Photoelectric Effect

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The objective of this experiment is to demonstrate the quantization of energy in electromagnetic waves and to determine Planck's constant h.

I. INTRODUCTION

It was discovered by Heinrich Hertz that light incident upon a matter target caused the emission of electrons from the target.The effect was termed the Hertz Effect (and later the Photoelectric Effect) and the electrons referred to as photo electrons. It was understood that the electrons were able to absorb the energy of the incident light and escape from the coulomb potential that bound it to the nucleus.

According to classical wave theory, the energy of a light wave is proportional to the intensity of the light beam only. Therefore, varying the frequency of the light should have no effect on the number and energy of resultant photoelectrons. We hope to disprove this classical hypothesis through experimentation, by demonstrating that the energy of light does indeed depend on the frequency of light, and that this dependence is linear with Planck's constant h as the constant of proportionality.

Light comes in discrete packets, called photons, each with an energy proportional to its frequency.

$$E = h\upsilon$$

For each metal, there exists a minimum binding energy for an electron characteristic of the element, also called the work function (W_0). When a photon strikes a bound electron, it transfers its energy to the electron. If this energy is less than the metal's work function, the photon is re-emitted and no electrons are liberated. If this energy is greater than an electron's binding energy, the electron escapes from the metal with a kinetic energy equal to the difference between the photon's original energy and the electron's binding energy (by conservation of energy). Therefore, the maximum kinetic energy of any liberated electron is equal to the energy of the photon less the minimum binding energy (the work function). Expressed concisely the relationship is as such:

$$K_{max} = h\upsilon - W_0$$

When $eVs = K_{max}$ we will cease to see any current through the circuit. By finding this voltage we calculate the maximum kinetic energy of the electrons emitted as a function of radiation frequency.

II. EXPERIMENTAL SETUP

- High pressure mercury lamp with power supply
- Spectrograph with a transmission grating
- Photocell with housing
- Current Amplifier
- Moving coil DC Voltmeter for the current amplifier (0-3 V)
- DC Voltmeter (0-3 V)
- Connecting leads
- Power supply (0-3 V)

TABLE I: Yellow

$Current\ (A10^{-10})$	$Volatge\ (V)$
-0.06	0.800
-0.05	0.745
-0.01	0.460
0	0.405
0.1	0.256
0.2	0.167
0.3	0.105

TABLE II: Green

$Current\ (A10^{-10})$	$Volatge\ (V)$
-0.12	1.705
-0.10	0.977
-0.05	0.565
0	0.491
0.10	0.405
0.15	0.374
0.30	0.298

III. DATA AND ANALYSIS

Our experiment has some data for each color:

I used V_s error as 0.02 V in finding stopping voltage is fitted graphs.

Any linear regression $y = mx + b$ calculated from our input variables and errors outputs an uncertainty on m and on b. In the case of finding the intersection of two linear regression lines $y = m_1x + b_1$ and $y = m_2x + b_2$, the error propagation formula was used to derive the following result for error on the X-coordinate of the intersection point in 2-D space:

$$\sigma_x^2 = \left(\frac{1}{m_1 - m_2}\right)^2 \sigma_{b_2}^2 + \left(\frac{1}{m_1 - m_2}\right)^2 \sigma_{b_1}^2 + \left(\frac{b_2 - b_1}{(m_1 - m_2)^2}\right)^2 \sigma_{m_1}^2 + \left(\frac{b_2 - b_1}{(m_1 - m_2)^2}\right)^2 \sigma_{m_2}^2$$

From these way I found :
By Using Table VI values, I fitted values to estimate h and W_0 with errors in such $y = max + n$

$$V_s = \frac{h}{q}\upsilon - \frac{1}{q}W_0$$

TABLE III: Turquoise

$Current\ (A10^{-10})$	$Volatge\ (V)$
-0.02	2.129
-0.015	1.292
-0.010	0.908
0	0.594
0.05	0.367
0.10	0.237
0.15	0.095

