Photoelectric Effect Experiment

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***Abstract*—The experiment aims at calculating the ratio of Planck Constant(h) to charge of the electron(q). The experiment is conducted by removing an electron from surface by hitting the surface with light beam with energy $h\nu$ and then applying a stopping potential V_s to stop the emmited electrons. We have found the ratio to be $1.037x10^{-15} \pm 1.702x10^{-17}$ V/ Hz compared to the theoretical value of 4.13610^{-15} J C Hz. Our result was 304.28 sigmas away from the recommended value.**

I. Theory

The discovery of photoelectric effect did not come out of nothing. There were already some discovered of the properties of materials due to the exposure of light upon them such as photovoltaic effect and photoconductivity which were discovered by Alexandre Edmond Becquerel and Willoughby Smith respectively in the 19th century. It is not till 1887 that the photoelectric effect was first observed by the famous physicist Heinrich Hertz after he noticed the absorption of UV radiation by glass. This observation by Hertz stimulated the scientists to study the phenomena and many research was going on at the time, which resulted in the discovery of the properties of the complex phenomena called photoelectric effect. 5 Years after the suggestion that the energy carried by electromagnetic waves can only be in packets of energy by Planck, Albert Einstein explained, in 1905, the photoelectric effect observed in the experiments in his most famous paper named "On a Heuristic Viewpoint Concerning the Production and Transformation of Light". He claimed that the energy is carried in discrete quantized packets, which happened to be the foundation of quantum mechanics. Those quantized energies, as Einstein theorized, is equal to the frequency of light times a constant, which was named later as Planck Constant. ın 1914, the results of Millikan's experiments agreed with the theoretical Planck Constant in Einstein's theory. Both Einstein and Millikan got Nobel prize for these studies in 1921 and 1923 respectively.[1]

As stated above, the energy of photon is:

$$E_{photon} = h\nu \tag{1}$$

Kinetic energy formula applies for the emmited electrons

$$E_{kinetic} = \frac{1}{2}mv^2 \tag{2}$$

W,work function, is the energy to remove an electron from the material. So, the highest kinetic energy of the electron is:

$$K_{maximum} = h\nu - W \tag{3}$$

If we apply a V_s,stopping voltage, in order to stop the emmited electrons, energy qV_s must be equal to the kinetic energy of the electron so:

$$h\nu = W + qV_s \tag{4}$$

Therefore, at the end of the day, we end up with:

$$\frac{h}{q}\nu = \frac{W}{q} + V_s \tag{5}$$

It can be easily seen that there exists a linear relationship between $\frac{h}{q}$ and V_s.

II. Method

We first have created the light and then separated it to different colors by reffraction inside the photocell. Because the main purpose of the experiment is to measure Planck constant, we get V_s values for different wavelengths, which are, in our experiment, yellow, green turquoise,blue and violet, in the given order. After the electron is removed as a result of the light hitting, then we take the voltage and current values from voltmeter and current amplifier

1) Light is produced by high-pressure mercury lamp
2) Light is refracted to different colors
3) Photocel is adjusted so that the desired color falls on the metal
4) Voltage is increased from 0 to 3.000 V by adjusting the moving coil
5) The Voltage value, which is equal to 10^9 times that of the current value, from the current amplifier
6) The same process is done with the light of different wavelength

