Photoelectric Effect

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1 Theory

Our investigation of Planck's constant and the work function of our metal began with the knowledge that the energy of a photon [1] is found from

$$E_{photon} = \frac{hc}{\lambda}, \tag{1}$$

where h is Planck's constant, c is the speed of light in a vacuum, and λ is the photon's wavelength. From introductory physics we know that the wavelength of a photon traveling at speed c is related to frequency as such:

$$\lambda = \frac{c}{f}, \tag{2}$$

and so Equation 1 was rewritten as

$$E_{photon} = hf. \tag{3}$$

From conservation of energy we observed that the kinetic energy of an electron ejected from the metal by a photon of a given energy is found with

$$KE_{electron} = E_{photon} - \phi, \tag{4}$$

where ϕ is the work function, or the energy required to release an electron from a metal. Inserting Equation 2 into Equation 4, and rewriting the kinetic energy of an electron using the logic from the our methods, we obtain

$$eV_{stop} = hf - \phi, \tag{5}$$

which is a linear model that was fit to our data to use the slope and the intercept to find Planck's constant and the work function, respectively.

2 Analysis

Since frequency was not measured directly, but rather wavelength, the uncertainty in the frequency was

$$\delta f = \sqrt{(\frac{\delta c}{c})^2 + (\frac{\delta \lambda}{\lambda})^2}, \tag{6}$$

where δc was taken to be zero, from NIST's value [2] for the speed of light. With Equation 6, the uncertainty in Planck's constant was calculated with

$$\delta h = h\sqrt{(\frac{\delta f}{f})^2 + (\frac{\delta V_{stop}}{V_{stop}})^2}. \tag{7}$$

The current-voltage plot displayed in Figure 1 took the observed shape because the photocell is a diode and requires a certain amount of voltage in the correct direction before current can flow. The shape is also consistent with the idea of the work function, where enough energy must be input to release an electron from a metal.

The wavelengths displayed in Table 1 came from the raw central peak, whereas the wavelengths in Table 2 came from both the FWHM and 2 FWHM (10 percent of the peak) away from the center value. With Python handling the fitting, the slope and the intercept were returned from the linear fit of the data detailed by Equation 5. The value for h, shown in Table 3 was measured to be $(4.3 \pm 0.1) \times 10^{-15}$ eV/Hz, which overlaps with the accepted value [3] after 2σ. Lastly, the work function was determined to be (1.61 ± 0.05) eV.

Wavelength [m]$\times 10^{-7}$	Stopping Voltage [eV]$\times 10^{-1}$
5.67 $\pm$ 0.02	7.45 $\pm$ 0.01
5.90 $\pm$ 0.02	6.12 $\pm$ 0.01
6.10 $\pm$ 0.02	5.99 $\pm$ 0.01
6.37 $\pm$ 0.02	4.76 $\pm$ 0.01
6.49 $\pm$ 0.02	4.08 $\pm$ 0.01
5.17 $\pm$ 0.02	9.98 $\pm$ 0.01
5.04 $\pm$ 0.02	10.59 $\pm$ 0.01
4.66 $\pm$ 0.02	12.93 $\pm$ 0.01
4.53 $\pm$ 0.02	13.35 $\pm$ 0.01
4.00 $\pm$ 0.02	17.19 $\pm$ 0.01

Table 1: Raw Data for central wavelengths and stopping voltage

10 Percent of Peak [m]$\times 10^{-7}$	FWHM [m]$\times 10^{-7}$
5.41 $\pm$ 0.02	5.54 $\pm$ 0.02
5.70 $\pm$ 0.02	5.80 $\pm$ 0.02
5.86 $\pm$ 0.02	5.98 $\pm$ 0.02
6.17 $\pm$ 0.02	6.27 $\pm$ 0.02
6.29 $\pm$ 0.02	6.39 $\pm$ 0.02
4.91 $\pm$ 0.02	5.04 $\pm$ 0.02
4.82 $\pm$ 0.02	4.93 $\pm$ 0.02
4.50 $\pm$ 0.02	4.58 $\pm$ 0.02
4.31 $\pm$ 0.02	4.42 $\pm$ 0.02
3.82 $\pm$ 0.02	3.91 $\pm$ 0.02

Table 2: Data for reduced wavelengths, both at FWHM and 10 percent of the central

Planck's Constant (h) $[\frac{eV}{Hz}]\times 10^{-15}$	Work Function [eV]
4.3 $\pm$ 0.1	1.61 $\pm$ 0.05
4.280 $\pm$ 0.013	

