Stefan-Boltzmann Law

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Abstract

In this experiment, I tried to show that the amount of radiation changes with inverse square of the distance from the source. Besides, I tried to see that Stefan-Boltzmann Law holds by determining the temperature dependence of the radiation. But, unfortunately, I found quite different results for all.

1 Introduction

The Stefan-Boltzmann Law states that the total power radiated by an object per unit area depends on its temperature. More specifically

$$R = \sigma T^4 \tag{1}$$

where σ is the Stefan-Boltzmann constant ($\sigma = 5{,}6703 \times 10^{-8}$ W$/m^2 K^4$

Amount of power falling on a specific area at a distance from the radiating object depends on the inverse square of the distance between the radiating object and the detector. This is obvious since the total power falling on the inner surface of a sphere centered at the position of the radiating object should be the same regardless of the radius of the sphere, while the power falling on per unit area varies as the inverse square of the radius r (surface area of a sphere: $4\pi r^2$) Hence, the power falling on a detector varies as the inverse square of the distance between the detector and the object radiating the power.[1]

2 Setup and Procedure

In this experiment, I used voltage amplifier, moving coil voltmeter (0-3 V DC), Stefan-Boltzmann lamp, radiation sensor, multimeter, DC power supply, Moll's thermophile, electrical oven and temperature probe.

First, 10.01 ± 0.01 V was supplied to the lamp. The lamp's side which looks to the sensor was stationary at position 63.0 ± 0.1 cm. At that configuration I took 7 data from the voltmeter connected to the sensor by moving away the sensor, which side was 53.1 ± 0.1 cm at the beginning. Then I realized that it is better to take the lamp to the one side of

[1]Advanced Physics Experiments by Erhan Gülmez (Boğaziçi University Publications, 1999, ISBN 975-518-129-6)

the desk, not at the middle as in first configuration. Thus, I moved it to the position 99.5 cm, and continue taking data. I measured the distance between the side of the lamp and the tungsten filament and also the distance between side of the sensor to the eye of the sensor. All data are given in the spreadsheet named "inverse.ods", which can be found, like all other spreadsheets, at the github link given at the Appendix.[2]

Secondly, I connected two multimeters to the lamp to get V and I data to determine its resistance at room temperature, namely, R300. To get R300, what I don't want was heat increase of the filament. The first thing come to my mind was to take data so fast that the filament couldn't heat up. But then, I decided that it is much more logical to take data with configurations having low power dissipation, which are low V and low I. So I took some data in mV and mA order. They can be found in the spreadsheet named "v_i.ods"

Then I chose 3 different distance between the lamp and the sensor while multimeters were still connected. For each distance value, I kept the distance constant and took data for different voltage and current values, i.e, different amounts of radiation. These data are given in the spreadsheet named "3-10.ods"

At last, I used the Moll's thermophile and electrical oven. I heated up the oven and wrote down the readings given by temperature probe with corresponding values of voltage readings proportional to radiation amount.

3 Analysis

Using the data in inverse.ods, I tried to show that radiation amount is proportional to the inverse square of the distance. Distance versus Voltage plot is given in Figure 1.[3]

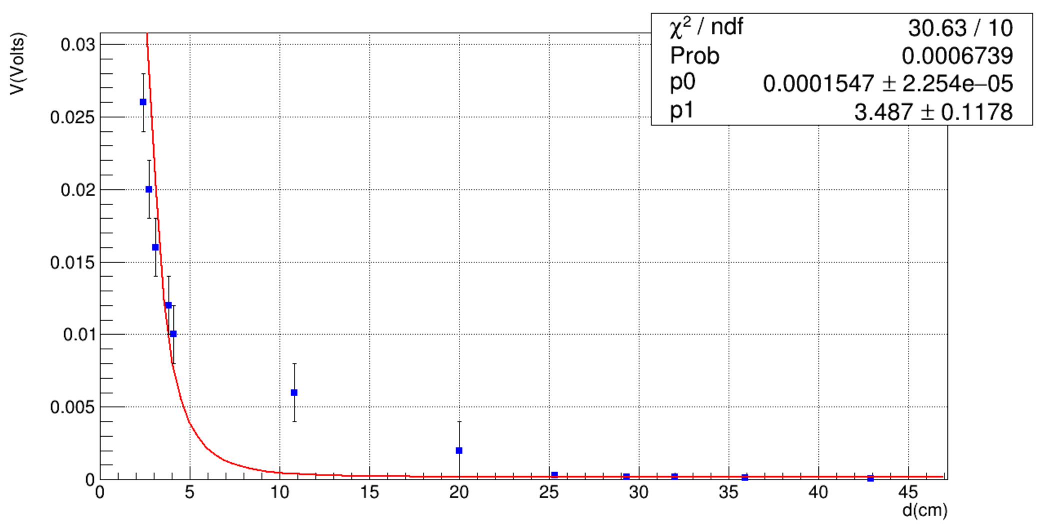

Figure 1: The plot which was supposed to show the inverse square relation

[2]All data for sensor voltage readings were taken after amplified. All amplification values are given in spreadsheets.