III. The Experimental Setup

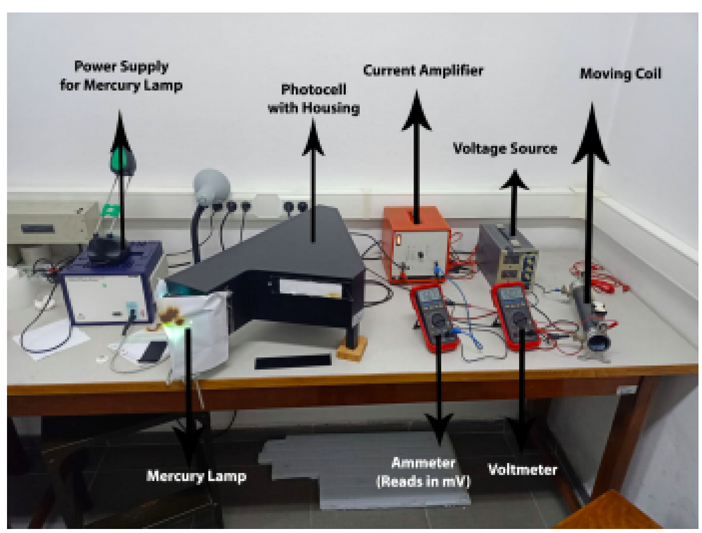

Fig. 1. Apparattus

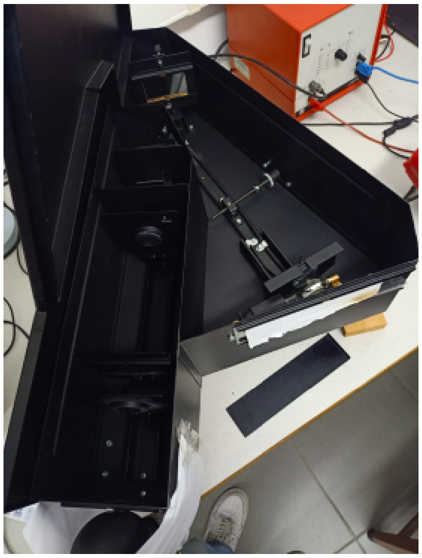

Fig. 2. photocell

- High-pressure mercury lamp with power supply
- Spectrograph creating different wavelengths of lights
- Photocell
- Current Amplifier
- Moving coil
- DC Voltmeter
- Voltage Source

IV. The Data

Here are the current and voltage values taken in the experiment. Our current amplifier reads in mV so we have to convert it to its equivalent current value(which is $10^{-}9$ times of the given value)

TABLE I
VOLTAGE AND CURRENT VALUES FOR GREEN

Voltage(mV)	Current(10^{-12}A)
210.4 $\pm$ 0.1	2.88 $\pm$ 0.01
241.7 $\pm$ 0.1	2.75 $\pm$ 0.01
273.8 $\pm$ 0.1	2.42 $\pm$ 0.01
304.9 $\pm$ 0.1	2.11 $\pm$ 0.01
314.1 $\pm$ 0.1	1.64 $\pm$ 0.01
343.3 $\pm$ 0.1	1.29 $\pm$ 0.01
368.4 $\pm$ 0.1	1.08 $\pm$ 0.01
397 $\pm$ 1.	0.52 $\pm$ 0.01
421 $\pm$ 1.	0.36 $\pm$ 0.01
451 $\pm$ 1.	0.31 $\pm$ 0.01
563 $\pm$ 1.	-0.27 $\pm$ 0.01
1051 $\pm$ 1.	-0.97 $\pm$ 0.01
1403 $\pm$ 1.	-1.16 $\pm$ 0.01
1645 $\pm$ 1.	-1.27 $\pm$ 0.01
1917 $\pm$ 1.	-1.32 $\pm$ 0.01
2168 $\pm$ 1.	-1.38 $\pm$ 0.01
2447 $\pm$ 1.	-1.43 $\pm$ 0.01
2617 $\pm$ 1.	-1.83 $\pm$ 0.01
2700 $\pm$ 1.	-1.89 $\pm$ 0.01
2760 $\pm$ 1.	-1.92 $\pm$ 0.01
2816 $\pm$ 1.	-1.96 $\pm$ 0.01
2858 $\pm$ 1.	-1.97 $\pm$ 0.01

Here I gave only the data values for green, for the lights with other wavelengths see appendix.