Table 3: Value for Planck's constant first found by linear fit, then SDOM, and Work Function

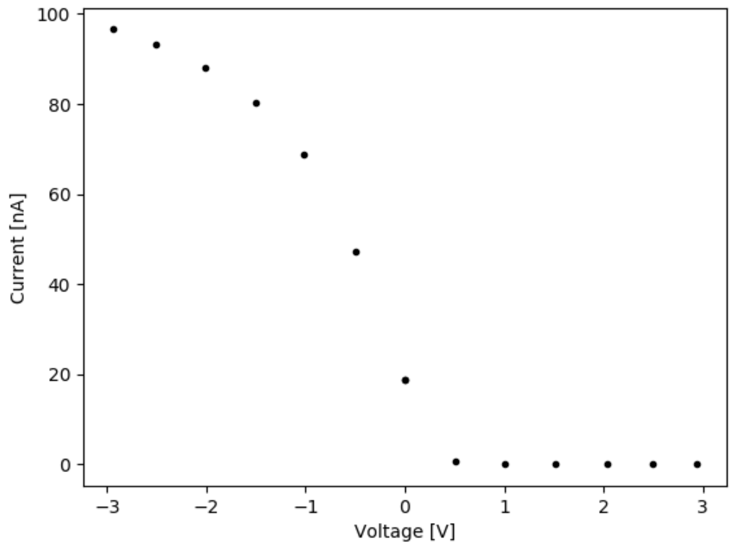

Figure 1: Plot of current vs voltage at 570 nm to find stopping voltage

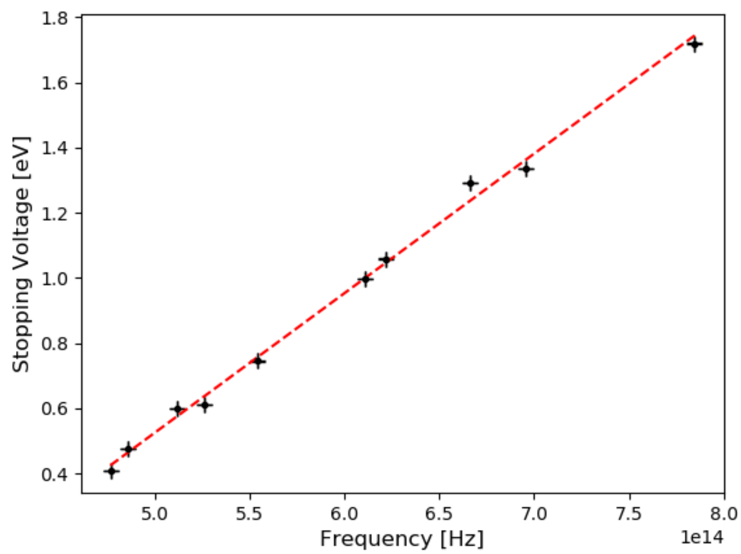

Figure 2: Weighted fit for stopping voltage vs frequency, where the value for h was the slope and the work function was the intercept

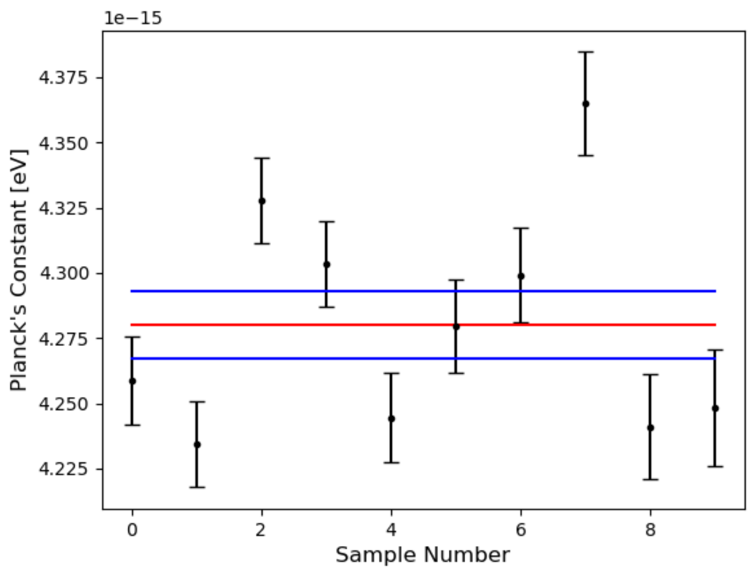

Figure 3: SDOM analysis of Planck's constant

References

[1] Photon - energy education. https://energyeducation.ca/encyclopedia/Photon.

