LAB 10
The Photoelectric Effect

OBJECTIVES
1. Experimentally verify that the emission of photoelectrons depends only on frequency of the incident light and not the intensity of the light.
2. Experimentally measure Planck’s constant $h$ and the work function $\Phi$ of a metal.
3. Use the PhET simulation to investigate work function and stopping potential.

EQUIPMENT
Photoelectric effect apparatus, digital multimeters, LEDs, PhET Photoelectric Effect Simulation.

THEORY
In photoelectric emission, light strikes a material, causing electrons to get emitted. The classical wave model predicted that if the intensity of incident light were increased, the amplitude and thus the energy of the wave would increase. This would then cause more energetic photoelectrons to be emitted. The new quantum model, however, predicted that higher frequency light would produce higher energy photoelectrons, independent of intensity, while increased intensity would only increase the number of electrons emitted (or photocurrent). In the 1900s several investigators found that the KE of the photoelectrons was dependent on the frequency and independent of intensity. Einstein applied Planck’s theory and explained the photoelectric effect in terms of the quantum model using

$$E = hf = KE_{\text{max}} + \Phi$$

where $KE_{\text{max}}$ is the maximum KE of the emitted photoelectrons, and $\Phi$ is the work function.

In the photoelectric effect experiment, a light photon with energy $hf$ is incident upon an electron in the cathode of a vacuum tube. The electron requires an amount of energy $\Phi$ to escape the cathode, leaving it with a maximum energy of $KE_{\text{max}}$. Normally the emitted electrons reach the anode of the tube, and can be measured as a photoelectric current. However, by applying a reverse potential (“stopping voltage”) $V_{\text{stop}}$ between the anode and the cathode, the photoelectric current can be stopped.

$KE_{\text{max}}$ can be determined by measuring the minimum stopping voltage needed to stop the photoelectrons and reduce the photoelectric current to zero. Relating KE to stopping voltage and the Photoelectric Effect equation gives us:

$$V_{\text{stop}} = \left(\frac{h}{e}\right)f - \frac{\Phi}{e}$$

If we plot $V_{\text{stop}}$ vs. $f$ for different frequencies of light, the y-intercept is equal to $\Phi/e$ and the slope is equal to $h/e$. Coupling our experimental determination of the ratio $h/e$ and
Φ / e with the accepted value for e, we can determine Planck’s constant \( h \) and the work function \( \Phi \).

**PROCEDURE**

Study the photoelectric apparatus carefully and note the interchangeable LED socket and LED intensity switch. These will enable us to control both the wavelength and intensity of the light striking the metal plate. The photocurrent ejected from the plate is measured with a multimeter. An adjustment knob sets the barrier voltage, which is measured with a second multimeter.

**Part 1: Predict the behavior of the photocurrent based on the wave model of light**

We have seen that the wave model of light is very successful at predicting and explaining diffraction and interference patterns, including the amazing operation of diffraction gratings. In this lab, we will use this wave model to predict the behavior of the photocurrent in our photoelectric effect apparatus as we vary the wavelength and intensity of the light striking the photodiode. We will then measure the photocurrent produced by different LEDs at different intensity levels and barrier voltages and compare with our predictions.

Specifically, this is what you will measure for each LED:

- Spectral characteristics (peak wavelength, upper and lower limit wavelengths at 10% of peak)
- Photocurrent at intensity levels 1, 2, 3, & 4
- Stopping voltage at intensity levels 2, 3, & 4

1) Make these predictions now (using the wave model) for later comparison with data:

- How should the photocurrent vary with intensity for a single LED? What does the wave model predict qualitatively?
- How should the stopping voltage vary with wavelength at a given intensity? Again, what does the wave model predict qualitatively?
- How should the stopping voltage vary with intensity for a given wavelength (i.e. a single LED)? What does the wave model predict qualitatively?

2) We have different LEDs. For each LED, analyze the spectrum (peak wavelength, upper and lower limit wavelengths at 10% of peak) from the manufacturer’s website:


Look at **Component LEDs** – the ones we are using in lab are 5mm (T-1 3/4).
Part 2: Measure the stopping voltage at different light intensities.

1) Insert the blue LED in the socket and cover the LED and photodiode with the light-tight cover. Set the intensity switch to 4 (highest setting) and adjust the stopping voltage until the current stops. Record this ‘stopping voltage’. Repeat with intensities 3, 2, and 1.

2) Repeat step 1 using the yellow LED.

3) Use Excel to plot the stopping voltage vs. intensity for both LEDs. Note that it will be a qualitative plot, since we don’t have actual values for intensity.

4) How does the stopping voltage depend on the light intensity for each LED? Compare the measured photocurrent behavior with your predictions from Part 1.

Part 3: Measure photocurrent vs. intensity.

1) Set the stopping voltage to 0V. Record the amount of current at intensity levels 1, 2, 3 and 4 for the blue, yellow, and infrared LEDs.

2) How does the current depend on intensity in general? Why do you think this is so? Compare the measured photocurrent behavior with your Part 1 predictions.

Part 4: Measure the stopping voltages for all LEDs at maximum intensity.

1) Make a table with columns for LED description (color), LED wavelength, LED frequency, and stopping voltage.

2) Using the blue LED, set the intensity switch to 4 and measure the stopping voltage (check to be sure these values agree with your values from Part 2.) Continue adding table rows for each LED at intensity 4 only.

3) Compare the measured photocurrent behavior with your Part 1 predictions.

Part 5: Plot stopping voltage vs. frequency and determine and work function.

1) With your data from part 4, plot the stopping voltage versus frequency (different LEDs) at maximum light intensity in Excel. Compare the trend with your predictions.

2) Which frequency do you think you should use – the 10% high, the peak, or the 10% low? Why? Which frequency will give the electrons the most energy and be the hardest to stop? Why?

3) Determine Planck’s constant and the work function of the cathode plate.
Part 6: The PhET Photoelectric Effect Simulation

1) Open up the PhET Photoelectric Effect Simulation:

   http://phet.colorado.edu/en/simulation/photoelectric

2) The work function of Copper is 4.70 eV. Predict that maximum wavelength that will cause electrons to be ejected from Copper and then test out your predictions using the simulation. Report on your results (both the predicted value and the “experimental” value).

3) Repeat step 2 for Zinc, which has a work function of 4.31 eV.

4) Predict what the stopping potential will be if you shine light of wavelength 150 nm onto the Zinc surface. Report on your results (both the predicted value and the “experimental” value).

5) Determine the identity of unknown target.

Part 7: Blackbody Radiation

All objects above absolute zero emit electromagnetic radiation called blackbody radiation. In this station, you will observe the visible and infrared radiation emitted by three hotplates at different temperatures.

a. Set up the video camera so that it is on the nighttime mode. In this mode, the video camera detects infrared light. Explain why we can use infrared light to help see objects at night.

b. View the three hotplates using both the video camera (IR) and your eyes (visible). Explain your observations of the IR and visible light given off by the three different hotplates in terms of blackbody radiation