TABLE IV: Blue

$Current\ (A10^{-10})$	$Volatge\ (V)$
-0.15	1.961
-0.10	1.268
-0.05	1.103
0	1.008
0.05	0.968
0.10	0.925
0.20	0.859

TABLE V: Violet

$Current\ (A10^{-10})$	$Volatge\ (V)$
-0.05	1.495
-0.02	1.281
-0.01	1.220
0	1.119
0.05	1.022
0.10	0.920
0.20	0.811

where $h = 1.6x10^{-19}m$, $\sigma_h = 1.6x10^{-19}\sigma_m$,$W_0 = -n$ and $\sigma_{W_0} = \sigma_n$

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This 'Planck's Constant Estimation' plot shows the values:

IV. RESULTS

Our experiment verified our hypothesis. We observed light behave as if it were a particle (not a wave) in its interaction with matter. We were able to demonstrate for light the linear dependence of its energy on its wavelength and determine to some accuracy the constant of proportionality. The actual value of Planck's constant fell inside of our errorbars, which is more than ideal. Our final uncertainty on the value proved to be 14.8% of the value itself. This is very small and makes the task of drawing solid conclusions difficult to believe to be close to the real value.

$$error = \frac{|(6.63-5.74)x10^{-34}|}{6.03x10^{-35}} = 14.8\%$$

Acknowledgments

I would like to thank my partner Kadir Simsek for his help to the experiment, and also to the teaching assistant Saime Sarikaya for her guidance during the experiment.

V. REFERENCES

- E. Gulmez, "Advanced Physics Experiment", Istanbul, Bogazici University Publication, 1999
- http://web.mit.edu/8.13/www/experiments.shtml

