The Photoelectric Effect

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Abstract

In this experiment, we tried to determine the Planck constant by using stopping voltage values of a photoelectric effect event. We found h as $1.781 \pm 3.773 \times 10^{-34}$, which is not a near value to the exact value of the Planck constant, 6.626×10^{-34}. Exact value is two sigma away from our result.

1 Introduction

Light and its behaviors have been a centre of attention for decades. The velocity of the electromagnetic waves was known from the Maxwell's equation and it turned out that this is the same value with the speed of light. Besides, the phenomena like double slit experiment conducted by Young could be explained with assuming that light is an electromagnetic wave. However, there were still some effects involving light and can't be explained by wave nature of the light. Photoelectric effect was one of them. After his examinations on black body radiation, Planck had already stated that the energy of the light can be transferred not continuously but by small energy pockets. But still wave nature of the light preserved its validity. However, the photoelectric effect, which was first observed by Hertz and Lenard observed that the energy of the electrons are proportional to the frequency of the incident light, which is an observation that contradicts with the Maxwell's theory, which predicts that energy of the light is proportional to its intensity. To solve this paradox, in 1902, Einstein described light as composed of discrete quanta rather than being a continuous wave, which resulted in Einstein's gaining Nobel Prize. This explanation fit so well since it also explained why electrons are cut almost instantaneously besides explaining the frequency relation of the energy of electrons.

In photoelectric effect, incident photon has an energy such that

$$E = h\nu \tag{1}$$

Each surface has a certain value of a necessary energy to free electron. We can express as W so that

$$h\nu = \frac{m_e {v_e}^2}{2} + W \tag{2}$$

where m_e and v_e represents mass of the electron and the velocity of the electron.

If one completes a circuit with the electrons freed by photoelectric effect, then stopping voltage for zero circuit can be expressed as

$$h\nu = qV + W \tag{3}$$

$$V = \frac{h}{q}\nu + \frac{W}{q} \tag{4}$$

2 Setup and Procedure

In the experiment, we used high pressure mercury lamp, photocell with housing, current amplifier, voltmeter and power supply.