V. The Analysis

We have measured voltage and current values for 5 different wavelengths of lights. As theory suggests, there is linear relationship between $\frac{h}{q}$ and V_s, Therefore We have reached different V_s by applying the formula:

$$V_s = \frac{m_2 - m_1}{n_1 - n_2} \tag{6}$$

where: $n1$ = slope of the first line $n2$ = slope of the second line $m1$ = the y-intercept of the first line $m2$ = the y-intercept of the second line

Therefore, the uncertainty of stopping voltage V_s is found according to the following formulas[2]:

$$V_s = \frac{m_2 - m_1}{n_1 - n_2} \tag{7}$$

Uncertainty for the upper part:

$$\sigma_{upper}\sqrt{\frac{\sigma_{m_1}^2}{m_1^2} + \frac{\sigma_{m_2}^2}{m_2^2}} \tag{8}$$

Similarly, uncertainty for the lower part:

$$\sigma_{lower} = \sqrt{\frac{\sigma_{n_1}^2}{n_1^2} + \frac{\sigma_{n_2}^2}{n_2^2}} \tag{9}$$

Now, for the error:

$$\sigma_{V_s} = V_s\sqrt{\frac{(\sigma_{upper})^2}{(m_2 - m_1)^2} + \frac{(\sigma_{lower})^2}{(n_1 - n_2)^2}} \tag{10}$$

I have used ROOT's built in function to apply a linear-fit to the linear parts of our datasets, which are the beginning and the end of the graph.