VI. APPENDIX

Python code for each color (example belongs to green) V vs. I plot

FIG. 1: Yellow

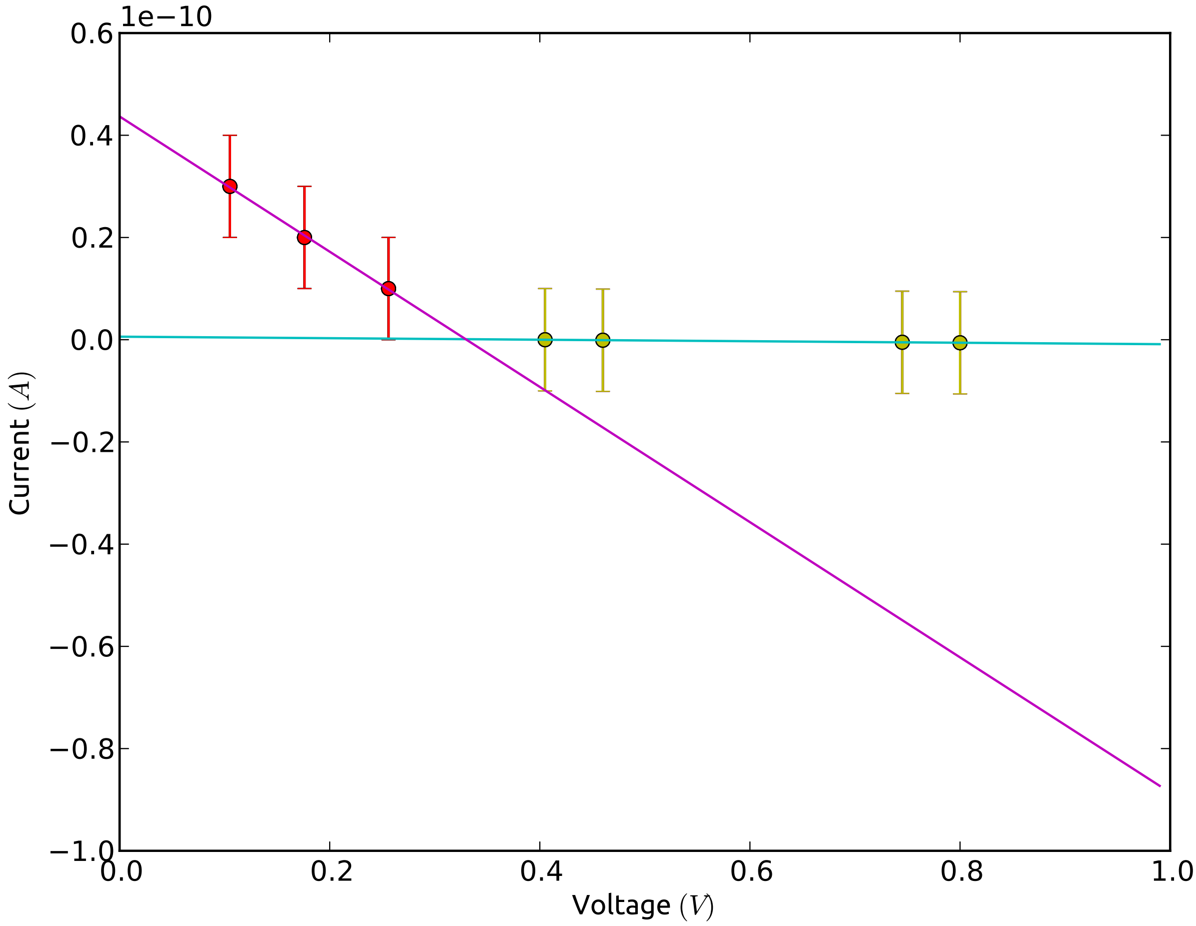


TABLE VI: Voltage Stopping

	Yellow	Green	Turquoise	Blue	Violet
$V_s(V)$	0.329	0.471	0.596	1.025	1.069
$\sigma V_s(V)$	0.020	0.026	0.053	0.096	0.150
$\upsilon(10^{14}Hz)$	5.19	5.49	6.08	6.88	7.41

```
from pylab import *


def VS(m1,n1,m2,n2):
    return abs(n1-n2)/abs(m1-m2)

def sigmavs(m1,n1,m2,n2,sm1,sn1,sm2,sn2):
    return sqrt( (1/(m1-m2))**2*(sn1)**2 + (-1/(m1-m2))**2*(sn2)**2 + ((n2-n1)/(m1-m2)



def analysis(x,y):
```