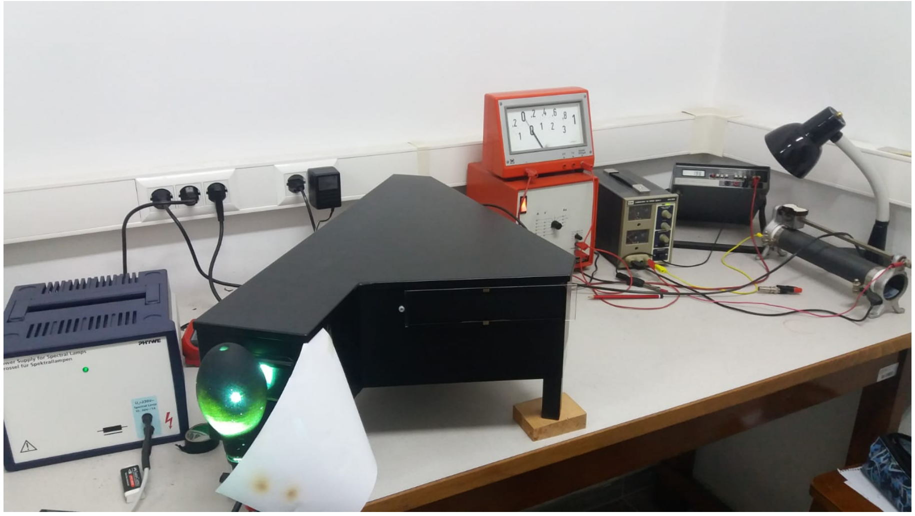

Figure 1: General view of the apparatus

First, we turned on the power supply and waited for the lamp to heat up. We observed the spectrum of the light after it passes through the optical setup. After observing the spectrum, we caused the each color of the spectrum to fall on the photocell's cathode. We noted down the current value we read from ammeter corresponding to each voltage value we applied starting from 0.05 V to 0.900 V with steps of 0.05. After some point of our data taking process we noticed that something seems odd with our data. So we looked around carefully and noticed that the incident color on the cathode is not the same with the color incident on the glass upon which the shadow of the little tip on the photocell which was supposed to guide us falls. Then we went back and checked if the previous colors also had the same problem and saw that green light has that problem, i.e, we examined yellow instead of green mistakenly. Thus, we took the data for the green light again. At whole process, we used amplifier to amplify the current. When we are dealing with small currents, we were planning to adjust amplifier so that we can read that values bigger/better at ammeter. However the amplifier was not in a good situation and when we changed its multiplier it showed an irrelevant value, apart from what we observed previously. Therefore, our whole data is suspicious because all of the current values are read after they passed from amplifier.

After the painful data taking procedure, we started our analysis. We drew the voltage vs current graphs for each color. Then we fit data with two straight. Then we found their intersection point. The x coordinate of that point gave us the stopping voltage for that color. The stopping voltage values, i.e., the intersection of the two fits were found to have negative y coordinates, which means negative current although we were expecting their y coordinate to be zero. This deviation is because of a phenomena called contact potential introduced by Melissinos and Napolitano. This effect occurs because the work function of the anode is usually higher than the work function of the cathode.[1]

After finding stopping voltage values, we drew stopping voltage versus frequency graph, whose slope turns out to be $\frac{h}{q}$ from Equation 4. Then, we used slope to find the value of h so that

$$h = slope * q \tag{5}$$

To propagate error, we used following method throughout the analysis:

$$\sigma = \sqrt{\sum_i \left(\frac{\partial f}{\partial n_i}\right)^2 \sigma_i^2} \tag{6}$$

3 Data and Analysis

The data taken when red was incident on the photocell is given below.[2]

Voltage (Volt)	Current (Ampere x 10^{-14})
0.050 ± 0.001	1.2 $\pm$0.2
0.100 ± 0.001	0.8 $\pm$0.2
0.150 ± 0.001	0.6 $\pm$0.2
0.200 ± 0.001	0.4 $\pm$0.2
0.250 ± 0.001	0.2 $\pm$0.2
0.300 ± 0.001	0.0 $\pm$0.2
0.350 ± 0.001	-0.2 $\pm$0.2
0.400 ± 0.001	-0.4 $\pm$0.2
0.450 ± 0.001	-0.4 $\pm$0.2
0.500 ± 0.001	-0.6 $\pm$0.2
0.550 ± 0.001	-0.6 $\pm$0.2
0.600 ± 0.001	-0.6 $\pm$0.2
0.650 ± 0.001	-0.6 $\pm$0.2
0.700 ± 0.001	-0.8 $\pm$0.2
0.750 ± 0.001	-0.8 $\pm$0.2
0.800 ± 0.001	-0.8 $\pm$0.2
0.850 ± 0.001	-0.8 $\pm$0.2
0.900 ± 0.001	-0.8 $\pm$0.2

[1]Melissinos, Napolitano; Experiments in Modern Physics; Academic Press, Second Edition

[2]For data table and graphs of other colors, see appendix.

The two graphs and two fits corresponding to the data above is given below. (Figure 1 and Figure 2)[3]