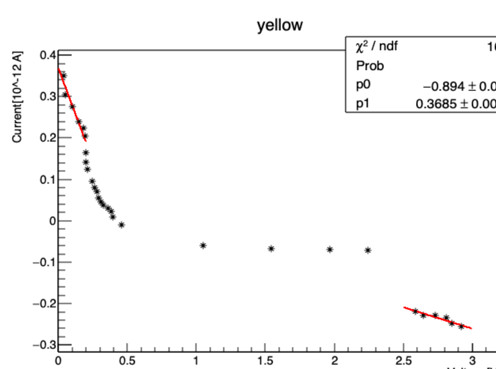

Fig. 3. Interception of lines 0.402 $\pm$ 0.013

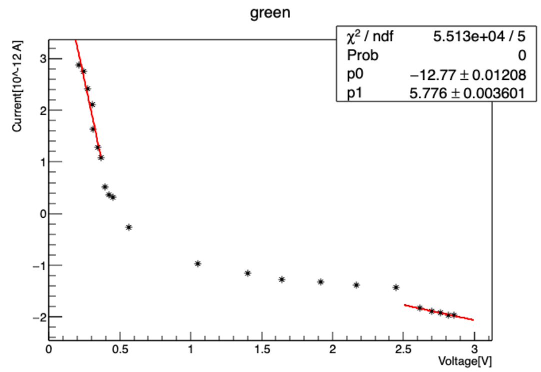

Fig. 4. Interception of lines 0.497 $\pm$ 0.001

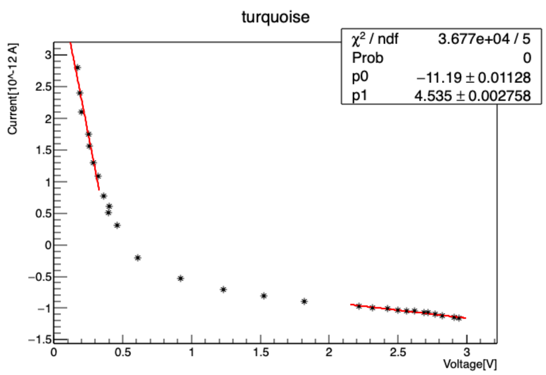

Fig. 5. Interception of lines 0.451 $\pm$ 0.001

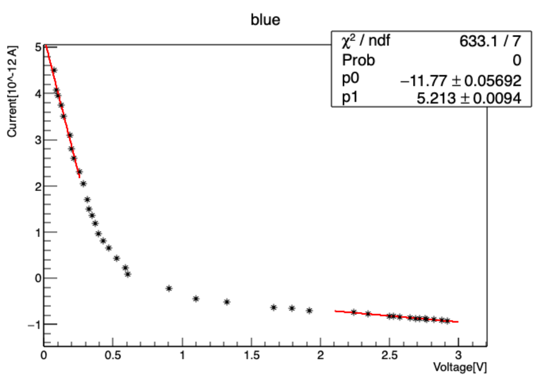

Fig. 6. Interception of lines 0.467 $\pm$ 0.004

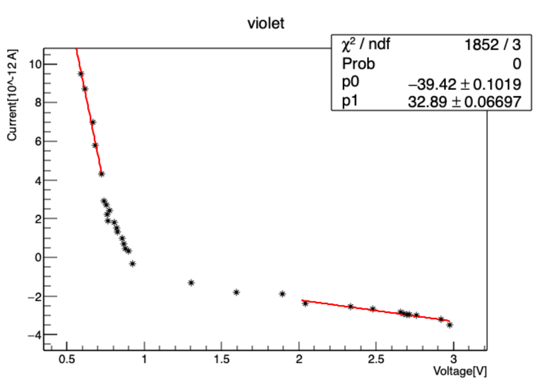

Fig. 7. Interception of lines 0.858 $\pm$ 0.003

Slope and y-intercept table for each dataset's linefit, here values are taken from ROOT's graphs:

TABLE II
SLOPE AND Y-INTERCEPT VALUES FOR LINE-FITS FOR GREEN

Color	Slope	y-intercept
yellow (1st fit)	-0.893 $\pm$ 0.006	0.369 $\pm$0.001
yellow(2nd fit)	-0.104 $\pm$ 0.004	0.050 $\pm$0.010
green(1st fit)	-12.769 $\pm$0.012	5.776 $\pm$ 0.004
green(2nd fit)	-0.593 $\pm$0.005	-0.284 $\pm$ 0.014
turquoise(1st fit)	-11.191 $\pm$0.011	4.535 $\pm$ 0.003
turquoise(2nd fit)	-0.252 $\pm$0.001	-0.400 $\pm$ 0.003
blue(1st fit)	-11.773 $\pm$0.057	5.212 $\pm$ 0.009
blue(2nd fit)	-0.264 $\pm$0.014	-0.156 $\pm$ 0.038
violet(1st fit)	-39.415 $\pm$0.102	32.893 $\pm$ 0.067
violet(2nd fit)t	-1.105 $\pm$0.012	0.004 $\pm$ 0.031

the intersection point of the stopping potential versus current plot is used rather than the x-intercept because the intersection point shows the true stopping potential required to stop the most energetic electrons and it is determined from the point where the linear portion of the photocurrent plot becomes zero. On the other hand, x-intercept may include experimental errors like background current,electrical noise,etc.

Here is the V_s values for each color After getting V_s values

TABLE III
V_s AND FREQUENCY VALUES

Voltage(V)	Frequency(x10^{14}Hz)
0.402 $\pm$ 0.013	5.19
0.497 $\pm$ 0.001	5.49
0.451 $\pm$ 0.001	6.08
0.467 $\pm$ 0.004	6.88
0.858 $\pm$ 0.003	7.41

for each dataset, I have plotted frequency vs V_s graph and applied a linear fit again by using ROOT's built-in function

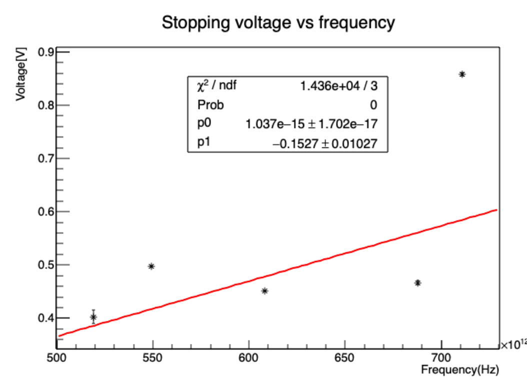

Fig. 8. The slope of the line is 1.037 x 10^{-15} $\pm$ 1.702x 10^{-17} with y-intercept -0.153 $\pm$ 0.010