[3]All codes are given in the link at the Appendix.

After the plot at Figure 1 failed, I tried to play with the uncertainties of the some data points to get a better result.(Figure 2)

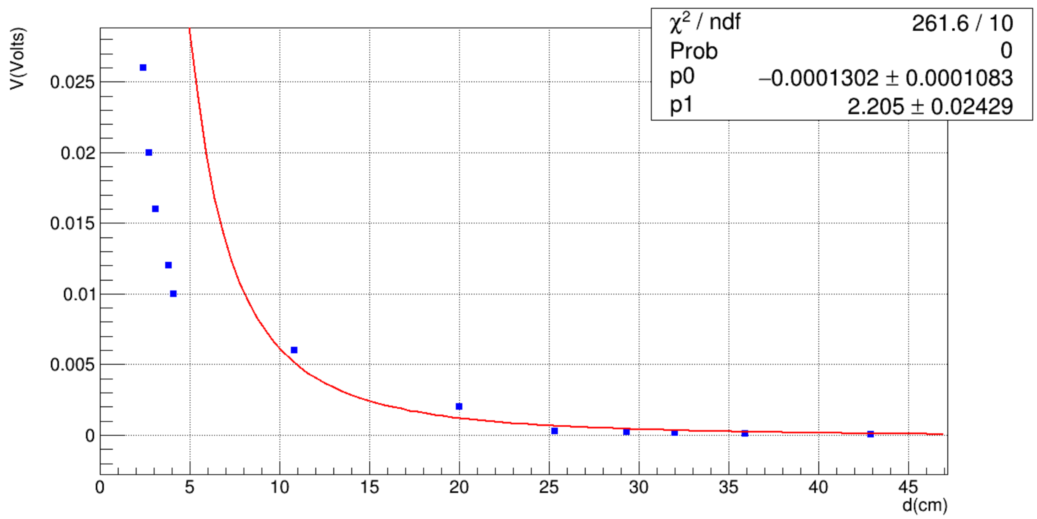

Figure 2: The plot which was supposed to show the inverse square relation better

This one, Figure 2, was much more better but surely a bit man-made and having a tremendous chi-square value, which is not a desirable thing to have.

Then I log-plot them. (Figure 3) It was great since the known value is in one sigma, and chi-square was not too big or too small.

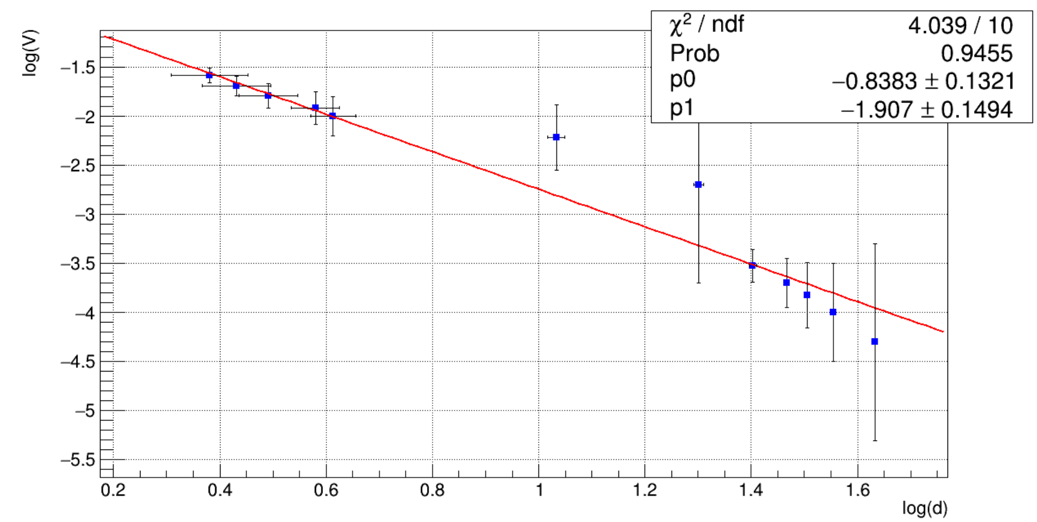

Figure 3: The plot which finally succeed to show the relation

After inverse square relation, I plotted the R/R300 vs Temperature data given in the table in the book in footnote 1 and made a fifth order polynomial fit to it.(Figure 4) I put no error on them since they are given values.