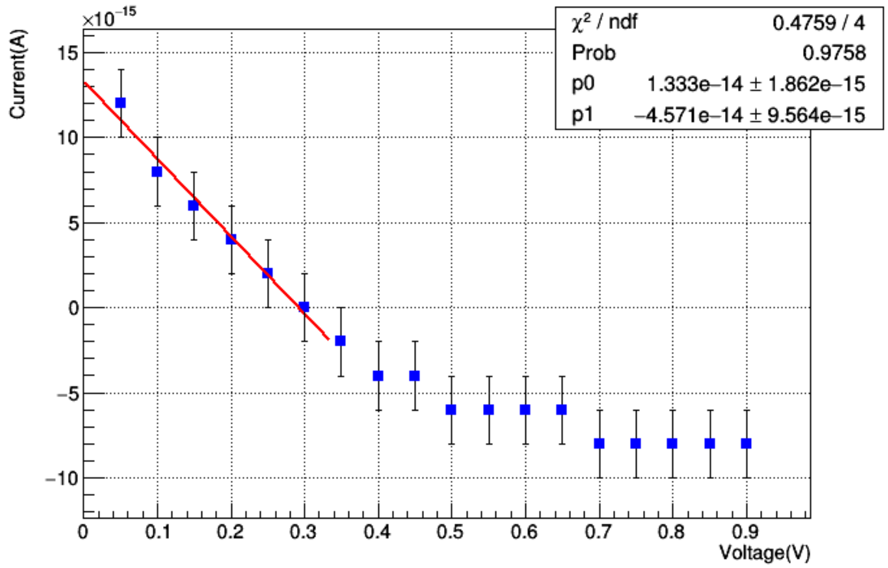

Figure 2: The positive fit for the red

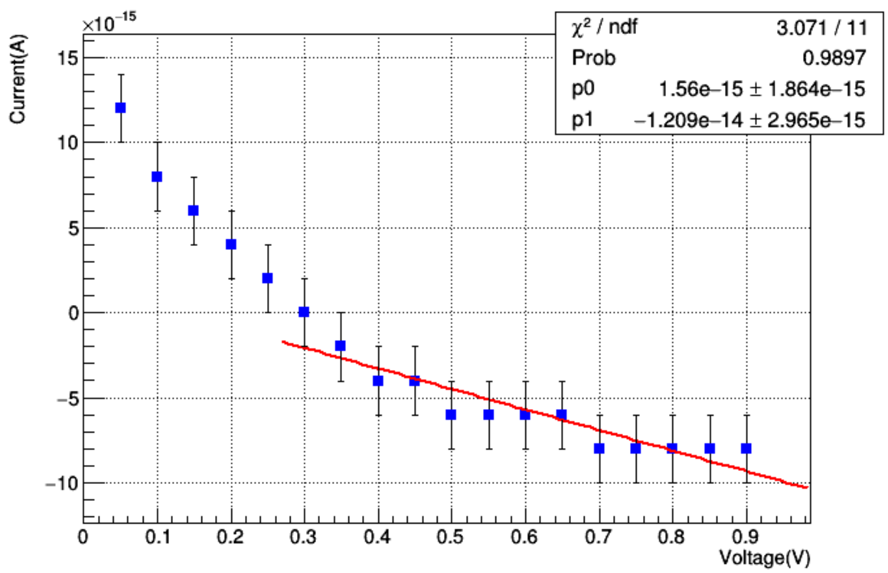

Figure 3: The negative fit for the red

We found the intersection point of the two fits which x coordinate is the stopping voltage. The intersection found by the following formula.

[3] In statistics bars of the graphs, p1 corresponds to the slope and p0 corresponds to the y intercept.

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

Here n_1 represents the y intercept of the positive fit and m_1 represents the slope of the positive fit. Similarly those with 2 at the sub index are corresponding values belonging to negative fit. Thus, we found stopping potential for red light as

$$V_{stopping,red} = 0.350 \pm 0.120V \tag{8}$$

The uncertainty found by Equation 6 as

$$\sqrt{\left(\frac{\sigma_{n_2}}{m_1 - m_2}\right)^2 + \left(\frac{\sigma_{n_1}}{m_1 - m_2}\right)^2 + \left(\frac{\sigma_{m_1}(n_2 - n_1)}{(m_1 - m_2)^2}\right)^2 + \left(\frac{\sigma_{m_2}(n_2 - n_1)}{(m_1 - m_2)^2}\right)^2} \tag{9}$$

where n's are p0's and m's are p1's.