So by using the y-intercept:

$$W = -V_s * q \tag{11}$$

$$W = -0.153 \pm 0.010V * -1.602x10^{-19}C \tag{12}$$

$$W = 2.45110^{-19} \pm 1.602x10^{-19}VC \tag{13}$$

VI. The Result

We have found $\frac{h}{q}$ value to be $1.037x10^{-15}$ V/Hz with the uncertainty of $1.702x10^{-17}$ V/Hz. CODATA recommended value for $h = 6.626x10^{-34}JHz^{-1}$ and for $q = -1.602x10^{-19}C$.[3][4], which means that the recommended value for $\frac{h}{q}$ is -4.136$10^{-15}$ J C Hz. The sign difference comes from the way of connection of V. Our result is 304.28 sigmas away from the theoretical value.

VII. The Conclusion

After calculating our final value, we have concluded that our experiment is a failure. Our result was 304.28 sigmas away from the theoretical value which is not acceptable. There are various reasons for that. First of all, the equipment we have used was so sensitive that touching even indirectly, by moving the moving coil for changing the resistance, to the table on which the set-up is has huge effect on the values that we are measuring. Also, There was another experiment that was conducted by other people in the same room, which means affecting our measurements both by touching the table and by turning the lights on in order for them to conduct their experiment. What is more, our set-up also easily affected by opening the door of the room, which happened several times during our experiment. Furthermore, the frequency values we have used in the analysis are theoretical. We have oriented the photocell so that we get approximately the desired color but we can do so by taking it a little bit of left or right because there was a range of colors which changes continuously so there was not exact points that we take. Therefore, the frequency values can cause some errors. Finally, the values the current amplifier reads are changing so fast that we lose most of times one significant figure due to the impossibility of taking the value exactly, so we had to take the average values read due to the instability of the equipment.

References

[1] *wiki*. URL: https://en.wikipedia.org/wiki/Photoelectric_effect#History (visited on 05/24/2024).

[2] *error propagation*. URL: https://www.siue.edu/~mnorton/uncertainty.pdf (visited on 05/24/2024).

[3] *codataq*. URL: https://physics.nist.gov/cgi-bin/cuu/Value?e (visited on 05/24/2024).

[4] *codatah*. URL: https://physics.nist.gov/cgi-bin/cuu/Value?h (visited on 05/24/2024).

[5] E. Gülmez. *Advanced Physics Experiments*. 1st. Boğaziçi University Publications, 1999.

VIII. Appendix

Here is my code used in analysis:

```
{
  std::vector<std::string> voltages = {
        "yellow-V.txt",
        "green-V.txt",
        "turquoise-V.txt",
        "blue-V.txt",
        "violet-V.txt"
  };

  std::vector<std::string> currents = {
        "yellow-I.txt",
        "green-I.txt",
        "turquoise-I.txt",
        "blue-I.txt",
        "violet-I.txt"
```

TABLE IV
Voltage and Current Values for Yellow

Voltage(mV)	Current(10^-12A)
38.0 ± 0.1	0.350 ± 0.001
50.1 ± 0.1	0.305 ± 0.001
101.8 ± 0.1	0.275 ± 0.001
148.5 ± 0.1	0.240 ± 0.001
181.0 ± 0.1	0.223 ± 0.001
196.4 ± 0.1	0.204 ± 0.001
198.8 ± 0.1	0.165 ± 0.001
202.1 ± 0.1	0.142 ± 0.001
211.9 ± 0.1	0.125 ± 0.001
246.1 ± 0.1	0.095 ± 0.001
261.8 ± 0.1	0.080 ± 0.001
278.1 ± 0.1	0.070 ± 0.001
293.6 ± 0.1	0.055 ± 0.001
308.7 ± 0.1	0.045 ± 0.001
324.7 ± 0.1	0.037 ± 0.001
360.5 ± 0.1	0.030 ± 0.001
384.1 ± 0.1	0.022 ± 0.001
396.9 ± 0.1	0.009 ± 0.001
457 ± 1.	-0.010 ± 0.001
1051 ± 1.	-0.059 ± 0.001
1544 ± 1.	-0.067 ± 0.001
1970 ± 1.	-0.070 ± 0.001
2243 ± 1.	-0.071 ± 0.001
2588 ± 1.	-0.218 ± 0.001
2647 ± 1.	-0.228 ± 0.001
2730 ± 1.	-0.229 ± 0.001
2813 ± 1.	-0.235 ± 0.001
2853 ± 1.	-0.248 ± 0.001
2919 ± 1.	-0.255 ± 0.001

