The Photoelectric Effect PLG 4/15/09

In this lab, we will investigate the photoelectric effect using a phototube and various light emitting diodes (LEDs). We will use the dependence of stopping voltage on wavelength to determine Planck's constant and verify that the photocurrent voltage depends on light intensity, while the stopping voltage does not.

Background

The photoelectric effect is of historical importance because it was one of the first experiments to provide evidence for the particle nature of light, or in other words, the existence of photons. When light strikes a metal surface, electrons are released. Some of the energy they gain from the light must be used to overcome the binding energy, or work function ϕ, of the metal. Classically, it is expected that the maximum energy of these released photoelectrons should be proportional to the intensity of the light. Also, photoelectrons should be released for light of any wavelength, if the intensity is sufficiently high. However, the experimental reality contradicted these classical predictions. Albert Einstein, in 1905, was able to explain these results by invoking the concept of the photon, a localized bundle containing the light energy. For a given frequency f of the light, the energy of each photon is quantized in a fixed amount given by hf. Here, h is Planck's constant, first introduced by Max Planck in 1900 to explain the spectrum of blackbody radiation. According to Einstein, an electron cannot absorb an arbitrary amount of light energy. It's all or nothing - it either absorbs a photon or it doesn't. Although Einstein is perhaps better known for his work in relativity, he actually won the Nobel Prize in 1921 for his theory of the photoelectric effect. Millikan, also famous for his oil drop experiment measuring the elementary charge, won the Nobel Prize in 1923 for his experimental work on the photoelectric effect and the resulting precise measurement of Planck's constant.

The basic idea of the photoelectric effect is shown in Fig. 1. A metal surface located in an evacuated tube is illuminated by light. Photoelectrons which escape from the surface travel to a nearby electrode (the collector) and are registered as a current. These electrons have a maximum kinetic energy determined by the energy of the photon and the work function of the metal:

$$KE_{max} = hf - \phi. \tag{1}$$

The maximum kinetic energy can be measured by applying a negative repelling (or stopping) voltage, V_s, to the collector. Since the electrons must climb this potential hill eV_s to reach the collector, the current drops to zero as soon as $eV_s = KE_{max}$. Different light frequencies f will result in different values of KE_{max}, and thus V_s. A plot of V_s vs. f should yield a straight line with a slope h/e and an intercept of $-\phi/e$. Knowing the value of the elementary charge e, Planck's constant and the work function can thus be determined.

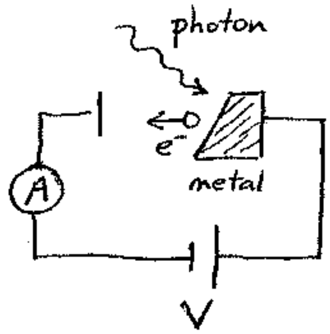

Fig. 1 Schematic of the photoelectric effect experiment

In the experiment, you will use a phototube and a sensitive amplifier to measure the resulting small photocurrents. The light sources are a series of light emitting diodes (LEDs) operating at various wavelengths. You will look at three aspects of the photoelectric effect: 1) measuring the stopping voltage as a function of wavelength in order to determine Planck's constant; 2) determining whether the stopping voltage depends on intensity; 3) measuring the dependence of photocurrent on light intensity.

Apparatus:

The Tel-Atomic EP-05 photoelectric effect apparatus consists of an IP39 phototube and a sensitive amplifier capable of measuring the very small (nanoamp) photocurrents from the tube. There are only two electronic adjustments on the apparatus: the stopping voltage (measured using a digital voltmeter); and the zero level of the photocurrent. The zero level is particularly important when determining the stopping voltage. It must be checked often since slow drifts are unavoidable.

The tube is illuminated through an opening in one end of the box. The light sources are LEDs at various wavelengths. Each LED is in its own box that is designed to slide over the opening in front of the phototube. As shown in Fig. 2, each box also contains a current limiting resistor chosen so that the LED light output provides a reasonable photocurrent reading when connected to the fixed output +5V supply. Note that exceeding 5V for the supply voltage risks burning out the LED. A separate box, shown in Fig. 3, allows adjustment of the LED current and thus the light intensity illuminating the phototube. It is used in the second and third portions of the lab. The circuit consists of a simple variable voltage divider and also allows the LED current to be measured via a 10Ω sense resistor.

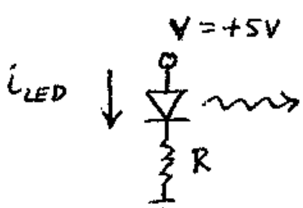

Fig. 2 LED circuit

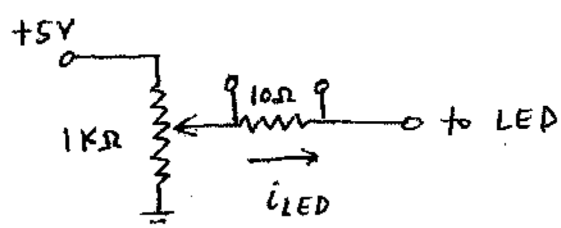

Fig. 3 Circuit for varying LED current

Procedure:

For the first portion of the lab, you will measure the stopping voltage for each of the LEDs when hooked up to the fixed +5V supply. This basically consists of finding the voltage at which the photocurrent goes to zero. Note that the photocurrent does not go to zer abruptly becase not all photoelectrons have the maximum possible kinetic energy. Most of them lose additional energy in escaping from the metal. Finding the zero of current sounds easy, but must be done carefully. It is suggested that for each LED you plot current vs. voltage and make a linear extrapolation of the last few points to find the zero intercept. This can be compared to several trials (by both team members) of simply trying to find the zero by continuously increasing the voltage. Estimate the uncertainties in your stopping voltages. Note that it is important to frequently check the zero level of the photocurrent. This can be done by either setting the voltage to a high value or by turning off the LED.

For the second portion of the lab, you will check the dependence of the stopping voltage on the light intensity. Select one of the LEDs and hook it up to the box that allows the current to be varied. Determine the stopping voltage, as in the previous section, for four different levels of light intensity. Note that at the low currents used here, the power emitted by an LED, and therefore the intensity illuminating the phototube, is proportional to the current through the LED. This current is measured via the voltage across the 10Ω sense resistor. Use a DVM to measure this voltage, being sure not to ground either terminal.

For the third portion of the lab, you will measure the photocurrent as a function of the light intensity. As in the previous section, select one of the LEDs and use it with the variable current box. Set the retarding voltage to zero so that all of the photoelectrons are allowed to reach the collector. Measure the photocurrent as a function of the LED current (ten data points should suffice), noting again that for the low currents we are using, the light intensity is proportional to the LED current.

Analysis:

Plot the stopping voltage vs. frequency and use the best linear fit to determine both Planck's constant and the effective work function for the phototube. Also give your uncertainties for these quantities. Note that unlike atomic spectral lines, an LED does not have a precisely defined wavelength. Their emission spectra are typically 20 nm wide. Comment on how this might affect your results.

Plot the stopping voltage vs. LED current and comment on the dependence.

Plot the photocurrent as a function of LED current. Is the data well described by a linear fit?