FIG. 2: Green

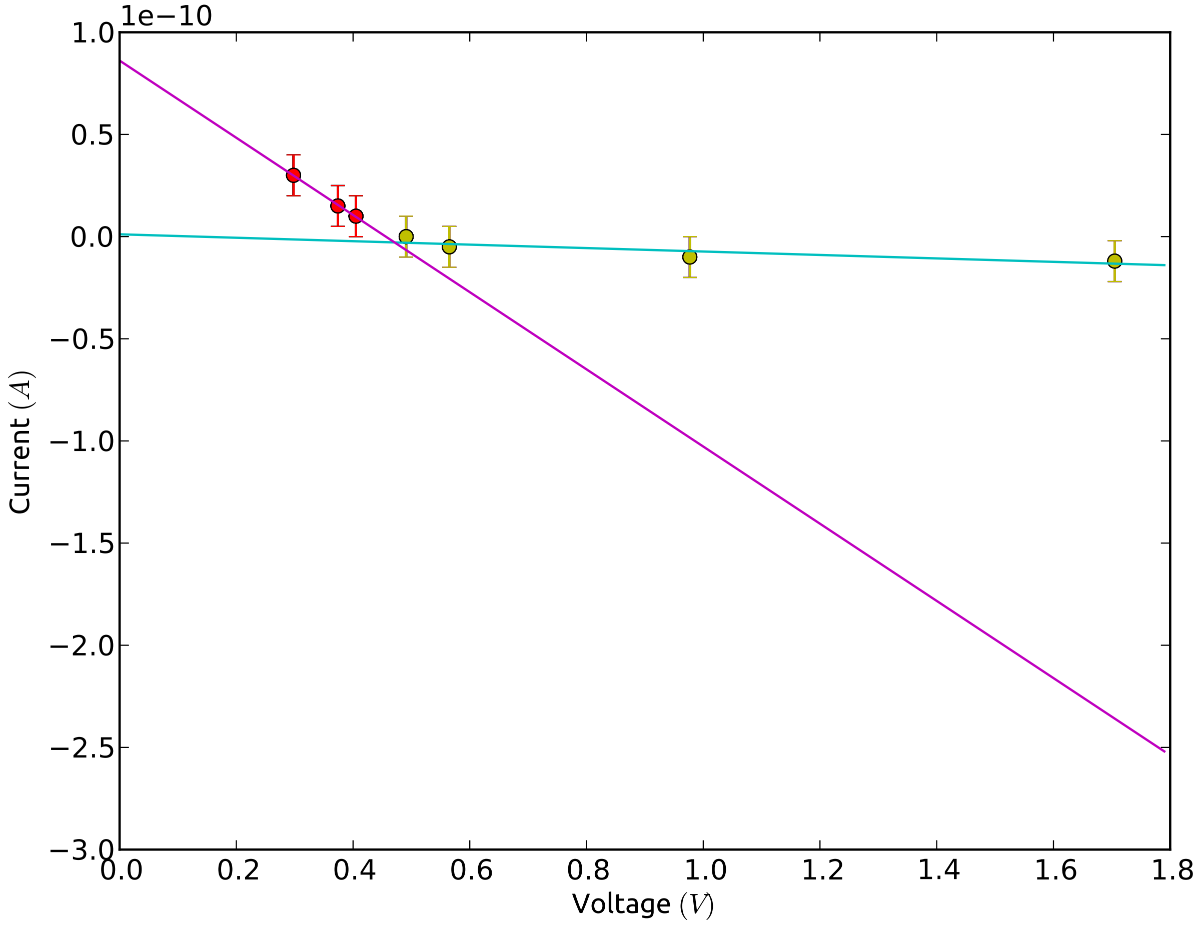
