Final Design Report: Using a Reliable Spark Gap to Determine Ionization Patterns of Electricity Through Air

Michael Bourdelais

Advisor: Dr. Robert Fersch

April 25, 2022

1 Abstract

The use of a spark gap was employed in the hopes of measuring various quantities pertaining to Paschen's law.A spark gap is created from a large applied voltage to a system of two unconnected electrodes. The breakdown voltage,pressure of air, and the separation distance of electrodes were scrutinized the most. Once these quantaties were measured, they were used to calculate the Secondary-Electron-Emission-Coefficient(SEEC).This project aimed to determine if using the breakdown voltage, pressure, and separation distance, the SEEC could be reliably approximated and how this approximation varies from understood theory. The results of the data from this experiment were interpreted using a chi square goodness of fit test and percent error calculations. As the resulting P-value from this chi square test was 0.99 which indicates the results for this experiment are not statistically sound. This is believed to be as a result of the tools for data acquisition not being precise enough to measure the breakdown voltages well enough for accurate data. However, despite the high p-value the distribution of the data appears to follow a similar form to the theoretical and thus another experiment with better equipment in the future could yield more substantial results.

2 Introduction

The purpose of this experiment was to determine that the SEEC can be calculated from spark gap data. A spark gap requires two unconnected electrodes one of which will be induced with high voltage and another that will be receiving the created spark and grounding it. The breakdown voltage needed to create a spark will vary heavily depending on the separation distance between the electrodes and the barometric pressure of the lab setting.The apparatus for this project was constructed specifically to determine the value for the SEEC. To accomplish this a brass plate and screw were used as the cathode and anode respectively. A large amount of voltage was applied to the plate while the brass screw received the spark discharge from this plate. The use of brass was important for this as it is a highly conductive material. upon getting the proper separation distance of 0.102 millimeters using a feeler gauge, data was taken over various days and lab settings. This separation distance was important as a certain range of Applied electric field over pressure (E/P) had to be maintained for data validity. If this value were to be too high or low the empirical values for certain coefficients within paschen's law could not be determined. With the use of this empirical data along with the recorded data from experiments, the SEEC can be estimated. The anticipated result for this data is to see a linear positive distribution in breakdown voltages compared to pressure distances. [2]

The expected result is to see an array of various breakdown voltages recorded as the pressure will be constantly changing between experiments thus changing the amount of voltage needed to create a spark gap. In terms of the theoretical SEEC value, A value was determined for this by examining other scholarly work by the title of "Effective Secondary Electron Emission Coefficient of Brass" Published by the "Current Smart Materials" journal, in this work the SEEC for brass was measured to be roughly 0.81 - 1.31.

3 Theory

This project used Paschen's law for the understanding of how breakdown voltage is correlated to the separation distance and pressure, as well as how the distribution of breakdown voltages plotted against pressure distance is supposed to propagate.Paschen's law describes the amount of applied voltage needed on an electrode to create an arc of electricity through the air over a set distance and pressure. As this voltage is applied the air will begin to be ionized by emitted electrons from the electrode causing an electron avalanche. As these electrons avalanche, they collide with the gas particles between the two plates turning the gas particles into positive ions. once these ions reach the other electrode the air between the two plates will become a suitable conductor for the electricity of the initial electrode. This law also contains various coefficients that pertain to the composition of the mediating gas and the material composition of the electrodes. The A and B coefficients are both constituent of the gas composition and for this experiment are most closely associated with air. the last coefficient γ is the SEEC, this coefficient is the ratio in which a receiving electrode, when struck with a positively charged ion, will emit a secondary electron.

Paschen's law is described by the following equation, Where V_b is the breakdown voltage, A and B are empirical constants, d is the separation distance, p is pressure, and γ is the SEEC to be determined.[3]

$$V_B = \frac{Bpd}{Ln(Apd/Ln(\frac{1}{\gamma}))} \tag{1}$$

The values for A and B are determined empirically for air to be 14.6 $\frac{1}{Torr*cm}$ and 365$\frac{Volts}{Torr*cm}$ for an Applied voltage over pressure range between 100-800 $\frac{Volts}{Torr*cm}$. This range is of great importance as the use of the A and B coefficient as the stated values is predicated on the spark gaps Applied voltage over pressure being between 100-800. Should the spark gap fall out of this range, then the A and B coefficients could change drastically and the data would be inaccurate to the theoretical value. With respect to theoretical values for this project, once the separation distance and pressure was measured the theoretical value for the breakdown voltage will be calculated by plugging those values and the known coefficients into paschen's law. This theoretical breakdown voltage is what will be used to test the gathered data for validity using a chi square goodness of fit test. Should the gathered data not be statistically sound a analysis between the experimental and theoretical value for the breakdown voltages will show this. If the resulting P-value is too high the data will be considered not statistically sound and thus the results for the calculated SEEC value will be inconclusive.