Similarly, we calculated $V_{stopping}$ for other colors as

$$V_{stopping,yellow} = 0.315 \pm 0.06V$$
$$V_{stopping,green} = 0.324 \pm 0.397V$$
$$V_{stopping,blue} = 0.505 \pm 0.396V$$
$$V_{stopping,violet} = 0.426 \pm 0.929V$$

Then, we graphed frequency versus $V_{stopping}$ graph.[4](Figure 3)
Here, we found h as

$$h = 0.201 \pm 2.007 \times 10^{-34} \tag{10}$$

by Equation 5.[5]
Since this is an absurd result, we tried omitting some discordant data points, namely data points of red and violet. This time we found Planck constant as

$$h = 1.781 \pm 3.773 \times 10^{-34} \tag{11}$$

which is a relatively good result. Still, its uncertainty is too big. Thus, we tried fitting only red, yellow and blue while omitting data points of green and violet, which have two biggest uncertainties. The result was in order of 10^{-35} this time. It failed.

[4]In frequency versus stopping voltage graphs, the axes are mistakenly labeled as voltage and current. The x-axis is frequency while y-axis is V_s

[5]The uncertainty found by Equation 6 as $1.602 \times 10^{-19} \times \sigma_{p1}$

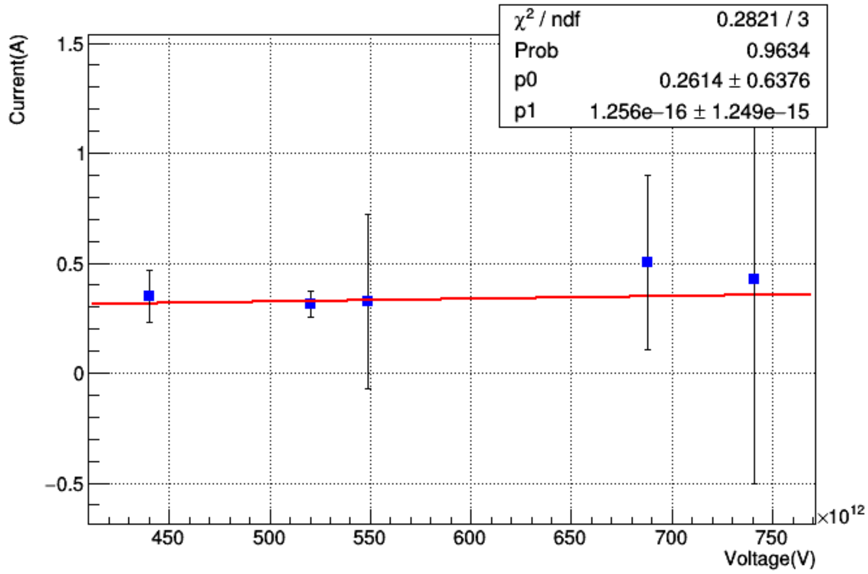

Figure 4: Frequency versus V_s graph with linear fit

4 Conclusion

The result is not pleasant. However, considering the bad situation of the setup, it is not surprising. The amplifier was showing absurd behaviors as mentioned before. The photocell's health was also suspicious since till our experiment it might have been exposed to the room light mistakenly several times.

Our raw data follows an expected trend. As voltage increases, the current decreases correspondingly. However, we got much more data for the negative region than our expectations relying on the information we get from the friends who did this experiment before. Looking at the our frequency versus V_s graphs, we observed that data points related to red and violet are not logical. We were expecting them to be preserve linear trend but they are not. And that is why we tried to omit them in second attempt.

Using better and more modern devices is the first and obvious way to get a better result. Besides, with a much more sensitive ammeter and amplifier, one could try to use smaller steps of voltage values to observe the change in current.

5 Appendix

A sample codes used at the analysis can be found at following github link: `https://github.com/beratgonultas/phys442/tree/master/photoelectric`

Raw data and graphs of yellow, green, blue and violet are given below. [6]

[6] Uncertainties of raw data are the same with the raw data of the red given at Data and Analysis part.