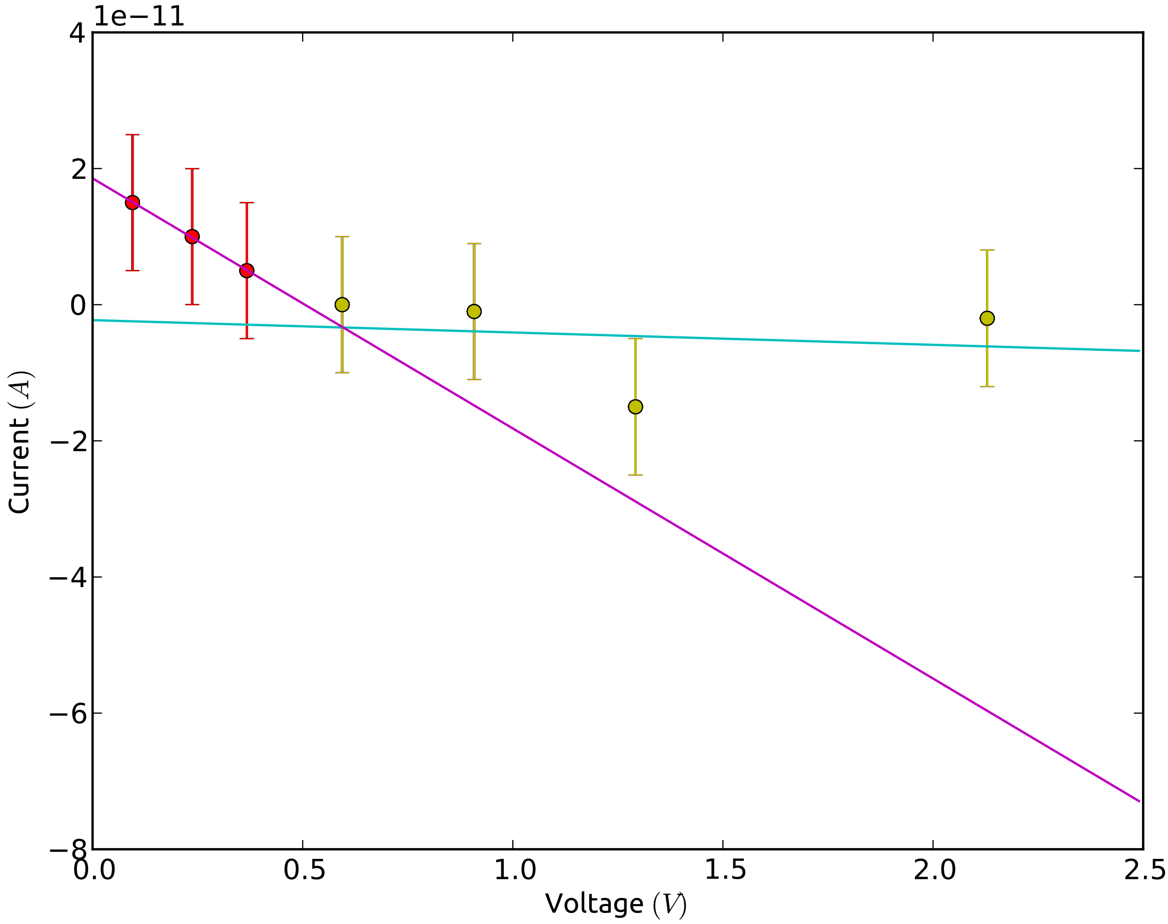


