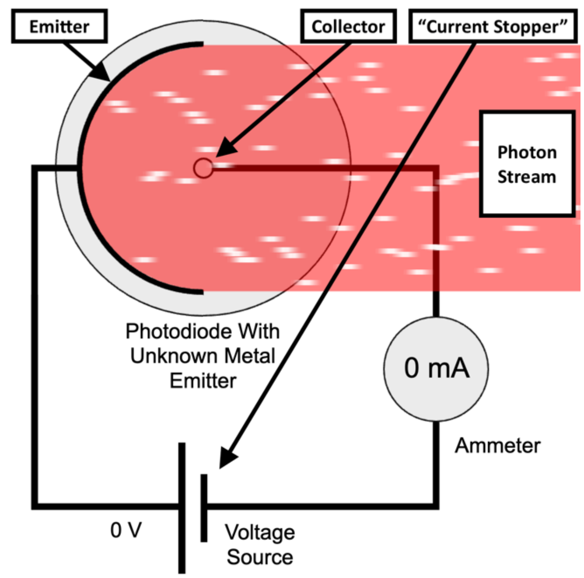
# The Photoelectric Effect

## Purpose:
To understand the nature of the photoelectric effect and why it led to a quantum or photon model of light.

## Getting Ready:
Navigate to the **Photoelectric Effect** Interactive at The Physics Classroom website:
https://www.physicsclassroom.com/Physics-Interactives/Atomic-Physics/Photoelectric-Effect/Simulation

## Navigational Path:
www.physicsclassroom.com ==> Physics Interactives ==> Atomic Physics ==> Photoelectric Effect

## Background:
In the late 1800s to the early 1900s, scientists were aware of and theoretically troubled by a phenomenon known as the **photoelectric effect**. The effect involves the emission or ejection of an electron by a metal when light is incident upon its surface. The fact that an electron was ejected was no surprise. But there were some details of the effect that were quite surprising. The current models of the day were unable to predict and explain such details. It wasn't until 1905 that Albert Einstein was able to explain all the details of the photoelectric effect using a quantum model.




In this simulation, you will investigate the photoelectric effect in an effort to understand the experimental set up and findings. And you will also explore how the wave model of light was unable to explain the details. The set-up includes a light source with an adjustable wavelength (and frequency) and an adjustable intensity. The light (**photon stream**) will be incident on a metal (sodium, magnesium, or an unknown metal). The metal is the **emitter** of electrons. The ejected electrons are attracted to the **collector**. This results in a current in the circuit. The voltage source can be used to create an *opposing potential* to stop the ejected electrons from reaching the collector. More voltage will be required to stop more energetic electrons.

**Something you should know**: The wavelength and frequency of light are inversely related. Red light has the longer wavelength, the lower frequency, and the lower energy. Violet light on the other end of the visible light spectrum has the shorter wavelength, the higher frequency, and the higher energy values. Thus, sliding the wavelength to lower values results in greater energy light. Light with wavelengths lower than violet is ultraviolet light. Light with wavelengths greater than red is infrared light.

**Part 1: Intensity Effects**

1. Adjust the following parameters:
   Emitter Material: **Sodium Metal** Intensity: **5-20%**
   Wavelength: **700 nm** (red light, low energy) Voltage Applied: **0 V**

2. Increase the intensity from a low value to a high value. What effect does this have on the photon stream?

3. At 700 nm, is a high intensity photon stream more likely to eject an electron (resulting in a current) than a low intensity photon stream?

4. Change the wavelength to 600 nm and answer the same question. Does increasing the light intensity increase the odds of having an electron ejected from the metal?

**Part 2: Wavelength Effects**

5. Set the **Light Intensity** to 100%. For sodium, gradually decrease the wavelength (increasing frequency and energy) until you observe electrons being ejected from the metal. At what wavelength does this occur?

6. For this very wavelength, decrease the intensity. Does decreasing the intensity result in no photoelectric effect?

7. Test to see if the photoelectric effect occurs for other lower wavelengths than the wavelength determined in Question #5. What did you find out?

8. Experiment, collect evidence, and make and support a claim that supports or refutes the following statement:

   The photoelectric effect is more likely to occur at 550 nm and an intensity of 100% than it is at 450 nm and an intensity of 5%.

Here is a Part 2 Lesson that you should have learned:

> A metal has a threshold wavelength and a related **threshold frequency** and threshold energy. The threshold frequency is the minimum frequency for which the photoelectric effect is observed. The photoelectric effect only occurs for a frequency greater than or equal to the threshold frequency.

**Part 3: The Kinetic Energy of the Emitted Electron**

9. Electrons are ejected from the metal with kinetic energy (as reflected by its ejection speed). Observations show that not all electrons are ejected with the same kinetic energy. There is a range of KE values for the ejected electron. Those electrons with the greatest KE are those ejected from surface atoms; we describe these electrons as having the **maximum KE ($KE_{max}$)**. Those with the least KE were ejected from atoms below the surface and lost some of their original KE in the process of exiting the metal.

   Conduct some experimenting to determine how the $KE_{max}$ value depends upon the wavelength (and frequency). Complete the following statement:

   As the wavelength decreases (while below the threshold wavelength), the $KE_{max}$ value ______________________. (increases, decreases, remains unchanged)

10. Light intensity makes a difference. But BEWARE of what it makes a difference to. For any wavelength below the threshold wavelength, vary the intensity and carefully describe what it affects. Does it affect the $KE_{max}$ value? Does it affect the current? Does it affect the # of electrons ejected per second?

11. Historically, one means of determining the $KE_{max}$ value involves using a voltage source to oppose the motion of the ejected electrons. The negative terminal of the voltage source is attached to the collector. The negative charge on the collected pushes back on the ejected electrons to stop them. A greater voltage is required to stop electrons with a greater $KE_{max}$ value. Set your parameters to sodium metal and 50% intensity. Then complete the table.

| Trial | λ (nm) | Stopping Voltage (V) |
|---|---|---|
| 1 | 500 | |
| 2 | 450 | |
| 3 | 400 | |
| 4 | 350 | |

12. Now let's re-evaluate your Question #10 answer. Repeat a couple of trials from the table for 100% intensity. Does light intensity affect the $KE_{max}$ value? Explain your answer.

**Part 4: The Wave Model and the Photoelectric Effect**

13. Now we will explore what the wave model of light would have predicted about the photoelectric effect. We hope to identify the details that the wave model was unable to explain. Tap on the button (shown above) at the top right of the simulation window. Reset the parameters to:

    But what might happen if light behaved according to classical physics?

    Emitter Material: **Sodium Metal**
    Wavelength: **700 nm** (red light, low energy)
    Intensity: **5-20%**
    Voltage Applied: **0 V**

14. Experiment with the wave model. Does it predict that all wavelengths (and frequencies) can cause the photoelectric effect? Report your findings:

15. According to the wave model, will light with an intensity of 100% and wavelength of 600 nm more effectively eject a photon than light with an intensity of 10% and a lower wavelength of 400 nm? Report your findings.

16. Complete the table at the right. Then answer the question:

    Does the wave model predict that light intensity affects the $KE_{max}$ value?

| Trial | λ (nm) | Light Intensity | Stopping Voltage (V) |
|---|---|---|---|
| 1 | 650 | 50% | |
| 2 | 650 | 20% | |