Yellow	
Voltage(V)	Current(A)
0.05	2E-13
0.1	1.2E-13
0.15	8E-14
0.2	4E-14
0.25	2E-14
0.3	0
0.35	-4E-14
0.4	-4E-14
0.45	-6E-14
0.5	-6E-14
0.55	-6E-14
0.6	-6E-14
0.65	-6E-14
0.7	-6E-14
0.75	-8E-14
0.8	-8E-14
0.85	-8E-14
0.9	-8E-14

Figure 5: Raw data of yellow

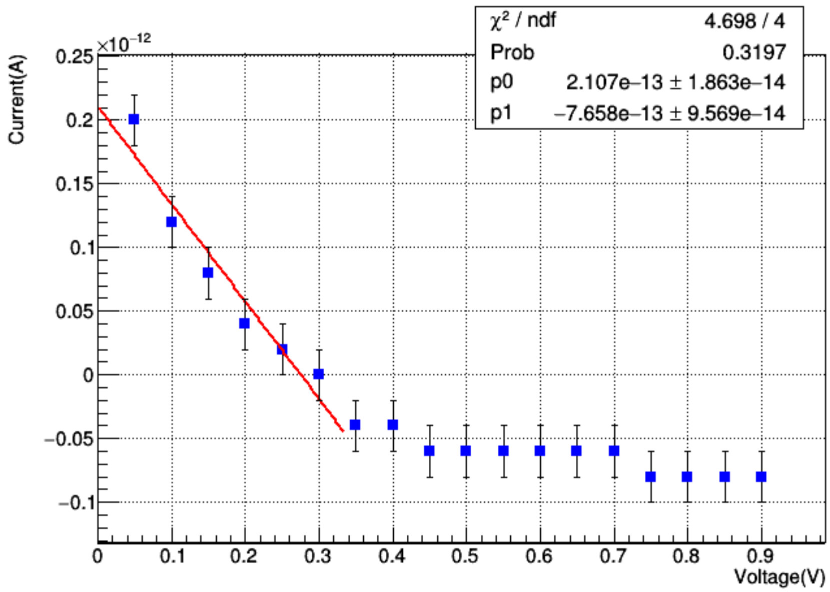

Figure 6: Positive fit of yellow

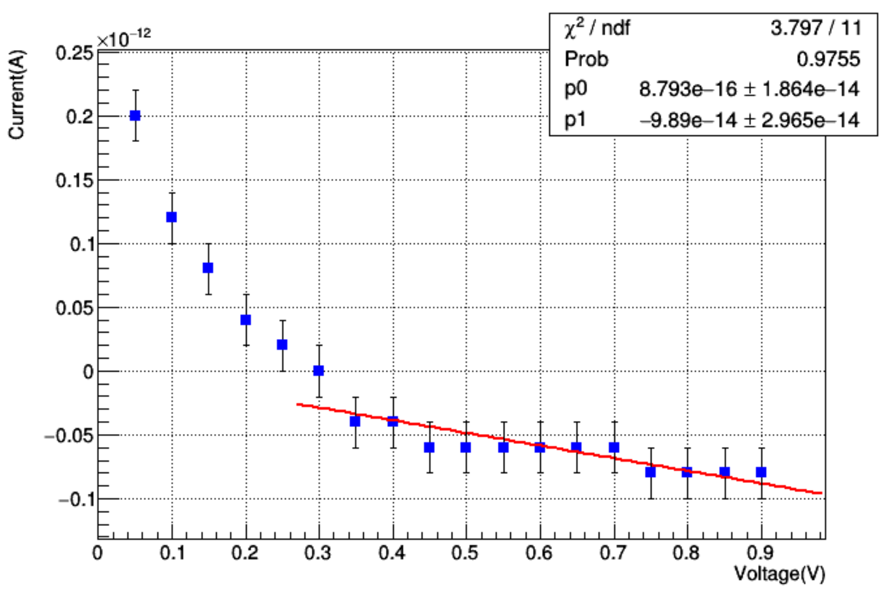

Figure 7: Negative fit of yellow

Green	
Voltage(V)	Current(A)
0.05	4E-14
0.1	2E-14
0.15	2.2E-14
0.2	0
0.25	-2E-14
0.3	-2E-14
0.35	-2E-14
