Photoelectric Effect

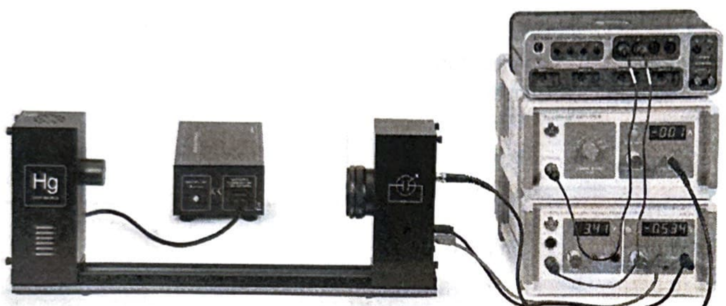
Equipment:

Mercury Lamp and Power Supply (in SE-6609)
Photodiode (in SE-6609)
Track (in SE-6609)
DC Current Amplifier (BEM-5004)
DC Power Supply I (BEM-5001)
850 Universal Interface (UI-5000) NOT USED FOR THIS LAB

Introduction

The photoelectric effect is the emission of electrons from the surface of a metal when electromagnetic radiation (such as visible or ultraviolet light) shines on the metal. At the time of its discovery, the classical wave model for light predicted that the energy of the emitted electrons would increase as the intensity (brightness) of the light increased. It was discovered that it did not behave that way. Instead of using the wave model, treating light as a particle (photon) led to a more consistent explanation of the observed behavior.

In this lab, you will study the effect of varying the frequency has on the energy of the emitted electrons and the magnitude of the photo-current. You will also determine Planck's constant.



Theory

The electrons in a metal are in potential energy wells (see Figure 1A). When light shines on the metal, the energy of the photon is absorbed by the electron and converted into potential energy and kinetic energy. If the photon has sufficient energy to raise the electron out of the potential well, the electron will be ejected from the surface of the metal with kinetic energy (K) equal to the difference between the photon energy (E) and the depth of the potential well (φ, the work function of the metal)(see Figure 1B).

$$K = E - \varphi \qquad (1)$$

The energy of the photon is proportions to its frequency:

$$E = hf \qquad (2)$$

where h is Planck's Constant.

If the energy of the photon is equal to the work function, the electron makes it out of the well with no kinetic energy and thus will not actually leave the surface of the metal. If the energy of the photon is greater than the work function, the electron makes it out of the well with some kinetic energy and the electron leaves the surface of the metal. If the energy of the photon is less than the work function, the electron does not make it out of the well.

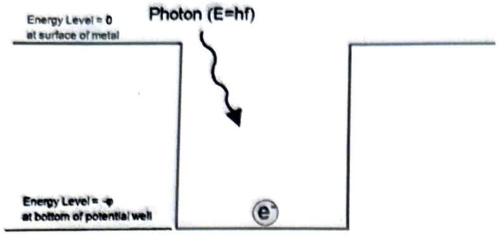


Figure 1A: Photon strikes the surface of the metal.

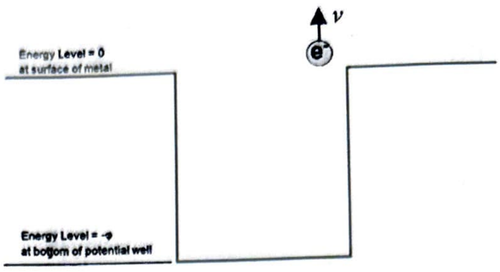


Figure 2B: Electron absorbs the photon and is ejected from the metal with some kinetic energy.

In this experiment, the kinetic energy of the emitted electron is measured by applying a potential difference (V) across the photodiode to just barely stop the electron from reaching the collector plate in the photodiode tube (Figure 2). The voltage is adjusted until the ammeter reads zero. The kinetic energy is then equal to the potential energy, which is the charge multiplied by the potential difference:

$$K = eV \quad (3)$$

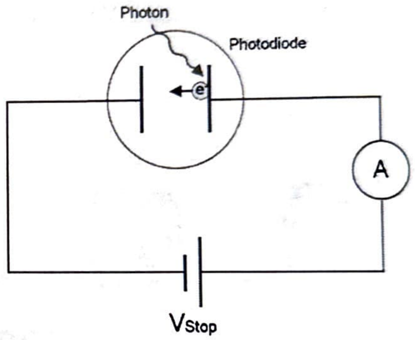
Substituting equations (2) and (3) into equation (1) gives:

$$eV = hf - \varphi \quad (4)$$

Solving for the potential difference yields

$$V = \left(\frac{h}{e}\right) f - \frac{\varphi}{e} \quad (5)$$

If different frequencies of light are incident on the metal, the electrons will be emitted with different kinetic energies, and thus it will take different potential differences to stop the electrons.



Setup

1. Mount the mercury lamp and the photodiode case on the track as shown in Figure 3.

2. Connect the power cord from the Mercury Light Source enclosure into the receptacle labeled "POWER OUTPUT FOR MERCURY ~220V" on the Mercury Lamp Power Supply. Connect the Mercury Lamp Power Supply to an outlet.

3. Turn on the Mercury Lamp and let it warm up for at least 10 minutes. Leave the cover on the lamp to avoid looking directly into the lamp.

4. Do not connect any cords to the photodiode yet.

5. On the DC Current Amplifier, turn the CURRENT RANGES switch to 10^{-13}A. Press the Calibration button in to zero the meter. Turn the knob until the meter reads 000 A (see Figure 4).