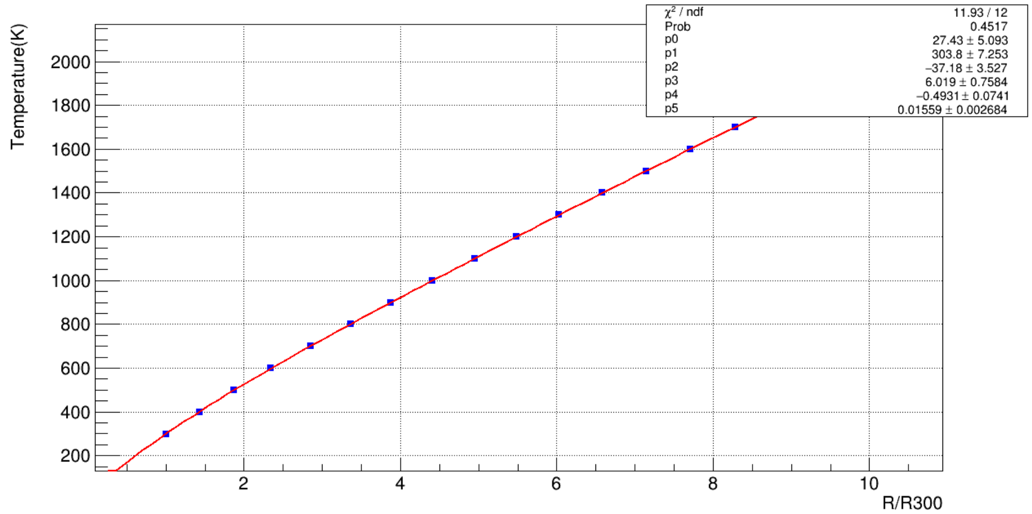

Figure 4: R/R300 vs Temperature

It is a fifth order polynomial since it was the first one giving a good chi-square value among all up to that order.

I used these coefficients to get a relation between temperature and R/R300. Then I used this knowledge to obtain temperature values for the measurements taken at the 3 different positions. All these calculations are given in the spreadsheet 3-10.ods

While propagating the error to the temperature values, I ignored the errors of the coefficients to make my work easy since it was hard enough to work with a fifth order polynomial.

Then I log-plotted T vs V_{sensor} for each of 3 distance values(Figure 5) It was a fiasco. The slope which was supposed to be 4 was around 11.5 with a huge chi-square.

So, I decided to play with uncertainties and plot it again.(Figure 6)

It was less bad but still unacceptable. I just gave up and continued with the hope to get better results with other distance values.

Their graphs are given in Figure 7 and Figure 8.

The second one made me happy and I thought that it gets better for small distances but this thought lasted till I saw the third one.

Since these values were not so good, I decided to use known value 4 to the plot which is to find σ/c, where c is the constant relates voltage to amount of radiation.

Plot for the 9.5 ± 0.1 cm is given in Figure 9

Again, as always in such situations, I played with error bars. (Figure 10)

This one is much worse regarding chi-square but it is just a matter of having less error on some points. But this looks better despite of the fact in the previous sentence.

I plotted other two graphs. (Figure 11 and 12)

The second is better as before. This thought me that that configuration was somehow better than others, so its slope is more reliable that the others'[4]

[4]At all these four graphs (Figure 9, 10, 11, 12) in y-axis label, meters is given as mistakenly instead of

