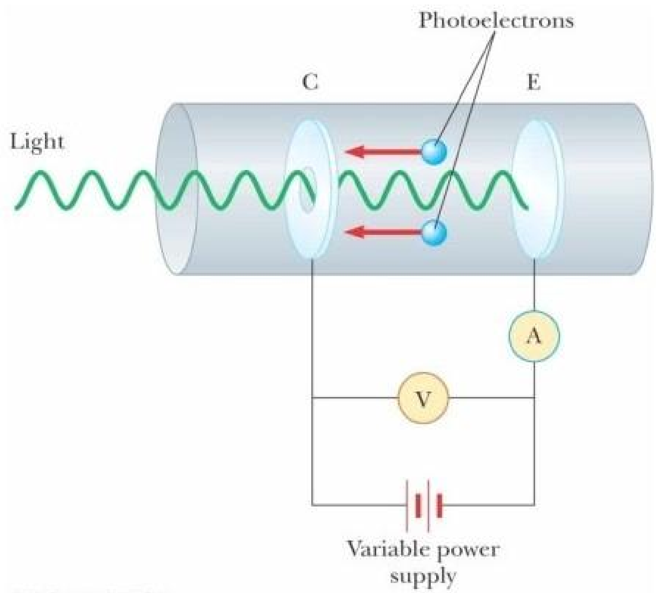
Uncertainty of Measurement and Report Writing

Pei Xian Yang and Arjun Behl
PCS 224-102 Liam Kischuck

Introduction:

The objective of this experiment is to showcase the relationship between the wavelength of light and the voltage required to the applied potential difference that stops the photoelectric current also known as the stopping voltage. This lab will also highlight how accurate Einstein's model of light was compared to the wave model of light.

Theory:



In the above apparatus, when light of appropriate frequency is shined on metal E, electrons are ejected from the metal and collected at plate C. A current is detected by the ammeter A. At a high potential difference, current reaches its maximum value and all electrons emitted from plate E are collected at plate C. When the battery in the circuit is reversed to make plate C negative and plate E positive, the electrons emitted are now repelled by plate C. Only those electrons with kinetic energy more than eΔV (where e is the charge of electrons and ΔV is the potential difference) reach plate C. When the potential difference is equal or more negative than the stopping potential(ΔVs) no electrons reach plate C. The minimum energy required to eject an electron from a particular metal is known as the work function($\boldsymbol{\phi}$). Einstein proposed that light of frequency f can be considered as a stream of photons. He claimed that the energy of light is proportional to its frequency. His hypothesis deviated from the wave model of light which suggested that light behaves as a wave and energy of light depends on the amplitude of the wave. Each photon has an energy E = hf, where h is the planck's constant. Using conservation of energy, we get:

$\Delta K + \Delta U = 0$, where K is kinetic energy and U is potential energy

$= (0 - Kmax) + (- e\Delta V - 0) = 0$

$= Kmax = - e\Delta V,$

$= Kmax = e\Delta Vs$ ….1 , $\Delta V = - \Delta Vs$

The total energy of light emitted at plate E will be equal to the sum of work function and the maximum kinetic energy acquired by an electron that stops just before reaching surface C, upon leaving the metal surface.

$E = Kmax + \boldsymbol{\phi}$ 2

Substituting the value of $Kmax$ from equation 1 we get,

$E = e\Delta Vs + \boldsymbol{\phi}$ 3

$E = hf = hc/\boldsymbol{\lambda}$, where c is the speed of light and $\boldsymbol{\lambda}$ is the wavelength

Substituting the value of E to equation 3 we get,

$hc/\boldsymbol{\lambda} = e\Delta Vs + \boldsymbol{\phi}$

$= hc/\boldsymbol{\lambda} - \boldsymbol{\phi} = e\Delta Vs$

$= hc/e\boldsymbol{\lambda} - \boldsymbol{\phi}/e = \Delta Vs$ ... 4

Comparing equation 4 with equation of straight line(y= mx + c) we get, y = ΔVs, x= 1/$\boldsymbol{\lambda}$, m = hc/e, c = -ϕ/e , where m is slope, c is y-intercept and y and x are lines in coordinate plane.