6. Press the Calibration button to put it in the OUT position for measuring.

NOTE: For the rest of the experiment, do not change the knobs on the DC Current Amplifier.

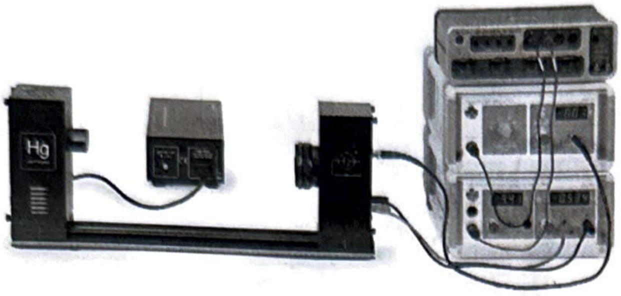


Figure 3: Complete Setup

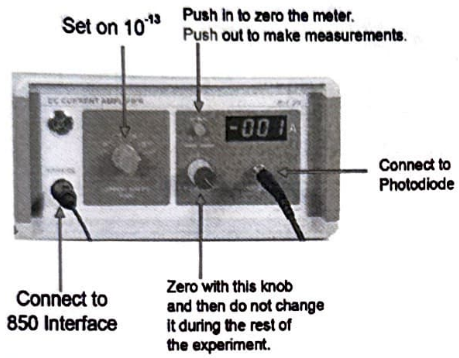


Figure 4: Current Amplifier Settings

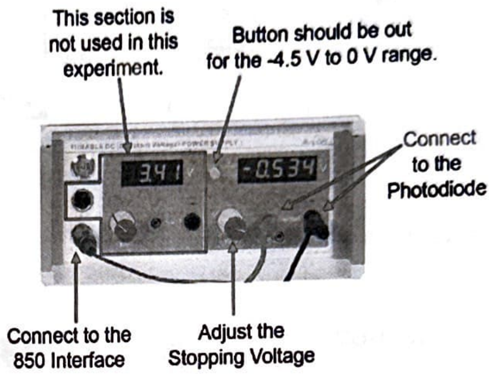


Figure 5: DC Power Supply Settings

7. On the DC Power Supply, make sure the button is out to select the -4.5 V to 0 V range (see Figure 5).

8. Connect the cables to the photodiode:
   a. Connect the special BNC-plug-to-BNC-plug cable between the port marked "K" on the Photodiode enclosure and the BNC jack on the DC Current Amplifier.
   b. Connect the red banana-plug patch cord between the port marked "A" on the Photodiode enclosure and the red banana jack on the right side of the DC Power Supply.
   c. Connect the black banana-plug patch cord between the black banana jack on the Photodiode enclosure and the black banana jack on the right side of the DC Power Supply.

9. During the experiment, you will be changing the aperture and the filters.
   a. To change the aperture, pull out on the Aperture Ring and rotate it until it clicks into place.
   b. To change the filter, do not pull out; just rotate the Filter Ring until it clicks into the next position.

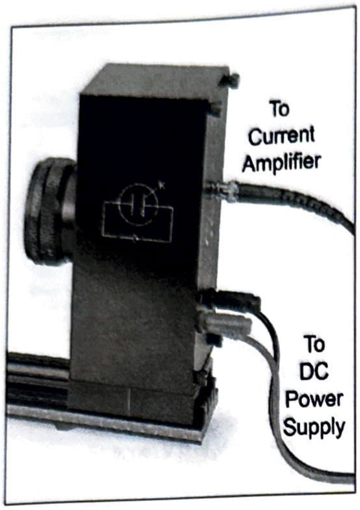


Figure 6: Photodiode Connections

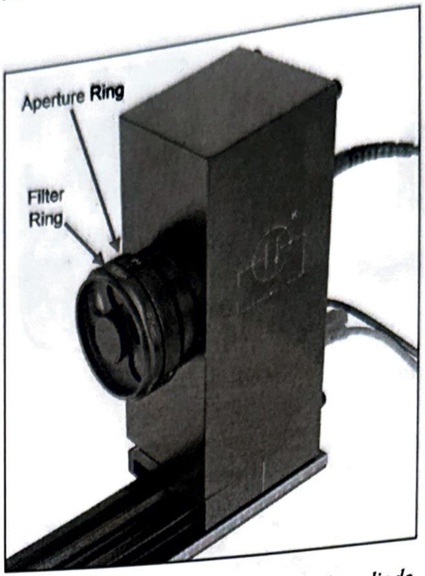


Figure 7: Filter Ring and Aperture Ring on Photodiode

10. Create a graph of Voltage vs. $1/\lambda$.

Data Collection

1. Select the 8 mm aperture and the 365 nm filter on the photodiode.
2. Remove the Mercury Light Source cover.
3. Adjust the VOLTAGE ADJUST knob on the DC Power Supply until the current on the ammeter is zero.
4. Rotate the filter ring to the next longer wavelength filter, click in the next row, and adjust the VOLTAGE ADJUST knob until the current on the ammeter is zero.
5. Repeat the procedure for all the filters three times.
6. Put the cover back onto the Mercury Light Source.

Analysis

1. Apply the fitting program from last week to the data using the standard deviation of your three measurements as your error.
2. Do you get a good fit?
3. Is the slope in agreement with prediction?
4. From the y-intercept, calculate the work function for the metal.