0.4	-4E-14
0.45	-4E-14
0.5	-4E-14
0.55	-4E-14
0.6	-4E-14
0.65	-6E-14
0.7	-6E-14
0.75	-6E-14
0.8	-6E-14
0.85	-6E-14
0.9	-6E-14

Figure 8: Raw data of green

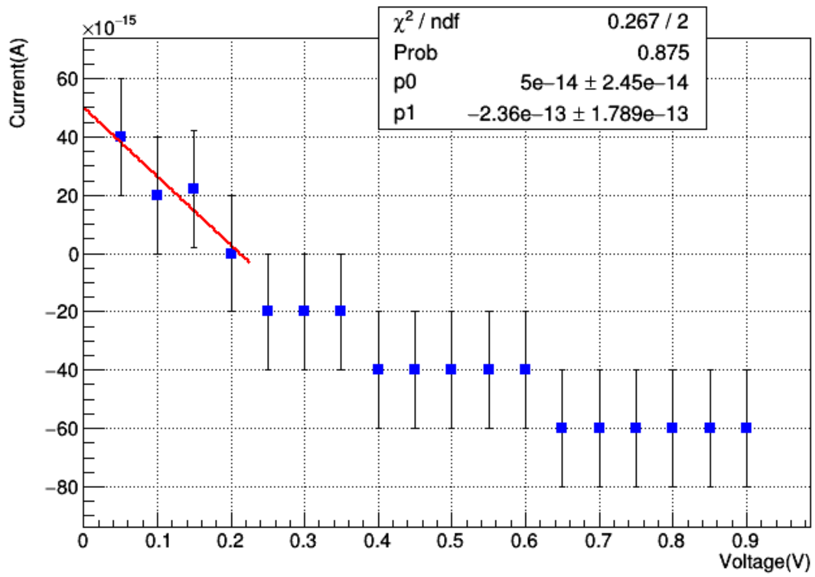

Figure 9: Positive fit of green

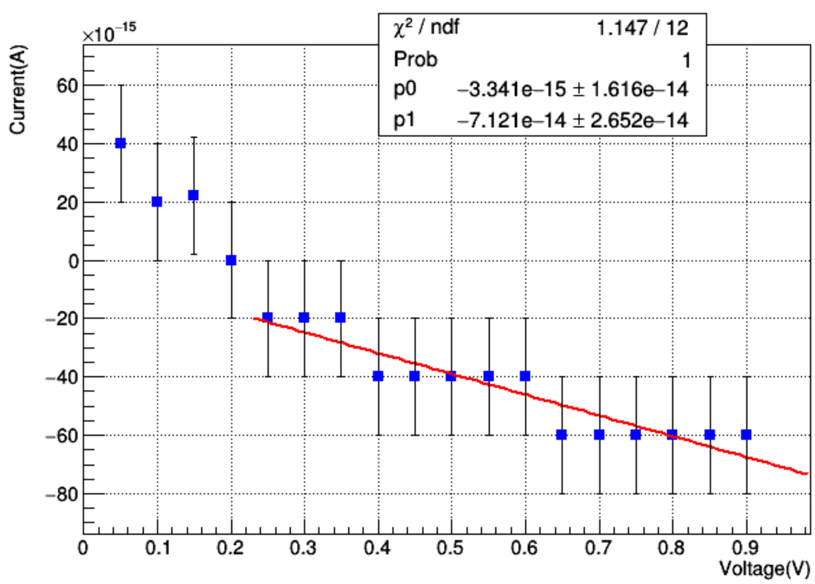

Figure 10: Negative fit of green

Blue	
Voltage(V)	Current(A)
0.05	1.2E-13
0.1	1E-13
0.15	8E-14
0.2	6E-14
0.25	6E-14
0.3	4E-14
0.35	4E-14
0.4	2E-14
0.45	2E-14
0.5	0
0.55	0
0.6	-2E-14
0.65	-2E-14
0.7	-2E-14
0.75	-4E-14
0.8	-4E-14
0.85	-4E-14
0.9	-4E-14