We will need to measure the stopping voltage of the photocell apparatus and the wavelength of the light source aperture and plot these values on a coordinate grid. Using the best fit line, we can find the slope and the y intercept, which will give us the value of planck's constant and work function. The only calculation, there is uncertainty about is the stopping voltage, which will affect the value of calculated planck's constant. $hc/e = m = \Delta y/\Delta x = \Delta Vs/\Delta(1/\boldsymbol{\lambda})$. As there is no uncertainty associated with wavelength,

$\boldsymbol{\delta} hc/e = m * \boldsymbol{\delta} Vs, \boldsymbol{\delta} h = \boldsymbol{\delta} Vs * me/c = 5.33 * 10^{-28} * m\boldsymbol{\delta} Vs$ 5

The uncertainty for y- intercept will also be equal to the uncertainty of stopping voltage, as they are the same coordinates. $\boldsymbol{\delta\phi}/e = \boldsymbol{\delta} Vs$, $\boldsymbol{\delta\phi} = \boldsymbol{\delta} Vs * e = 1.60 * 10^{-19} * \boldsymbol{\delta} Vs$ 6

Procedure

In this experiment, a digital multimeter, a green and yellow light filter, and banana plugs were used in conjunction with a PASCO photoelectric apparatus. This consisted of a light source and light block, a photodiode apparatus, coupling bars, grating and lens.

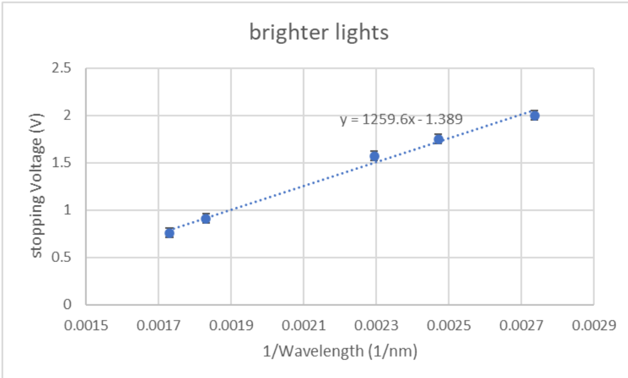
1. Switch on the vapor light source. Keep it on for at least 5 minutes before the start of the experiment.
2. Turn on the multimeter and plug the banana cables into the V and COM ports. Ensure the meter is measuring DC voltage.
3. To check the photodiode battery, perform the following:
   a. Plug the black cable into the ground on the photodiode
   b. Plug the red cable into the “+6 MIN” on the photodiode. If the reading on the multimeter is below 6.0V, replace the battery on the photodiode.

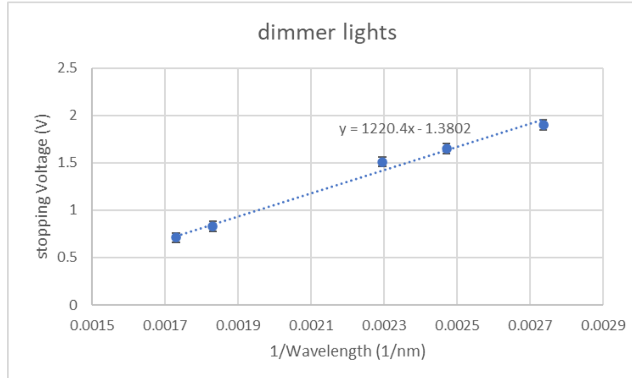
c. Replug the red cable into the “-6 MIN” on the photodiode. If the reading on the multimeter is between -6.0V and 0V, replace the battery on the diode.

4. Plug the cables into the “OUTPUT” on the photodiode. Follow the polarity of the multimeter.
5. By placing a flat surface in front of the lens, the five colors of the mercury spectrum should appear. Three blue/purple, one green, and one yellow/orange light. This pattern repeats on either side of a bright center (white) light. Use the brighter side for measurements.
6. Rotate the coupling bar so the photodiode is across the lens. Focus the lens by sliding it back and forth.
7. Adjust the photodiode so a single wavelength projects into the slit of the photodiode.
8. Move the light shield to reveal the window to the inside of the photodiode, ensure that the light of one color only is entering the photodiode. If adjustment is needed, use the thumbscrew beneath the diode.
9. Once the single wavelength is focused and positioned well, return the shield to its position in front of the window.
10. When measuring the yellow or green light, apply the appropriate filter on top of the photodiode slit.
11. Use the multimeter to measure the stopping potential. The “PUSH TO ZERO” button may be used to obtain more data values. Record the data with uncertainty.
12. Repeat steps 7-11 for all visible lights. Ensure all data is properly labeled.
13. Turn off all components once finished.