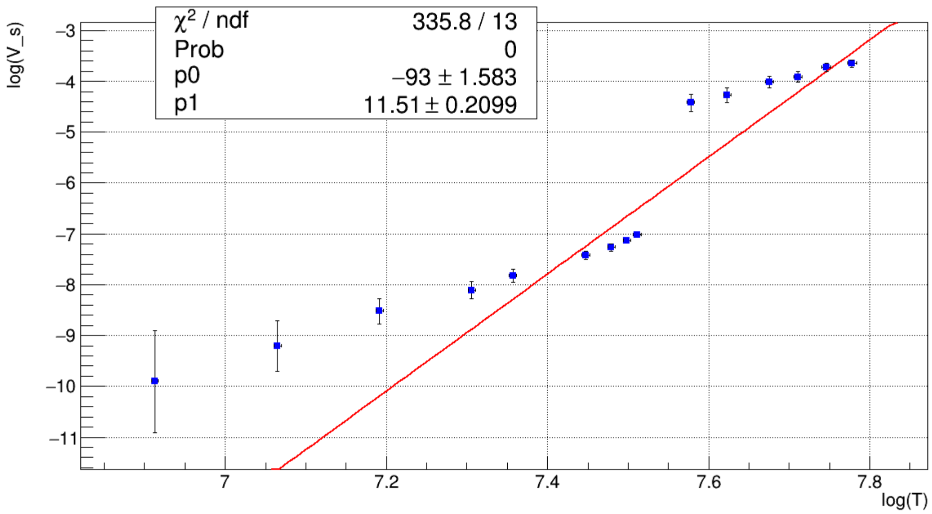

Figure 5: T vs V_{sensor} for 9.5 ± 0.1 cm distance

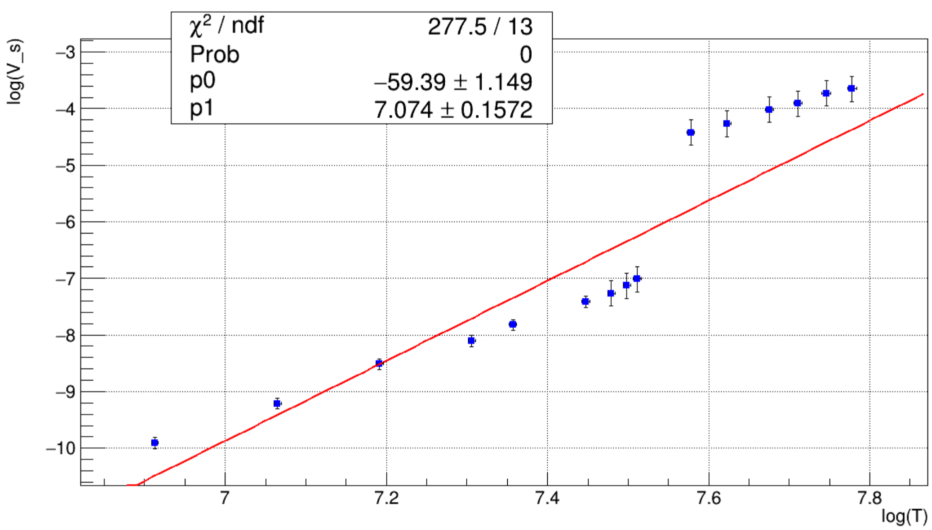

Figure 6: Re-plot of Figure 5

All of c value calculations and all data of the last part which is given in spreadsheet named "t-v.ods"

At first, I forgot to convert Celsius to Kelvin and got very bad results for the power of T. The graphs of them are given below (Figure 13 and 14) Figure 13 is the one only second c is used and the Figure 14 is the one average c is used.[5] I do that to see if the second will or will not give a better result alone. But anyways these were wrong graphs because of Celsius scale.

cm

[5] I used c to multiply with V to get the intensity.