TABLE V
Voltage and Current Values for Turquoise

Voltage(mV)	Current(10^{-12}A)
168.5 ± 0.1	2.80 ± 0.01
191.2 ± 0.1	2.40 ± 0.01
200.5 ± 0.1	2.10 ± 0.01
249.9 ± 0.1	1.75 ± 0.01
258.9 ± 0.1	1.56 ± 0.01
286.4 ± 0.1	1.30 ± 0.01
320.2 ± 0.1	1.08 ± 0.01
362.2 ± 0.1	0.77 ± 0.01
396.0 ± 0.1	0.51 ± 0.01
460.3 ± 0.1	0.31 ± 0.01
400.2 ± 0.1	0.61 ± 0.01
611 ± 1.	-0.20 ± 0.01
918 ± 1.	-0.53 ± 0.01
1233 ± 1.	-0.71 ± 0.01
1524 ± 1.	-0.81 ± 0.01
1822 ± 1.	-0.89 ± 0.01
2220 ± 1.	-0.97 ± 0.01
2314 ± 1.	-0.99 ± 0.01
2424 ± 1.	-1.01 ± 0.01
2499 ± 1.	-1.03 ± 0.01
2563 ± 1.	-1.05 ± 0.01
2618 ± 1.	-1.05 ± 0.01
2687 ± 1.	-1.07 ± 0.01
2721 ± 1.	-1.07 ± 0.01
2770 ± 1.	-1.09 ± 0.01
2823 ± 1.	-1.12 ± 0.01
2906 ± 1.	-1.14 ± 0.01
2941 ± 1.	-1.16 ± 0.01

TABLE VI
VOLTAGE AND CURRENT VALUES FOR BLUE

Voltage(mV)	Current(10^{-12}A)
75.1 ± 0.1	4.50 ± 0.01
89.5 ± 0.1	4.08 ± 0.01
100.3 ± 0.1	3.95 ± 0.01
125.5 ± 0.1	3.74 ± 0.01
141.3 ± 0.1	3.50 ± 0.01
186.0 ± 0.1	3.10 ± 0.01
199.8 ± 0.1	2.80 ± 0.01
216.7 ± 0.1	2.60 ± 0.01
254.0 ± 0.1	2.30 ± 0.01
286.2 ± 0.1	2.05 ± 0.01
314.3 ± 0.1	1.70 ± 0.01
322.7 ± 0.1	1.50 ± 0.01
347.4 ± 0.1	1.35 ± 0.01
371.1 ± 0.1	1.18 ± 0.01
396 ± 1.	0.96 ± 0.01
431 ± 1.	0.80 ± 0.01
468 ± 1.	0.65 ± 0.01
524 ± 1.	0.43 ± 0.01
587 ± 1.	0.22 ± 0.01
608 ± 1.	0.08 ± 0.01
904 ± 1.	-0.230 ± 0.001
1100 ± 1.	-0.440 ± 0.001
1324 ± 1.	-0.520 ± 0.001
1664 ± 1.	-0.630 ± 0.001
1793 ± 1.	-0.654 ± 0.001
1920 ± 1.	-0.700 ± 0.001
2240 ± 1.	-0.733 ± 0.001
2346 ± 1.	-0.780 ± 0.001
2499 ± 1.	-0.820 ± 0.001
2529 ± 1.	-0.832 ± 0.001
2572 ± 1.	-0.850 ± 0.001
2648 ± 1.	-0.860 ± 0.001
2690 ± 1.	-0.869 ± 0.001
2716 ± 1.	-0.877 ± 0.001
2759 ± 1.	-0.884 ± 0.001
2768 ± 1.	-0.886 ± 0.001
2819 ± 1.	-0.900 ± 0.001
2876 ± 1.	-0.910 ± 0.001
2918 ± 1.	-0.924 ± 0.001

```
};std::vector<std::string> names = {
      "yellow",
      "green",
      "turquoise",
      "blue",
      "violet"


};

std::vector<std::vector<double>>
    fitRangesFirst = {

   {0,0.200},{0,0.370},{0,0.330},{0,0.260},{0,0.727}

   };

   /*std::vector<std::vector<double>>
       fitRangesFirst = {

   {0.025,0.220},{0.205,0.370},{0.145,0.330},{0.065,0.230},{0.574,0.850}

   };
   */
```