TABLE VII: Planck's Constant and Errors

h	W_0	σ_h	σ_{W_0}
$5.74x10^{-34}$	1.527	$6.03x10^{-35}$	0.205

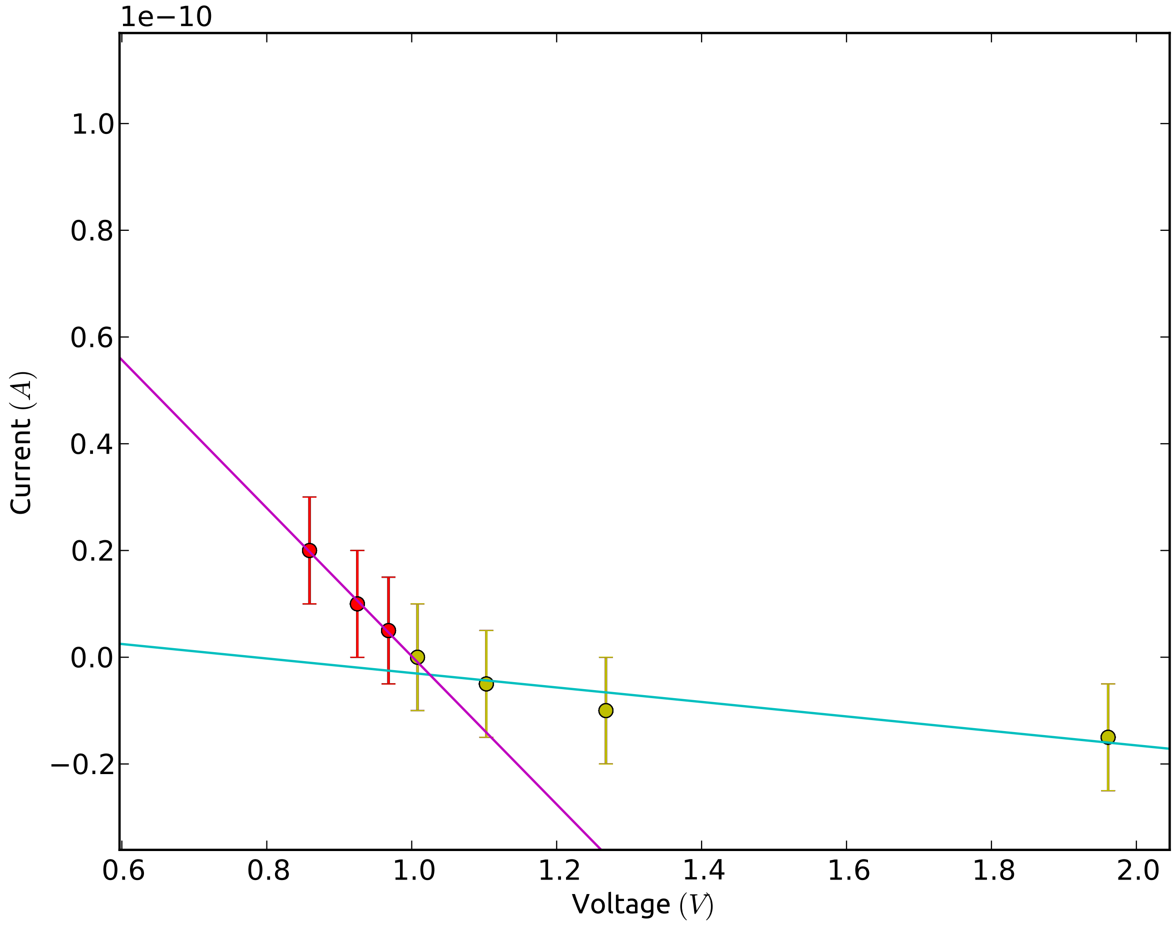
```
sy=ones(len(y))*1e-11
S   = sum(1 / sy**2)
Sx  = sum(x / sy**2)
Sy  = sum(y / sy**2)
Sxx = sum(x**2 / sy**2)
Sxy = sum(x*y / sy**2)

delta = S*Sxx - Sx**2

n = (Sxx*Sy - Sx*Sxy) / delta
m = (S*Sxy - Sx*Sy) / delta

sn = sqrt(Sxx / delta)
sm = sqrt(S / delta)
```