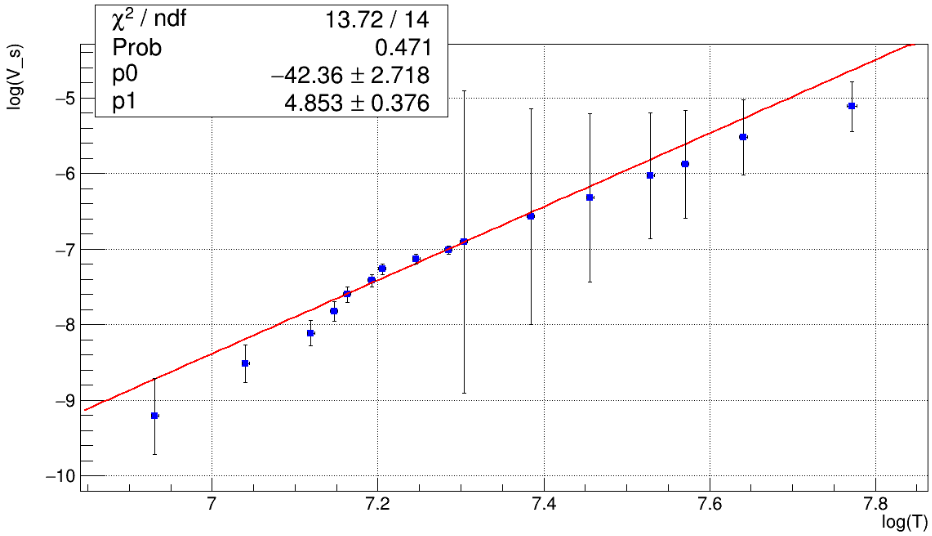

Figure 7: T vs V_{sensor} for 5.5 $\pm$ 0.1 cm distance

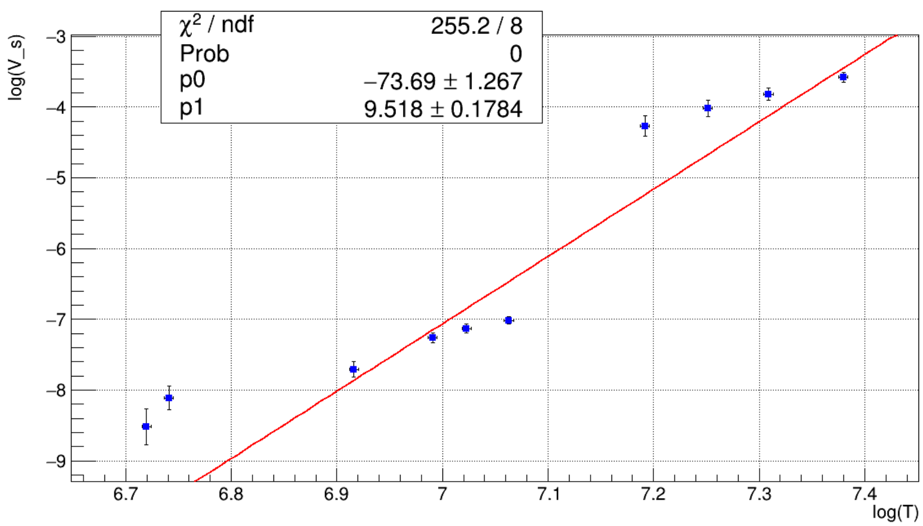

Figure 8: T vs V_{sensor} for 3.5 $\pm$ 0.1 cm distance

Then I corrected them. (Figure 15 and 16)

4 Conclusion

Regarding inverse square relation, the log plot gave a great result. But the normal plot did not. This difference may because I took data near the light reflecting meter on the table. The table might reflect the light such that sensor senses it as a multiple of the real value. This make a difference in normal plot since it is not a linear relation but it does not in log plot, since it becomes linear when log-plotted, and that constant multiple only can only

