Lab 5: Photoelectric Effect

Purpose

- to observe the particle nature of light
- to determine Planck's constant
- to obtain the work function of a metallic photocathode

Equipment

EP-05 Photoelectric Effect apparatus   digital multimeter   four interference filters
semiconductor lasers: red (650 nm) & green (532 nm)   mercury arc lamp
light blockers on both corridor windows   file folder (to shield the lamp)

Procedure (*adapted from Daedalon Corp. Instruction Manual for EP-05*)

1. Set up the EP-05 Photoelectric Effect (PE) Apparatus on a table so that the aperture in front of the photodiode faces the mercury arc lamp. The phototube is very sensitive to small amounts of stray radiation, particularly shorter wavelengths than those being measured. The minimum detectable current is of the order of $5x10^{-10}$ A. The schematic of the apparatus is shown in Fig. 1.

2. Connect a digital voltmeter to the PE apparatus. The terminals are connected across the photodiode and measure the <u>stopping potential</u> across the tube.

3. *Caution: the mercury arc lamp emits ultraviolet radiation that is harmful to your eyes.* Construct a cardboard shield to cover the sides of the lamp, then turn the lamp on.

4. On an optical component holder, place the 436-nm interference filter as close as possible to the photodiode aperture. The <u>shiniest</u> side should face the light source. The filter allows the selected wavelength ±5 nm to pass through. Be careful not to touch the glass surfaces of the filter.

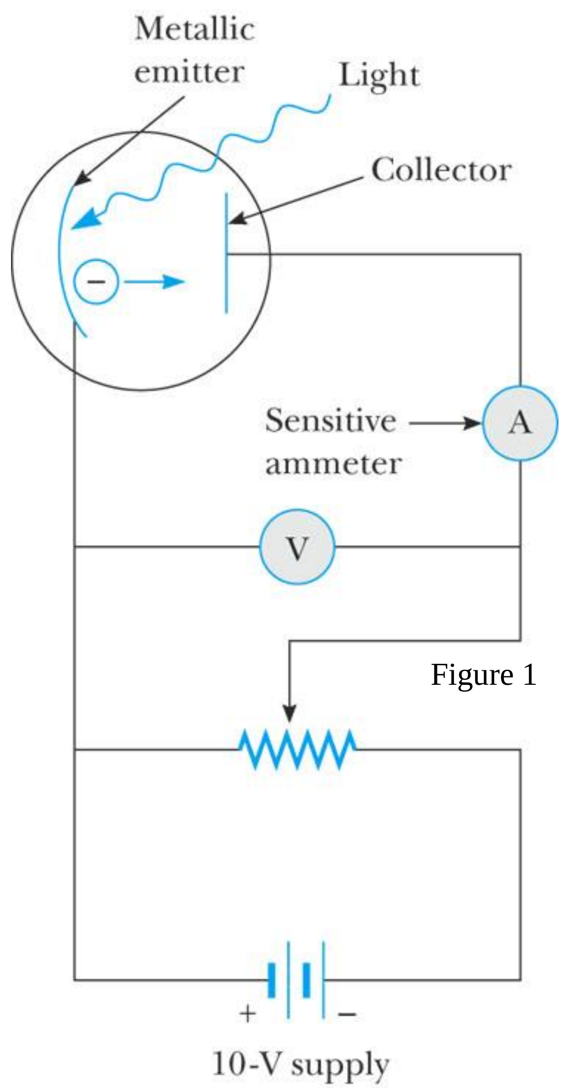

Figure 1

5. Turn off the room lights (first check if all the lab groups are ready).

6. All photocells have some dark current, which arise because of the random generation of charge carriers within the device. To eliminate dark current, you will need to zero the meter. Turn on the PE Apparatus. Set the VOLTAGE ADJUST knob to a voltage high enough so that the needle pointer does not move when the voltage is increased further. At such a voltage, even the most energetic photoelectrons are stopped and any remaining current represents dark current. Next, turn the "ZERO ADJUST" knob so that the needle pointer is over the zero, thus eliminating dark current.