Figure 11: Raw data of blue

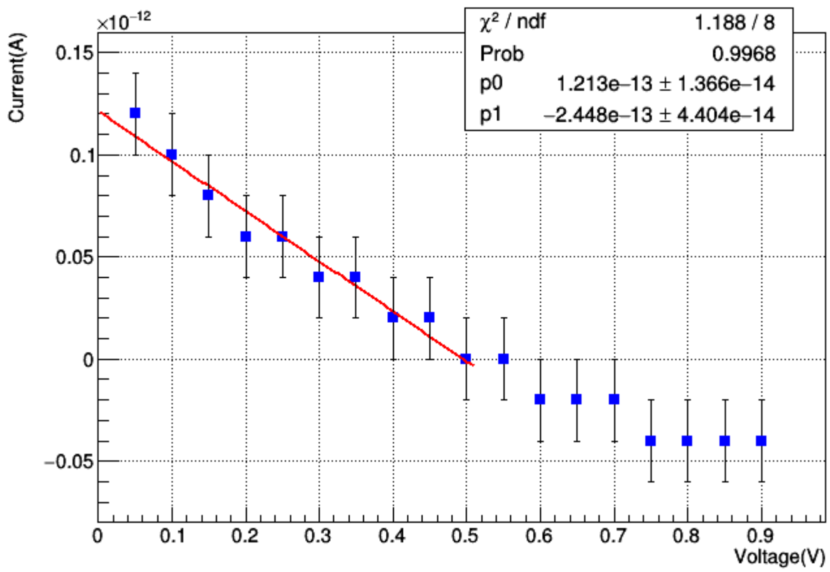

Figure 12: Positive fit of blue

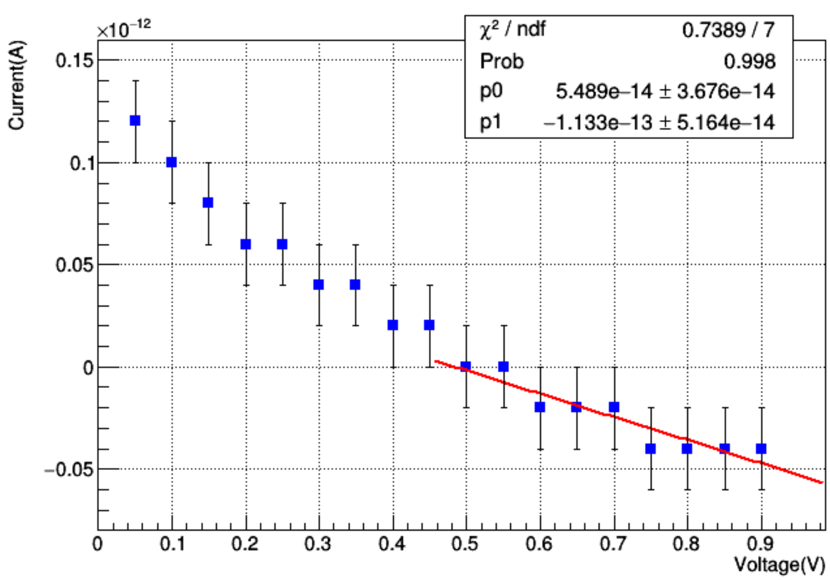

Figure 13: Negative fit of blue

Violet	
Voltage(V)	Current(A)
0.05	4E-13
0.1	2E-13
0.15	2E-13
0.2	2E-13
0.25	0
0.3	0
0.35	0
0.4	0
0.45	-2E-13
0.5	-2E-13
0.55	-2E-13
0.6	-2E-13
0.65	-2E-13
0.7	-2E-13
0.75	-4E-13
0.8	-4E-13
0.85	-4E-13
0.9	-4E-13