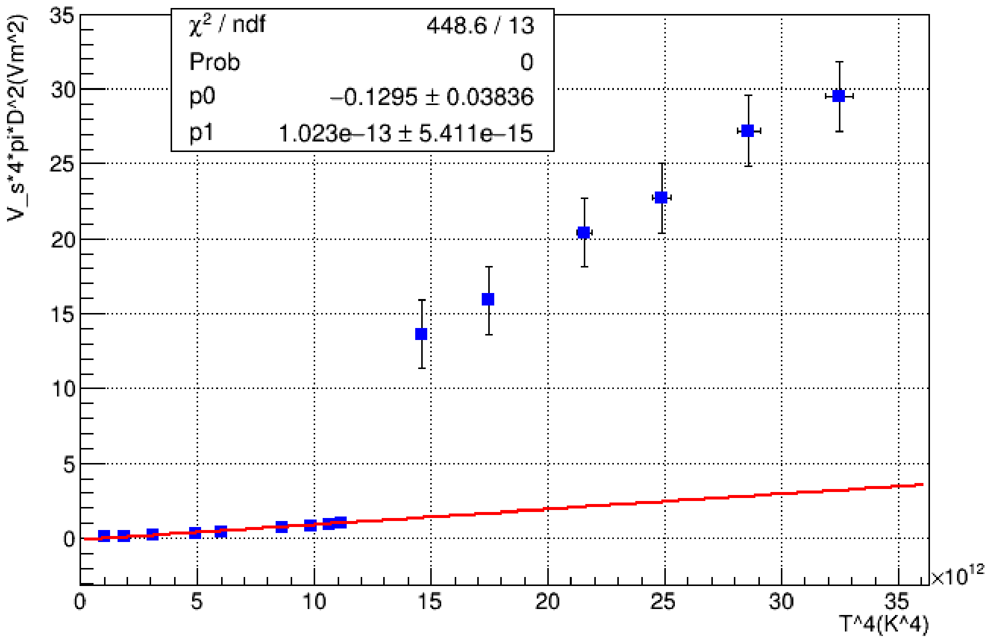

Figure 9: T^4 vs $4\pi D^2 V_s$ for 9.5 ± 0.1 cm

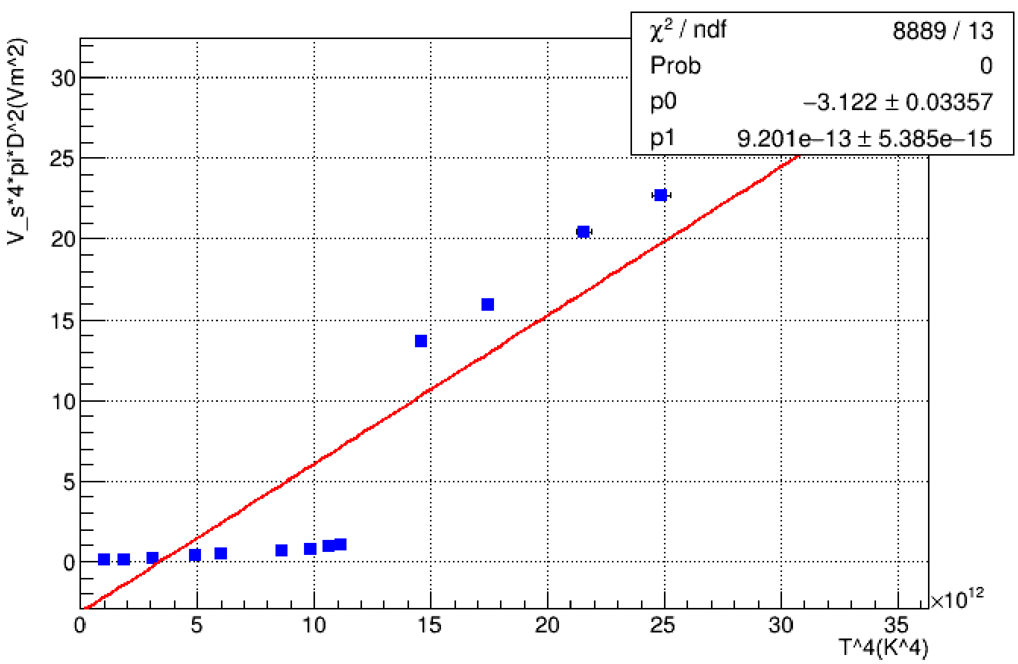

Figure 10: Re-plot of Figure 9

cause a movement of graph, not a change in slope.

I don't know exacly why among all these 3 distance values, the middle one seems to give