   Note: The zero adjustment should be frequently checked during the measurements. If the zero drifts between readings, the radiation intensity on the photosurface is too high and a phenomenon known as fatigue is occurring. Reduce the intensity by moving the light source away from the aperture. The amplifier is quite stable but, since the measurement is made at the scale zero, any drift causes an error.

7. Turn the VOLTAGE ADJUST knob to its counterclockwise limit (the voltmeter should read 0 or very close to it). Align the apparatus until the radiation is striking the center of the photodiode. The radiation intensity should be adjusted so that the meter reading is as high as possible. If the meter goes off scale, the photosurface won't be harmed. The meter won't be harmed either, since the amplifier limits the current delivered to it.

8. Slowly turn the VOLTAGE ADJUST knob to increase the voltage and monitor the output current. (In Fig. 1 this is symbolized by moving the arrow above the resistor.) As the voltage increases, fewer and fewer photoelectrons have enough energy to leave the cathode, and the current drops. The critical point is the voltage at which the current just falls to zero (stopping voltage, V_s). The current remains at zero for voltages higher than V_s. Try to vary the applied voltage in sufficiently small increments so that you can determine V_s as precisely as possible.

9. Repeat the procedure in step 7 additional three times, each time measuring and recording the stopping voltage for zero current, and resetting the zero if needed. In Table 1, record the average value of the stopping potential from the four measurements.

10. Repeat steps 4 - 8 using the 405 nm, 546 nm and 577 nm interference filters. Record the stopping potentials in Table 1.

11. Replace the mercury lamp with the green diode laser (532 nm). Place the green plastic filter <u>over the photodiode aperture</u>. Repeat steps 4 - 8 to measure the stopping potential. Record in Table 1.

12. Replace the green laser with the red diode laser (650 nm) and the green filter with the red filter. Repeat steps 4 -8 to measure the stopping potential and record in Table 1.

13. Using your data, plot V_s vs. $(1/\lambda)$ and perform a linear fit ($y = mx + b$). Recall that the photoelectric equation is:

$$\frac{\mathrm{hc}}{\lambda} = \mathrm{e} \cdot \mathrm{V_s} + \Phi$$

where the charge of the electron $e = 1.602 \cdot 10^{-19}$ C and the speed of light in vacuum $c = 2.998 \cdot 10^{8}$ m/s. The above equation can be rewritten as:

$$\mathrm{V_s} = \left(\frac{\mathrm{hc}}{\mathrm{e}}\right) \cdot \frac{1}{\lambda} - \frac{\Phi}{\mathrm{e}}$$

This is a linear equation of V_s as a function of inverse λ, with the slope equal to $\left(\frac{\mathrm{hc}}{\mathrm{e}}\right)$ and the y-intercept equal to $\left(-\frac{\Phi}{\mathrm{e}}\right)$. Using the coefficients of the fit, determine <u>Planck's constant</u>, h, and <u>work function</u>, Φ, of the metallic surface emitter.

14. Calculate the experimental error in your determination of Planck's constant using the following analysis. For a set of N data pairs (x_i, y_i) the uncertainty in the measurements (y_i) is given by:

$$\sigma_y = \sqrt{\left(\frac{1}{N-2}\right) \sum_{1}^{N} (y_i - m x_i - b)^2}$$

Next, calculate:

$$\Delta = N \sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2$$

and use it to find the uncertainties in the parameters m and b:

$$\sigma_m = \sigma_y \sqrt{\frac{N}{\Delta}} \qquad \text{and} \qquad \sigma_b = \sigma_y \sqrt{\frac{\sum_1^N x_i^2}{\Delta}}$$

(Reference: J.R. Taylor, "An Introduction to Error Analysis," 2nd ed., University Science Books, Sausalito, CA, 1997.)

Data and Analysis (you may include this page in your Lab Notebook)

Table 1

λ (nm)	V_s (V) (average)	$1/\lambda$ (nm^{-1}) $\cdot 10^6$
405		
436		
532		
546		
577		
650		

Results

Slope = $\frac{hc}{e}$ = ___________________

Experimental h = ___________________ Uncertainty σ_h = _________________

Within the calculated uncertainty, does your experimental value for h agree with the accepted value of $6.626 \cdot 10^{-34}$ J·s?

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Work function, Φ = _________________________ (eV)