Figure 14: Raw data of violet

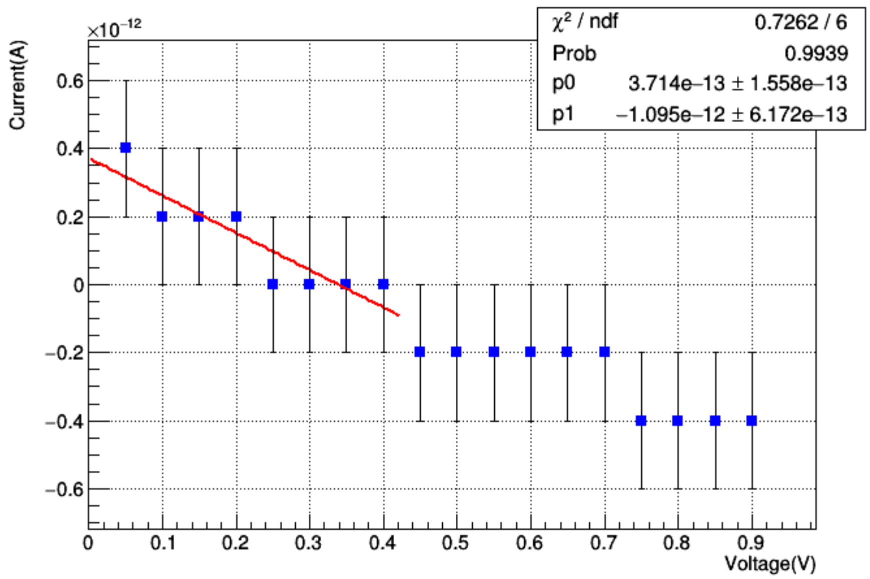

Figure 15: Positive fit of violet

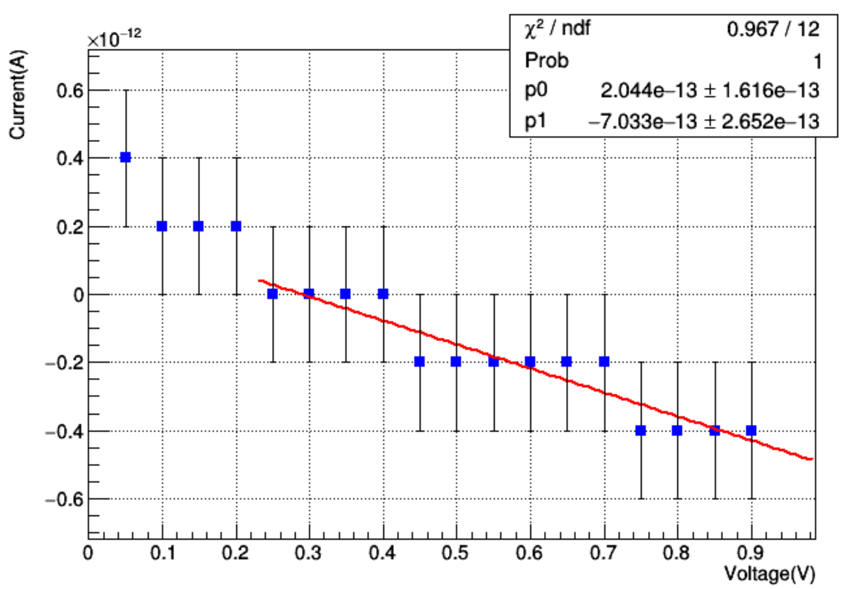

Figure 16: Negative fit of violet