FIG. 3: Turquoise



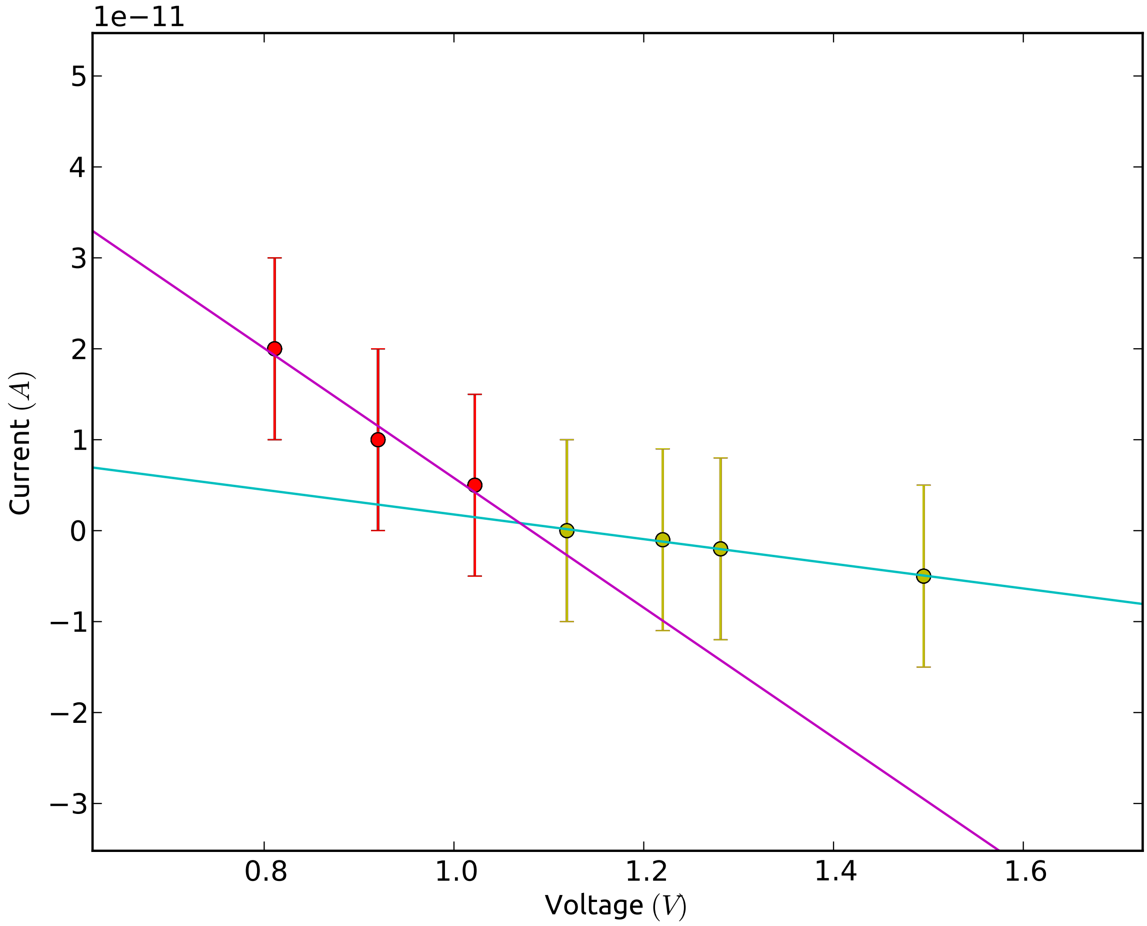

```
    errorbar(x,y,yerr=sy,fmt='o')

    xx = arange(0,1.8,1e-2)
    yy = n + m*xx



    return yy,m,n,sm,sn



x=[[1.705,0.977,0.565,0.491],[0.405,0.374,0.298]]
y=[[-0.12,-0.10,-0.05,0.0],[0.1,0.15,0.30]]

yy=analysis(array(x[0]),array(y[0])*1e-10)[0]
yy1=analysis(array(x[1]),array(y[1])*1e-10)[0]
```