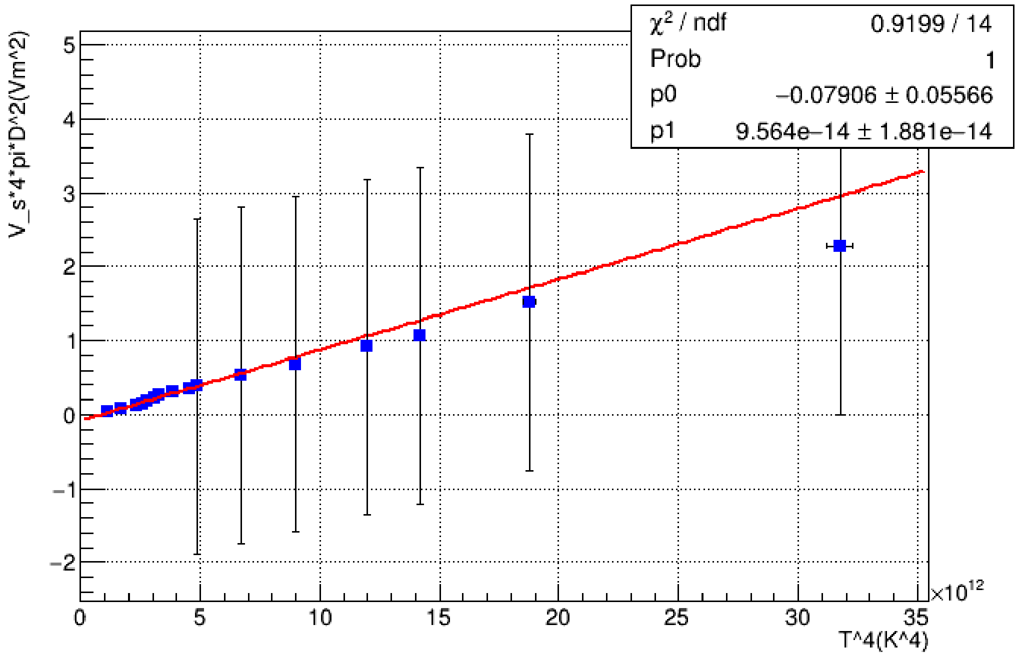

Figure 11: T^4 vs $4\pi D^2 V_s$ for 5.5 ± 0.1 cm

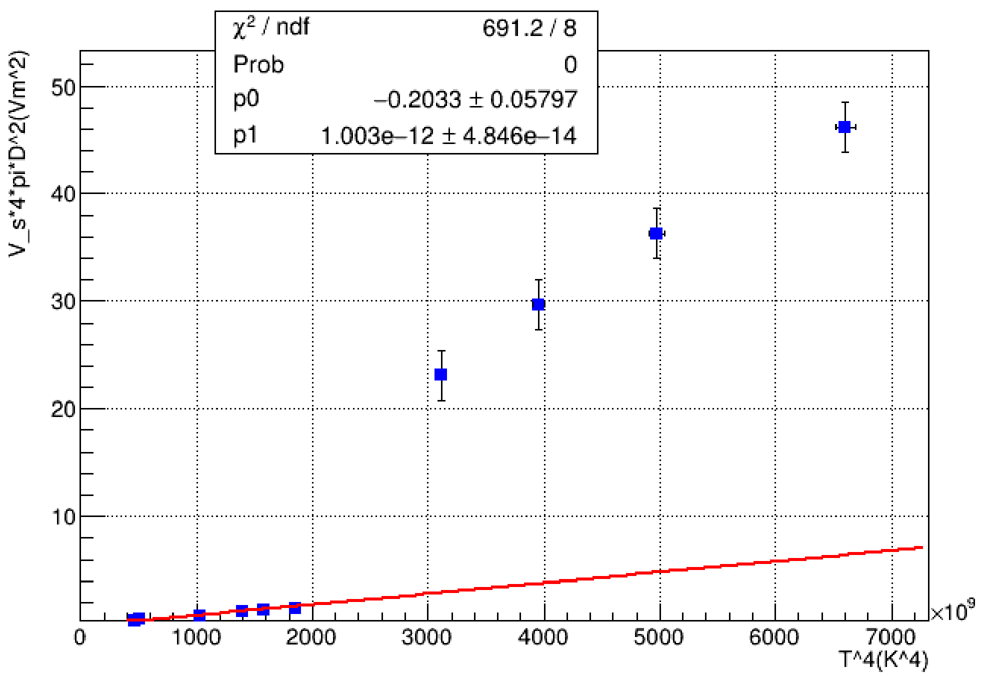

Figure 12: T^4 vs $4\pi D^2 V_s$ for 3.5 ± 0.1 cm

better results. But what I observed is that even for small time durations(like the time passes as I write down the values) the voltmeter and ammeter were changing, probably because of

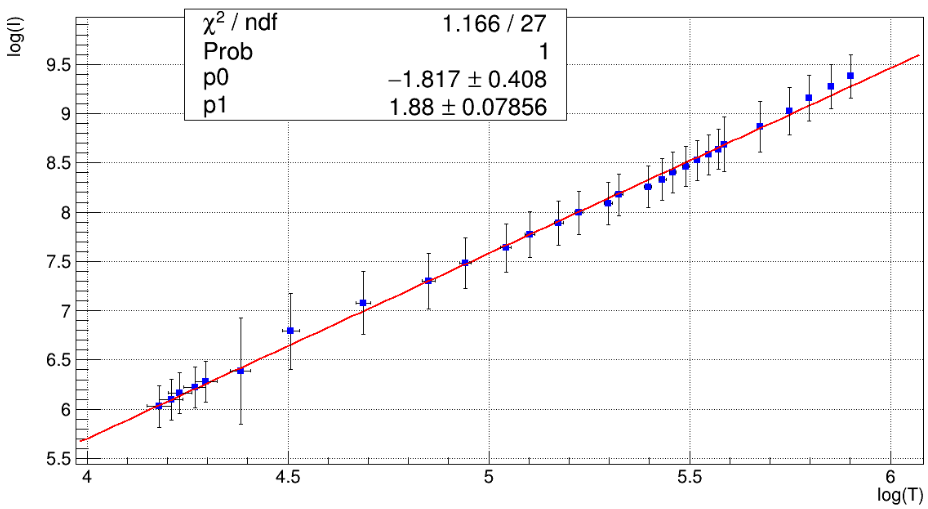

Figure 13: The graph with Celsius values and with only the second c

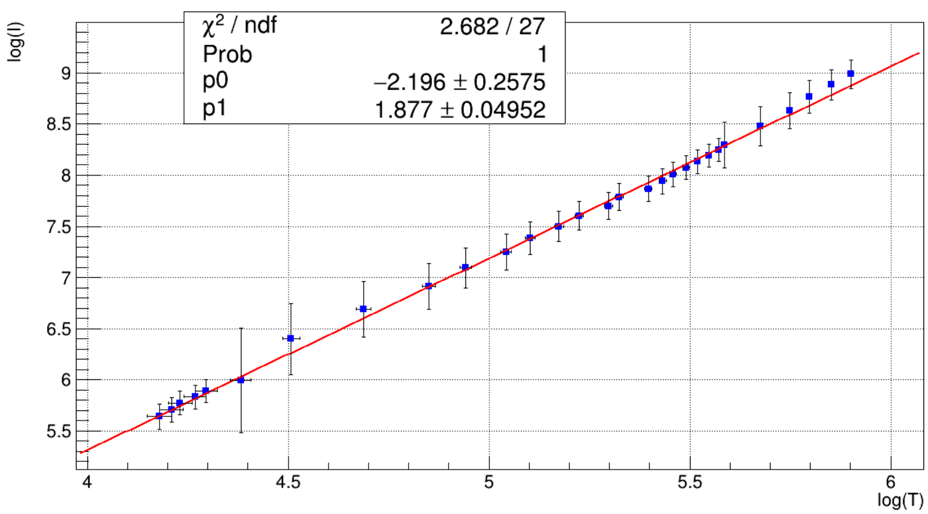

Figure 14: The graph with Celsius values and with only the average c

heating filament. This effect was much more for near configurations so the nearest distance may effected by this. The farthest one may effected by the reflections from environment much more compared to others. So, those may be the causes for the second one to be the best one.

