The Photoelectric Effect

General Description
The photoelectric effect is the liberation of electrons from the surface of a material by absorption of energy from light striking the surface (see Figure 1). The simplest experimental arrangement for observing this effect is shown in Figure 1.

The cathode is illuminated with monochromatic light, and the current (resulting from the photoemission of electrons from the cathode) is measured as a function of voltage.

The most important experimental observations are the following:

1. The kinetic energy of the photoelectron (as determined by the reverse voltage needed to stop completely the flow of electrons from cathode to anode) is independent of the intensity of the light, but is a linear function of the frequency of the radiation.

2. There is a minimum frequency below which photoemission does not occur; the value of this minimum depends on the composition of the surface.

3. The saturation photocurrent is directly proportional to the light intensity.

The experimental observations of the photoelectric effect were first understood by Albert Einstein in 1905. He interpreted them in terms of the quantization of light first postulated by Planck five years earlier. In this model a beam of light is said to be composed of a number of light quanta, or...
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photons, each with energy related to its frequency, \( \nu \), by \( E = h\nu \) where \( h \) is Planck’s constant. Each photon acts like a ”particle” of light. The intensity of the light increases when the number of photons increases. The interaction of light with an electron in the photoelectric effect is modeled as a collision in which the electron can absorb the energy of the photon and destroy the photon.

To remove an electron from the surface of a material requires an amount of energy, \( W \), called the work function of the material. The higher the work function, the more tightly bound are the electrons. When an electron is emitted, by conservation of energy, the initial energy of the photon equals the resulting kinetic energy of the electron plus the energy lost in overcoming the work function. That is,

\[
h\nu = \frac{1}{2}mv^2 + W
\]

The negative potential, \( V_o \), needed to stop the electron flow is determined by setting the potential barrier, \( eV_o \), equal to the electron’s kinetic energy. Thus equation (1) can be rearranged to yield:

\[
eV_o = h\nu - W
\]

If the reverse voltage is more negative than this cutoff voltage, \( V_o \), no current flows. Note that, \( V_o \) is a linear function of frequency, as observed experimentally. Measuring \( V_o \) as a function of frequency should provide values for \( h \) and \( W \) as shown in figure 2.
Procedure

1. The photodiode is very sensitive so the first thing we need to do is calibrate the apparatus. This is done by covering the aperture with a black piece of cardboard or metal to set the zero adjustment on the amplifier. Your hand is not opaque enough. Turn on the amplifier and adjust the right hand "Zero Adjustment" knob until the meter reads zero. The amplifier is quite stable but, since the measurement is made at the scale zero, any drift causes an error. The zero adjustment should be frequently checked during the measurements.

2. Turn the "Voltage Adjustment" knob on the middle of the panel to its counterclockwise limit. The voltmeter should read zero or very close to it. Uncover the aperture. Move the apparatus until the radiation is striking the center of the photodiode. The reading on the output meter is helpful in making the adjustment. The radiation intensity should be adjusted so that the reading on the meter is maximized. Recall that the amplifier gain is high (1 mA on the meter is $5 \times 10^{-9}$ A of photocurrent), so if the meter goes off scale, the photodiode won’t be harmed. The meter won’t be harmed either: the amplifier limits the current delivered to it.

3. Measure the output current as a function of Stopping Voltage. As the voltage increases, fewer and fewer electrons have enough energy to leave the cathode, and the current drops. The critical point on the curve is the voltage at which the current falls to zero.

4. Measure the voltage for zero current five times, resetting the zero after each setting. Be careful not to pass the zero current value. The curve remains at zero for stopping voltages higher than the critical value. The value you need is when the current just reaches zero.

5. Change the wavelength striking the cathode and repeat steps 3 and 4. The 3 wavelengths emitted by the Mercury source are 436nm, 546nm, and 580nm.

What you need to do

1. Collect data for stopping voltage as a function of frequency.

2. Graph and perform a linear fit on the data.

3. Determine Planck’s constant from your fit and compare to the actual value.