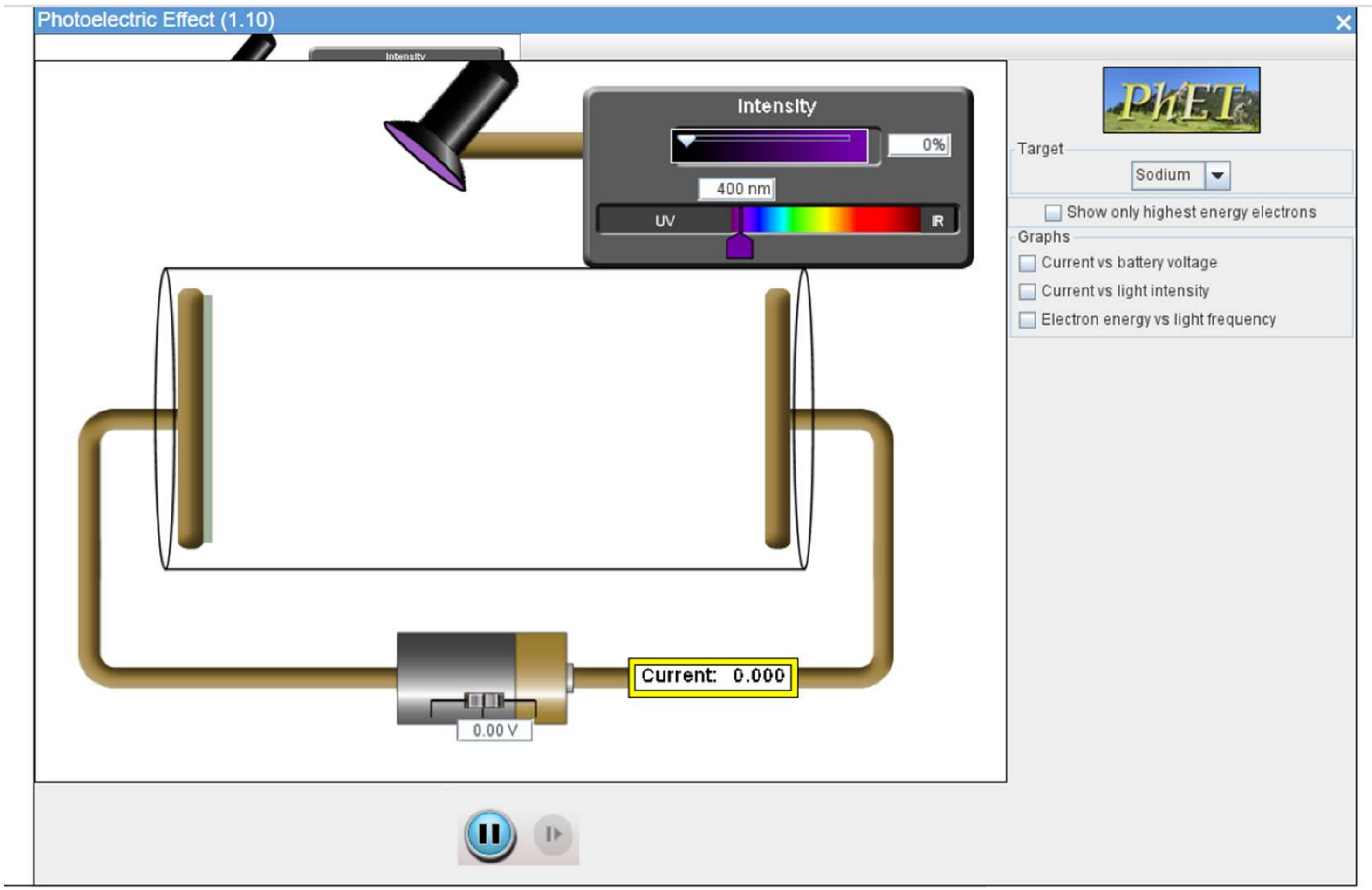


- A variable voltage source applying a voltage V across the two electrodes (blue & red).

- The two electrodes are enclosed inside a vacuum tube. An ammeter is measuring the current.

Photoelectric effect

https://phet.colorado.edu/en/simulations/photoelectric



Photoelectric effect

https://phet.colorado.edu/en/simulations/photoelectric

Input parameter:

- light intensity
- wavelength of light
- voltage
- target materials

Output:

- current
- You can plot or manually note the values

Photoelectric effect

1. Current vs light wavelength?
   - *hint: first increase light intensity from 0.*

2. Current vs voltage?
   - *hint: fix the wavelength.*
   - find voltage that stops the current.

3. Stopping voltage vs wavelength?

4. Current vs light intensity?

What can we learn from the experiment?

- No light, no current at any voltage V.
- When shining light on one electrode, current starts to flow meaning **electrons are kicked out** (generation of photoelectrons).
- There is **a cutoff frequency**, below which no photoelectrons are emitted by light.
- The current increases with light intensity.
- Stopping voltage depends on only the frequency of the light, not its intensity.