I couldn't figure out why we used c to convert V to I at the last part. It was written to be done so in your notebook. But I think it is like the constant multiple I mentioned about the error in inverse square thing. Or, it seemed to me unnecessary. Also I did, with your instructions, the similar log-plot before at those three distances with V, not I.

At last but not least, use of only second c turned out to be a good idea since its result was much more better than the result from the averages.

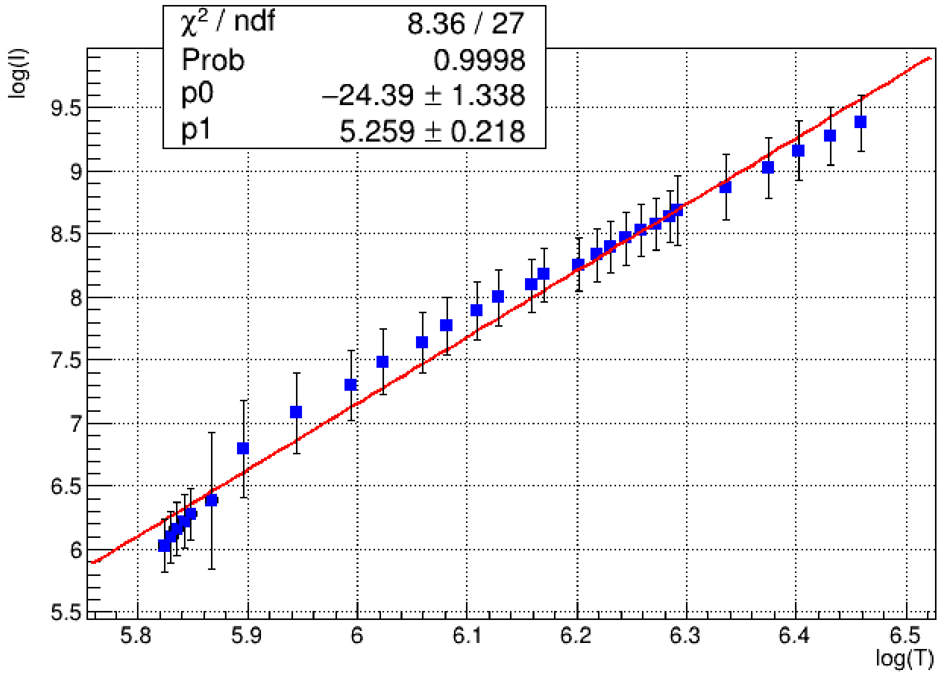

Figure 15: The graph with Kelvin values and with only the second c

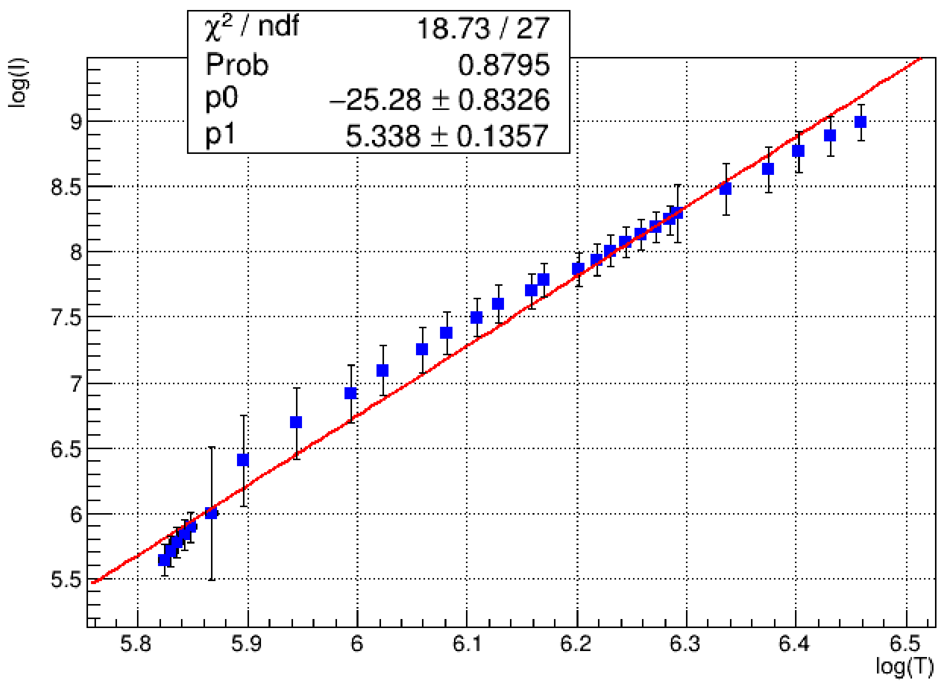

Figure 16: The graph with Kelvin values and with only the average c

5 Appendix

The photos, spreadsheets, and codes are in the following link. All references are gives as footnote.

https://github.com/beratgonultas/443