Results and Calculation:

	Stopping voltages (Volts):		
Colour:	**Set A:**	**Set B:**	**Uncertainty:**
light purple	2.00	1.90	+- 0.005
purple	1.75	1.65	+- 0.005
blue	1.57	1.51	+- 0.005
green	0.91	0.83	+- 0.005
yellow/orange	0.76	0.71	+- 0.005





Uncertainty of Stopping voltage is 0.005. Using equation 5 we get,

$\boldsymbol{\delta} h = 5.33 * 10^{-28} * 0.005 * 1259.6 * 10^{-9} = 3.36 * 10^{-36}$ for first order

$\boldsymbol{\delta} h = 5.33 * 10^{-28} * 0.005 * 1220.4 * 10^{-9} = 3.26 * 10^{-36}$ for second order

Using equation 6 to find the uncertainty of work function

$\boldsymbol{\delta\phi} = \boldsymbol{\delta} Vs * e = 1.60 * 10^{-19} * 0.005 = 8.00 * 10^{-22}$

<u>Brighter Lights:</u>

Planck's constant: $6.71 * 10^{-34} \pm 3.36 * 10^{-36}$
Percent error: 1.21%

Average work function: $2.07 * 10^{-19} \pm 8.00 * 10^{-22}$

<u>Dimmer Lights:</u>

Planck's constant: $6.50 * 10^{-34} \pm 3.26 * 10^{-36}$
Percent error: 1.96%

Average work function: $2.20 * 10^{-19} \pm 8.00 * 10^{-22}$

$h = \frac{e}{c} \cdot m$

$= (5.33 \times 10^{-28}) \cdot m$

$h = (5.33 \times 10^{-28})(1220.4 \times 10^{-9})$

$= 6.50e^{-34}$

Example calculation for Planck's constant.

$$\phi = \frac{hc}{\lambda} - Ev$$

$$= \frac{(6.5 \times 10^{-34})(299\ 792\ 458)}{(365.5 \times 10^{-9})} - e(1.9)$$

$$= \frac{1.94865 \times 10^{-25}}{365.5 \times 10^{-9}} - (1.602 \times 10^{-19})(1.9)$$

$$= 5.33146 \times 10^{-19} - 3.0438 \times 10^{-19}$$

$$\phi = 2.2876 \times 10^{-19}$$

Example calculation for one of the work constant values used to find the average work value constant of the dimmer lights.

The accepted value fails to fall within the uncertainty range for both calculated values of Planck's constant for both first order and second order, however both values have a small percentage error.

Conclusion:

1. Even though the stopping voltage of bright light is larger than the stopping voltage of dim light, the difference between them is pretty small.
2. The values of the stopping voltages for dim and bright light supports Einstein's model of light which claims that light is more dependent on its wavelength because the stopping voltages of dim and bright light are similar.
3. The threshold frequency is proportional to the work function.

$$hfo = \boldsymbol{\phi},\ fo = \boldsymbol{\phi}/h$$

plugging in values we get the threshold frequency for first order ,

$$fo = (2.07 * 10^{-19})/(6.71 * 10^{-34})$$

$= 3.08 * 10^{14}$

For the second order we get,

$fo = (2.20 * 10^{-19})/(6.50 * 10^{-34})$

$= 3.38 * 10^{14}$

Calculating uncertainty,

$\Delta fo = fo * [(\Delta \boldsymbol{\phi}/\boldsymbol{\phi})^2 + (\Delta h/h)^2]^{0.5}$

$\Delta fo = 1.95 * 10^{12}$, for first order

$\Delta fo = 2.09 * 10^{12}$, for second order

The threshold frequency is inversely proportional to the threshold frequency,

$fo = c/\boldsymbol{\lambda} o$, $\boldsymbol{\lambda} o = c/fo$

Calculating threshold wavelength for the first order,

$\boldsymbol{\lambda} o = 3 * 10^8/3.08 * 10^{14} = 9.74 * 10^{-7}$

Calculating threshold wavelength for the second order,

$\boldsymbol{\lambda} o = 3 * 10^8/3.38 * 10^{14} = 8.88 * 10^{-7}$

Calculating uncertainty ,

$\Delta\boldsymbol{\lambda} o = \boldsymbol{\lambda} * \Delta f/f = 6.17 * 10^{-9}$ for first order

$\Delta\boldsymbol{\lambda} o = \boldsymbol{\lambda} * \Delta f/f = 5.49 * 10^{-9}$ for second order

4. A bright light of a certain wavelength has the same energy as a dim light of the same wavelength. The brightness of light depends on the number of photons rather than on the wavelength of light. A dim light has low amount of photons whereas a bright light has high amount of photons

References:

Physics for Scientists and Engineers with Modern Physics”, by Raymond A. Serway and Jewett, Jr., 10th edition, Thomson, Inc.