Experiment 10
Photoelectric Effect

1 Introduction

The experiment on the photoelectric effect was an historical milestone for physics, because it presented a dilemma that the physics of the day (now called classical physics) could not explain, and started the creation of the new physics of quantum mechanics. The experiment involves shining light on a metal plate to excite electrons in the metal. Classical physics predicts that the maximum kinetic energy that the electrons can acquire is proportional to the intensity of the light. In fact, the original investigators found the maximum kinetic energy to be independent of the light intensity and instead proportional to the frequency of the light.

Thus, blue light created more energetic electrons than did red light (which is of a lower frequency). The intensity of the light affected only the number of electrons emitted, but not their energy. Einstein hypothesized that light energy comes in packets called photons whose energy, $E$, is related to the frequency, $f$, by

$$E = hf$$

where $h$ is a constant known as Planck’s constant, which is equal to $6.63 \times 10^{-34}$ joule-seconds. Except in rare situations an electron will only absorb a single photon.

2 Experiment

The experiment uses the phototube shown in Figure 1. When light of a specific frequency (or color) is incident on the photocathode, electrons there will acquire kinetic energy equal to $hf$. Some of these will be traveling in the correct direction to leave the metal. This
requires expending energy $W$—the bonding energy of the electrons to the metal, called the work function. Thus, the electrons ejected from the metal will have kinetic energies up to $hf - W$ (most will have lost some additional energy moving through the metal). Of the ejected electrons, some will travel to the anode and so create a current between the two electrodes. By attaching a power supply to the electrodes and applying a voltage, $V$, which creates a repelling electric field, these electrons can be stopped from reaching the anode if the potential energy of the repelling fields, $eV$, is greater than the maximum electron kinetic energy.

Thus, the minimum stopping voltage, $V_0$, is given by:

$$eV_0 = hf - W$$

By measuring $V_0$ of several different frequencies of light, one should be able to calculate $hf$ and $W$.

3 Procedure

1. In this experiment, we will use light-emitting diodes (LED’s) with 4 different wavelengths. For each wavelength, $\lambda$, the appropriate LED is plugged into a socket in the ‘LED Box’, and directed at the phototube.

2. The LED wavelengths are given in the Table below:

<table>
<thead>
<tr>
<th>Color</th>
<th>$\lambda$, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>697</td>
</tr>
<tr>
<td>Yellow</td>
<td>587</td>
</tr>
<tr>
<td>Green</td>
<td>565</td>
</tr>
<tr>
<td>Blue</td>
<td>430</td>
</tr>
</tbody>
</table>
3. Set up the apparatus as shown in Figure 2. Before inserting an LED, make sure the phototube voltage, and the LED power supply is off. Then pull the LED box off the main chassis, and insert an LED. Turn on the LED power supply (10 volts). If the LED does not produce light, it means it is plugged in backwards. Simply remove the LED from its socket and plug it in with the pins reversed.

4. Return the LED box to its position on the main chassis.

5. The measurements of the tube voltage and current can be directly measured using the ammeter and voltmeter attached to the indicated banana jacks on the apparatus. Before directing the LED light onto the tube it is necessary to zero out the leakage current as much as possible. To do this make sure the LED light is off and turn on the apparatus, the voltmeter and the ammeter. Vary the voltage with the adjustment knob and look at the ammeter. If the ammeter is registering a value when set on the lowest setting (current is in the microamp range), turn the ammeter adjustment knob until the ammeter reads zero. Now you are ready to take data as the circuit leakage current has been effectively removed.

6. With the ammeter on its most sensitive setting, turn on the LED. Vary the voltage until the phototube current goes to zero. This is the stopping potential, $V_0$.

7. For an estimate of the uncertainty in $V_0$, it is OK to use the smallest scale division of the voltmeter.

8. Repeat the above for the three other wavelengths. Graph $V_0$ versus frequency. ($f = \frac{c}{\lambda}$)

9. Do a least-squares fit to determine $\frac{h}{e}$ and its uncertainty. Compare it to the accepted value. Note that the Excel line fitter will determine the slope and intercept, but not their uncertainties. You will need to use the equations given in “Least-squares Fitting Formulas” on the course web site.