October 24, 2022

# THE PHOTOELECTRIC EFFECT

**Objective:** To test Einstein's hypothesis that the energy in each quantum of light is equal to the frequency times a constant and to measure Planck's constant.[1]

**Preparation:** To be done *before* starting the lab.

1. Read section 4.3 of the textbook.

2. When light is shines on a metal the metal surface may emit electrons. This "photoelectric effect" was first noted, in passing, by H. Hertz in 1887. Lenard, Thomson, and others studied the effect in greater detail; however, the experiment was not easily interpreted using the idea of electromagnetic radiation propagating as waves. Why? What does the classical theory of electromagnetism predict about the kinetic energy of the emitted electrons?

3. Starting with conservation of energy and Einstein's equation for the energy of a photon, $E = hf$ derive the following equation for the stopping potential $V_s$ as a function of the frequency of the incident photon,

$$V_s = \frac{h}{e} f - \frac{\phi}{e}, \tag{1}$$

   where $\phi$ is the work function of the metal.

**Procedure:** In this experiment, you will use filters to separate the frequencies of light coming from a mercury lamp. This light will then be directed onto a photocathode inside a small vacuum tube (see Figure 1). A power supply will allow you to adjust the voltage between the photocathode and the anode. You will read the current flowing from the photocathode to the anode using an ammeter. You will determine the stopping voltage $V_s$ by adjusting the voltage between the photocathode and the anode until the current is zero. By doing this for several different light frequencies and plotting $V_s$

[1] Like the speed of light in a vacuum Planck's constant is a defined value in SI units. Its exact value is $h = 6.62607015 \times 10^{-34} J\, Hz^{-1}$. See the video at https://www.youtube.com/watch?v=IZjyAn3ma4 for a nice introduction to the base SI units.

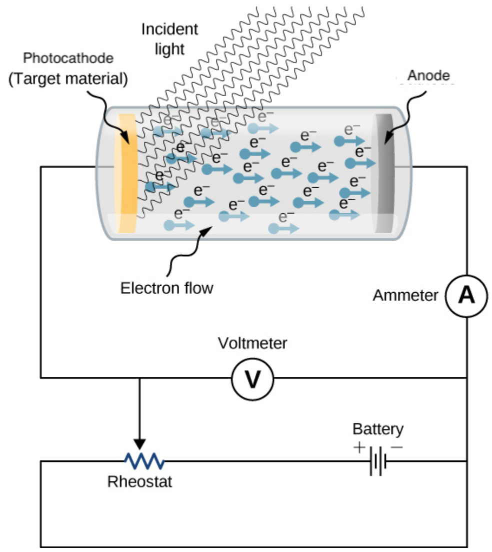


Figure 1: Circuit to measure the photoelectric effect. By adjusting the voltage $V$ until the current through the ammeter is zero you can determine the stopping voltage $V_s$.

versus $f$ you will able to measure Planck's constant[2] and the work function of the photocathode.

Before you turn anything on examine the apparatus and make sure you understand how it works. Ask your lab instructor for a quick checkout before you begin to take data.

Here are some things to keep in mind while doing the experiment.

- The mercury lamp is a strong UV source. **Do not look directly into the lamp.**
- Determine the stopping potential for each wavelength. You should go through all wavelengths more than once. The stopping potential is the *minimum* voltage that will stop the current. Any voltage greater than $V_s$ will also stop the current so take care to adjust the voltage slowly.
- The intensity of the light is controlled by putting a different size opening or aperture in front of the light. Use all three aperture sizes to explore how the photocurrent depends on intensity.

[2]We know the charge of an electron $e = 1.60217657 \times 10^{-19}$ C.

- The frequencies of the mercury spectral lines are shown in the table below.

| Color | Frequency (Hz) | Wavelength (nm) |
|---|---|---|
| Yellow | $5.196 \times 10^{14}$ | 577 |
| Green | $5.491 \times 10^{14}$ | 546 |
| Blue | $6.876 \times 10^{14}$ | 436 |
| Violet | $7.402 \times 10^{14}$ | 405 |
| UV | $8.213 \times 10^{14}$ | 365 |

Table 1: Frequencies and wavelengths of mercury spectral lines.

**Analysis:** Plot values for the stopping potentials as a function of frequency. You don't need to average your stopping potential results. You can just plot each of the measurements. This means you will have more that one point at each frequency. The `curve_fit` program you use to determine slope and intercept will use the spread in stopping potentials into account when computing the uncertainties.

Determine the work function $\phi$ and Planck's constant $h$ from the slope and intercept of your plot. Don't forget to propagate the error properly when you do these computations.

**Interpretation and Summary:** Answer the following questions.

1. Compare your result for $h$ to the accepted value. Does it agree within the uncertainty of the measurement. If not, can you explain why?
2. Look up some values for the work functions of various metals. How does your measured value for the work function compare to the work function of typical metals?
3. Calculate the cut-off frequency. In what part of the EM spectrum is this frequency?