TABLE VII
VOLTAGE AND CURRENT VALUES FOR VIOLET

Voltage(mV)	Current(10^-12A)
590 ± 1.	9.50 ± 0.01
615 ± 1.	8.70 ± 0.01
667 ± 1.	6.98 ± 0.01
682 ± 1.	5.80 ± 0.01
723 ± 1.	4.32 ± 0.01
739 ± 1.	2.90 ± 0.01
754 ± 1.	2.70 ± 0.01
762 ± 1.	2.22 ± 0.01
764 ± 1.	1.90 ± 0.01
777 ± 1.	2.42 ± 0.01
805 ± 1.	1.79 ± 0.01
820 ± 1.	1.52 ± 0.01
828 ± 1.	1.33 ± 0.01
858 ± 1.	0.97 ± 0.01
869 ± 1.	0.69 ± 0.01
880 ± 1.	0.46 ± 0.01
899 ± 1.	0.31 ± 0.01
925 ± 1.	-0.32 ± 0.01
1304 ± 1.	-1.30 ± 0.01
1594 ± 1.	-1.80 ± 0.01
1892 ± 1.	-1.90 ± 0.01
2042 ± 1.	-2.38 ± 0.01
2335 ± 1.	-2.54 ± 0.01
2480 ± 1.	-2.66 ± 0.01
2657 ± 1.	-2.85 ± 0.01
2678 ± 1.	-2.92 ± 0.01
2699 ± 1.	-2.96 ± 0.01
2716 ± 1.	-2.97 ± 0.01
2761 ± 1.	-2.99 ± 0.01
2921 ± 1.	-3.20 ± 0.01
2976 ± 1.	-3.50 ± 0.01

```
std::vector<std::vector<double>>
    fitRangesSecond = {


   {2.500,3.000},{2.500,3.000},{2.150,3.000},{2.100,3.00

   };
std::vector<std::vector<double>>
    parameterRanges = {


   {0.4,-1.0},{-12.39,5.66},{-12,4.7},{-12.21,5.264},{-3

   };


float del_I = 0.01;
float del_V = 0.1*pow(10,-3);
float freq
    [5]={519e12,549e12,608e12,688e12,711e12};
float stopping[5];
float error_sy[5];


for(int i =0;i<voltages.size();i++){


   std::ifstream
       fileVoltage(voltages[i].c_str());
   int ndata;
   std::string line;
   int linecount = 0; // Initialize a counter
   while (std::getline(fileVoltage, line)) {
```

```
    // Loop through each line in the file
   linecount++; // Incrementing line count
       for each line read

}

ndata = linecount;
float x[ndata],
    y[ndata],sx[ndata],sy[ndata];
std::vector<float> retarded;
std::vector<float> amplified;

std::ifstream infile1(voltages[i]);
float value1;

while (infile1 >> value1) {
   float InsertV = value1*pow(10,-3);
   retarded.push_back(value1);
}

std::ifstream infile2(currents[i]);
float value2;

while (infile2 >> value2) {
   float InsertI = value2*pow(10,-12);
   amplified.push_back(InsertI);
}

for(int k =0;k<ndata;k++){
   x[k] = retarded[k]/pow(10,3);
   y[k]= amplified[k]*pow(10,12);
   sx[k] = del_V;
   if(i<3){
      sy[k] = 0.001;
   }
   else {
      sy[k] = del_I;

   }
}



 /*for(int p = 0;p<ndata;p++){
    cout<< p<<"th voltage element
        is"<<x[p]<<"\n";

 }
 for(int r = 0;r<ndata;r++){
    cout<< r<<"th current element
        is"<<y[r]<<"\n";

 }

 for(int t = 0;t<ndata;t++){
    cout<< t<<"th elements are"<<x[t]<<" V
        "<<y[t]<<" I "<<"\n";