[2] Speed of light. https://physics.nist.gov/cgi-bin/cuu/Value?c.

[3] Planck constant value. https://physics.nist.gov/cgi-bin/cuu/Value?hev.

Appendix: Code

```
import matplotlib.pyplot as plt
import numpy as np
from scipy.optimize import curve_fit
from pint import UnitRegistry
import sys
sys.path.append('../PYTHON_LIBRARIES/')
import qLabTools as ql
ureg = UnitRegistry()

e = 1.602176634e-19
c = 2.99792458e8

## IV Curve
with open('photoelectricIV.csv','r') as iv:
    ivHeader = iv.readline()
    V = []
    dV = []
    I = []
    dI = []
    line = iv.readline()
    while line:
        line = line.split(',')
        V.append(float(line[0]))
        dV.append(float(line[1]))
        I.append(float(line[2]))
        dI.append(float(line[3]))
        line = iv.readline()

## Wavelengths and stopping voltages
with open('photoelectric.csv','r') as pe:
    peHeader = pe.readline()
    wave = []
    halfWave = []
    dWave = []
    vStop = []
```

```python
    dVStop = []
    line = pe.readline()
    while line:
        line = line.split(',')
        wave.append(float(line[0]))
        halfWave.append(float(line[1]))
        dWave.append(float(line[2]))
        vStop.append(float(line[3]))
        dVStop.append(float(line[4]))
        line = pe.readline()

## Cast lists to arrays
wave = np.array(wave)
dWave = np.array(dWave)
halfWave = np.array(halfWave)
vStop = np.array(vStop)
dVStop = np.array(dVStop)


deltaW = wave - halfWave
doubleDelta = halfWave - deltaW
squareDelta = wave - deltaW*np.sqrt(5)
# xData = [wave,halfWave,doubleDelta,squareDelta]
xData = [doubleDelta]
# print(wave)
# print(deltaW)
# print(doubleDelta)

def func(x,A,B):
    return(A*x + B)
def plots(x,y,dVx,dVy,fitFunction):

    popt,pcov = curve_fit(func,x,y,sigma = dVx)
    perr = np.sqrt(np.diag(pcov))
    slopeErr = perr[0]
    p_weight = np.poly1d(popt)
    xtheory = np.linspace(min(x),max(x))
    yfit = fitFunction(xtheory,popt[0],popt[1])

    plt.errorbar(x,y,yerr = dVy, fmt ='b.',capsize = 4)
    plt.plot(xtheory,yfit,'k--')

    print(popt[0])

plt.figure()
```

```
plt.plot(V,I,'k.')
plt.xlabel('Voltage [V]')
plt.ylabel('Current [nA]')
plt.savefig('IVcurve.png')

plt.figure()
for xVals in xData:
    freq = c/(xVals*10**-9)
    plots(freq,vStop,dWave,dVStop,func)
plt.xlabel('Frequencies [Hz]')
plt.ylabel('Stopping Voltage [eV]')
plt.savefig('vStopvsFreqs.png')

freq = c/(doubleDelta*1e-9)
freqUnc = (dWave/doubleDelta)

def wFit(x,h,w):
        return((h*x) - w)

latexTemp, latexRets, numRets = ql.fitPlotter(wFit, freq, vStop,
     [ureg.hertz, ureg.eV], ["Frequency", "Stopping Voltage"],
    uncX = freqUnc, uncY = dVStop)
print(latexTemp)

def valFunction(wavelength, stoppingVoltage):
        return((wavelength/c)*(stoppingVoltage + numRets[1][0]))

def uncFunction(wavelength, stoppingVoltage, deltaWave,
    deltaVolt):
        h = valFunction(wavelength, stoppingVoltage)
        deltaH = h*np.sqrt((deltaWave/wavelength)**2 + (
            deltaVolt/stoppingVoltage)**2)
        return(deltaH)

latexTemp1, latexRets1, numRets1 = ql.sdomPlotter(valFunction,
    uncFunction, ureg.eV, "Planck's Constant", [doubleDelta*1e-9,
     vStop], [dWave*1e-9, dVStop])
print(latexTemp1)

print(ql.latexTable(["Wavelength", "Stopping Voltage"], [
    doubleDelta*1e-9, vStop], [dWave*1e-9, dVStop], [ureg.meter,
    ureg.eV]))
print(ql.latexTable(["Planck's Constant (h)", "Work Function"],
    [[numRets[0][0],numRets1[0]], [numRets[1][0]]], [[numRets
    [0][1], numRets1[1]], [numRets[1][1]]], [ureg.eV, ureg.eV]))
```