Can we understand this in classical physics?

In classical E&M, people expect light to *continuously* transfer energy to electrons in the material. When enough energy is accumulated, an electron will be kicked out.

Consequences from classical E&M:

-- For high enough intensity, any wavelength of light should produce the photoelectric effect.

NO

-- The maximum kinetic energy of the photoelectrons should scale with light intensity

NO

-- The maximum kinetic energy should be independent of the frequency

NO

-- The photoelectrons need a measurable amount of time to gain enough energy to be ejected. (See example 3.2)

NO

Einstein’s theory of the photoelectric effect

- Einstein proposed that **electromagnetic radiation is quantized.**
- The field and energy in it comes in discrete packets called **photons.** The photon is a **quantum** of electromagnetic energy.
- A photoelectron is released as a result of an encounter with **a single photon.**

Can this explain your observations?

What observations can now be explained?

- The existence of the cutoff frequency
- No measurable time delay

Einstein's theory of the photoelectric effect (2)

- The energy of each photon is related only to the frequency of the EM radiation:

  E = hf

  where h is the Planck's constant: $h = 6.626 \times 10^{-34}$ J·s

- The momentum of each photon

  p = h/λ   because p=E/c

A handy formula to estimate photon energy:

$$\lambda f = c \rightarrow E_\lambda = \frac{hc}{\lambda} = 1240 eV \cdot nm/\lambda$$

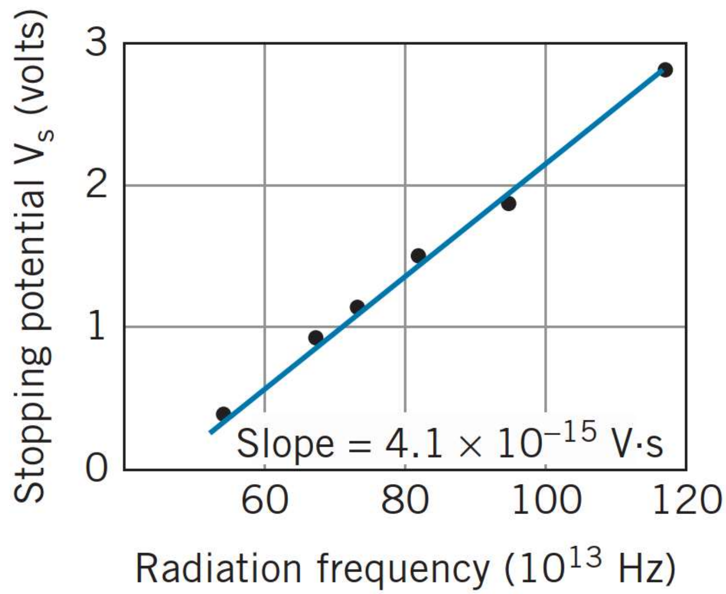
Useful when wavelength is in the unit of nanometer.

Kinetic energy of the photoelectron

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

- The "grocery" analogy
- Φ: work function
- Cutoff frequency? Hints: Kmax=0.
- Stopping voltage Vs?
  Hints: Kmax =eVs. The stopping voltage will prevent electrons from reaching the other electrode and the current drops to zero.

Millikan’s experiments



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

$$K_{max} = eV_s$$

$$eV_s = hf - \phi$$

$$\text{slope} = \frac{h}{e}$$

What does the slope mean?

Can you confirm that the value agrees with your theoretical prediction?

Millikan uses this experiment to determine Planck’s constant!

Example: light on aluminum cathode

TABLE 3.1 Some Photoelectric Work Functions

Material	ϕ (eV)
Na	2.28
Al	4.08
Co	3.90
Cu	4.70
Zn	4.31
Ag	4.73
Pt	6.35
Pb	4.14

Known: Incident light is 200nm;

The work function of Al is $\Phi = 4eV$

Question:

What is the stopping voltage V_s to stop the photocurrent?

$$hc = 1240\ eV \cdot nm$$

$$E = hf = \frac{hc}{\lambda} = \frac{1240\ eV \cdot nm}{200\ nm} = 6.2\ eV$$

$$K_{max} = E - \phi = 6.2\ eV - 4\ eV = 2.2\ eV$$

$$K_{max} = eV_s = 2.2\ eV$$

$$V_s = 2.2\ V$$

Example (2): light on aluminum cathode

- What happens if intensity of light is increase by a factor of 2?

1) What is the stopping voltage V_s to stop the photocurrent?

2) Photocurrent for $V < V_S$?

Example (2): light on aluminum cathode

- What happens if intensity of light is increase by a factor of 2?

1) What is the stopping voltage V_s to stop the photocurrent?

2) Photocurrent for $V < V_S$?

1) V_S does not change: determined by photon energy E and work function Φ

2) For $V<V_S$, every photon creates an electron in the circuit that contributes to the current. So if intensity (#photons/s) increases by 2, so does photocurrent.