FIG. 4: Blue




```
m1=analysis(array(x[0]),array(y[0])*1e-10)[1]
n1=analysis(array(x[0]),array(y[0])*1e-10)[2]
sm1=analysis(array(x[0]),array(y[0])*1e-10)[3]
sn1=analysis(array(x[0]),array(y[0])*1e-10)[4]
m2=analysis(array(x[1]),array(y[1])*1e-10)[1]
n2=analysis(array(x[1]),array(y[1])*1e-10)[2]
sm2=analysis(array(x[1]),array(y[1])*1e-10)[3]
sn2=analysis(array(x[1]),array(y[1])*1e-10)[4]

print 'Vs'+str(VS(m1,n1,m2,n2))
print 'Sigma Vs'+str(sigmavs(m1,n1,m2,n2,sm1,sn1,sm2,sn2))

xx=arange(0,1.8,1e-2)

plot(xx,yy)
plot(xx,yy1)
xlabel('Voltage $(V)$',fontname='Ubuntu')
ylabel('Current $(A)$',fontname='Ubuntu')

show()
```

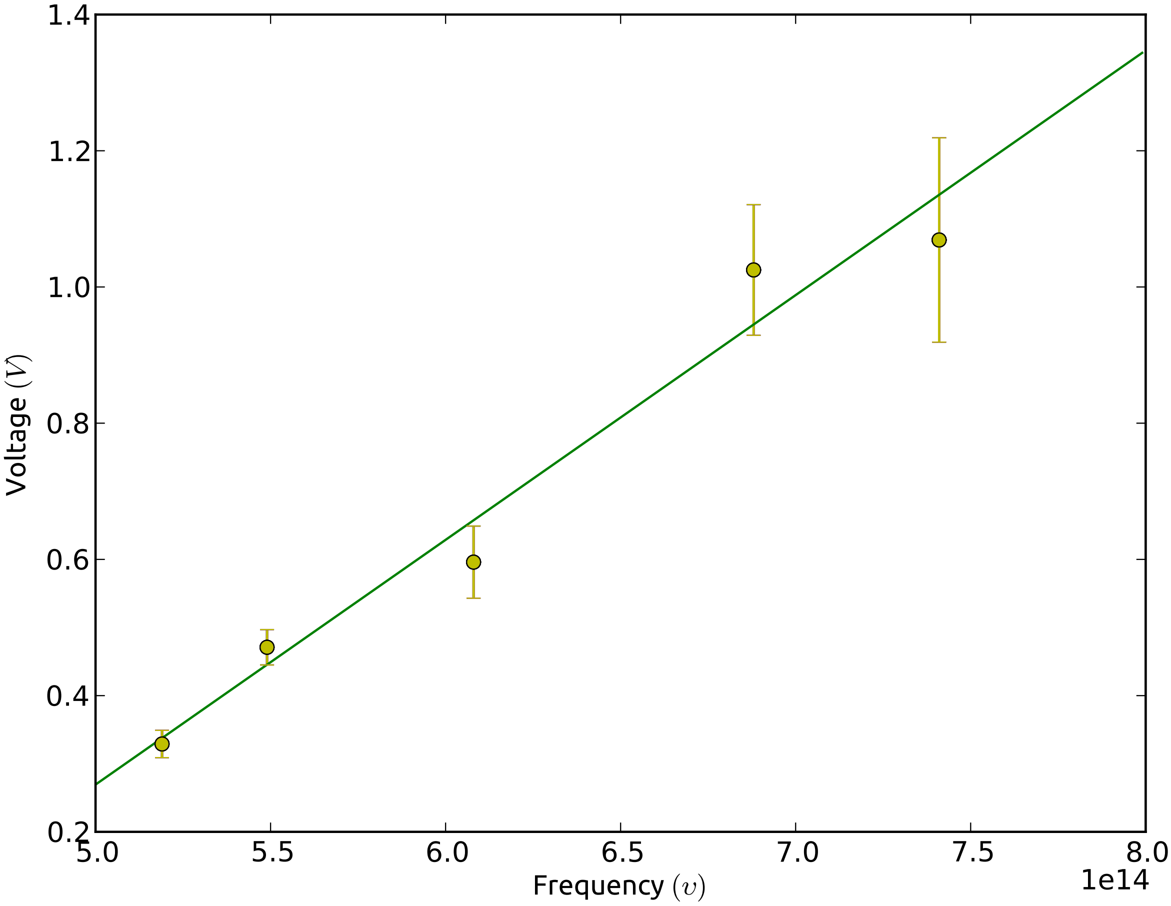
FIG. 5: Violet



Python code for v vs. V plot:

```
from pylab import *

def analysis(x,y,sy):


    S   = sum(1 / sy**2)
    Sx  = sum(x / sy**2)
    Sy  = sum(y / sy**2)
    Sxx = sum(x**2 / sy**2)
    Sxy = sum(x*y / sy**2)

    delta = S*Sxx - Sx**2

    n = (Sxx*Sy - Sx*Sxy) / delta
    m = (S*Sxy - Sx*Sy) / delta

    sn = sqrt(Sxx / delta)
    sm = sqrt(S / delta)
```

FIG. 6: Planck's Constant Estimation




```
    errorbar(x,y,yerr=sy,fmt='o')

    xx = arange(5e14,8e14,1e12)
    yy = n + m*xx


    return yy,m,n,sm,sn

y=array([0.329,0.471,0.596,1.025,1.069])

sy=array([0.020,0.026,0.053,0.096,0.150])*10

x=array([5.19,5.49,6.08,6.88,7.41])*1e14


yy=analysis(x,y,sy)[0]

xx = arange(5e14,8e14,1e12)
```

```
plot(xx,yy)
xlabel('Frequency $(\upsilon)$',fontname='Ubuntu')
ylabel('Voltage $(V)$',fontname='Ubuntu')


print analysis(x,y,sy)[1]*1.6*1e-19
print analysis(x,y,sy)[2]*(-1)
print analysis(x,y,sy)[3]*1.6*1e-19
print analysis(x,y,sy)[4]




show()
```