 }
 */

TGraphErrors *mygraph = new
    TGraphErrors(ndata,x,y,sx,sy);
TCanvas *c = new TCanvas();


mygraph->Draw("A*");
mygraph->SetTitle(names[i].c_str());
mygraph->GetXaxis()->SetTitle("Voltage[V]");
mygraph->GetYaxis()->SetTitle("Current[10^-12
    A]");

TF1 *line1 = new
    TF1("line","[0]*x+[1]",fitRangesFirst[i][0],fitRa
line1->SetParameter(parameterRanges[i][0],parameterRa
mygraph->Fit(line1,"R");

TF1 *line2 = new
    TF1("line","[0]*x+[1]",fitRangesSecond[i][0],fitR
mygraph->Fit(line2,"R+");

float m1 = line1->GetParameter(1);
float n1 = line1->GetParameter(0);
float m2 = line2->GetParameter(1);
float n2 = line2->GetParameter(0);

float m1_error = line1->GetParError(1);
float n1_error = line1->GetParError(0);
float m2_error = line2->GetParError(1);
float n2_error = line2->GetParError(0);

cout<<"for m1,n1,m2,n2:
    "<<m1<<","<<n1<<","<<m2<<","<<n2<<"
    errors are "
<<m1_error<<","<<n1_error<<","<<m2_error<<","<<n2_err

cout<<"for"<< currents[i].c_str()<<endl;
cout<<"for first line "<<"\n";
cout <<"intercept is "<< n1
    <<"+-"<<n1_error<<"slope is
    "<<m1<<"+-"<<m1_error<<"\n";
cout<<"for second line "<<"\n";
cout <<"intercept is "<<n2
    <<"+-"<<n2_error<<"slope is "<<
    m2<<"+-"<<m2_error<<"\n";

float Vs = (m2-m1)/(n1-n2);
cout<<"Vs potential is "<<Vs<<endl;



gStyle->SetOptFit(1111);



stopping[i]= Vs;

float up= m2-m1;
float down= n1-n2;
float up_error =
    sqrt(m1_error*m1_error+m2_error*m2_error);
float down_error =
    sqrt(n1_error*n1_error+n2_error*n2_error);


float error = Vs *
    sqrt((up_error*up_error)/(up*up)+(down_error*down

error_sy[i]=error;




cout<< "final Vs value for
    "<<names[i].c_str()<<"is " << Vs
```

```
        <<"+-"<<error<< endl;


}
   TGraphErrors *finalgraph = new
       TGraphErrors(5,freq,stopping,0,error_sy);
   TCanvas *c6 = new TCanvas();
   finalgraph->Draw("A*");
   TF1 *finalFit = new
       TF1("finalFit","[0]*x+[1]");
   finalgraph->Fit(finalFit);
   finalgraph->SetTitle("Stopping voltage vs
       frequency");
   finalgraph->GetXaxis()->SetTitle("Frequency(Hz)");
   finalgraph->GetYaxis()->SetTitle("Voltage[V]");
   float m = finalFit->GetParameter(1);
   float n = finalFit->GetParameter(0);
   float m_error = finalFit->GetParError(1);
   float n_error = finalFit->GetParError(0);

   cout<<"the final value
       is"<<n<<"+-"<<n_error<<"with the
       y-intercept "<<m<<"+-"<<m_error<<endl;


}
```