4 Methods

To begin this project a frame for the spark gap needed to be created so that both the brass plate and screw could be fastened and measured with a feeler gauge. This frame was created using an Ultimaker 3D printer. There was a separate 3D printed plate for the receiver that was constructed to be synonymous to the height and width of the brass plate. However this plate was printed with a hole through it that would allow for the fastening of a brass screw provided a rubber washer was connect to the frame prior. The rubber washer served as a means for holding the screw in place as well as allowing for the separation distance to be adjusted easily as needed. in order to measure the exact distance between the brass plate and the screw a feeler gauge was used. While adjusting the screw, the feeler gauge was used spacer between the two electrodes and removed once the screw was properly distanced. upon completion of the spark gap construction, a kilavolt source was connected to the brass plate while the screw was connected to ground. An oscilloscope was connected between the screw and the ground so as to verify that a spark gap occurred. This verification shows on the oscilloscope as an impulse function that sharply increases then sharply decreases.

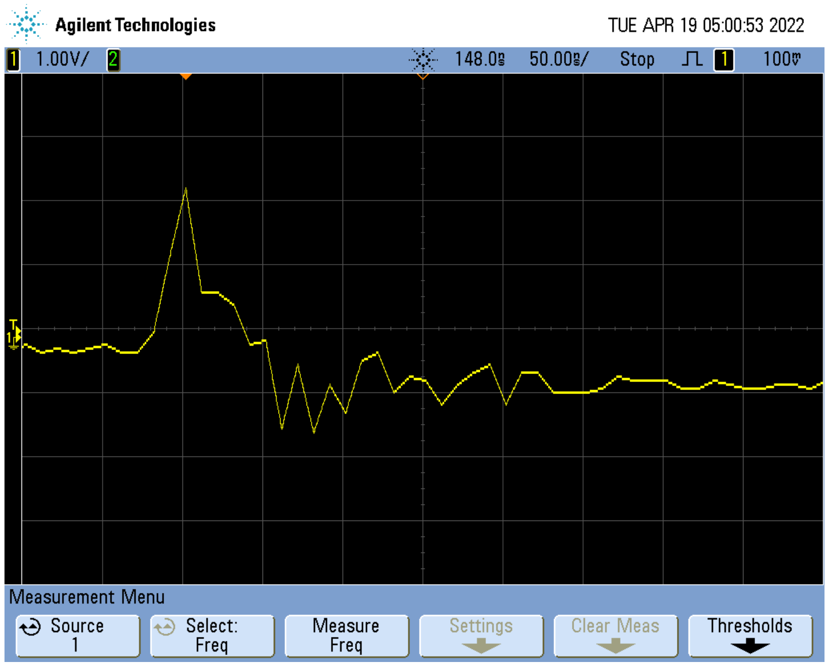

Figure 1: This is an impulse propagation on an oscilloscope.

When conducting an experiment, the barometric quantities for the lab were recorded. These values included the pressure, temperature, and humidity of the lab. Once recorded, personal protective equipment namely 12 kilavolt rated electrical gloves were used to increase the applied voltage. Once enough voltage was applied a spark would be either heard or seen and the breakdown voltage would be recorded as the current voltage reading on the kilavolt source. Multiple breakdown voltages were recorded over various days to allow for varying pressures in the lab room.

Upon collecting an ample amount of data, in this case more than 3 points to allow for the use of a chi square test, the data was written into a Comma Separated Value file and imported into python for processing. This python code calculated the theoretical values for the breakdown voltages using the pressure and distances recorded prior. The value for γ was also calculated using this code.

5 Data

From the data gathered, a graph was constructed displaying both the theoretical and experimental data points pertaining to breakdown voltage against pressure distance. A conjoining graph was constructed for the uncertainty in the breakdown voltages and pressure distances. From the graph a linear trend can be seen for the theoretical values however the experimental data does not clearly display this linearity. This discrepancy is likely due to the high fluctuation of breakdown voltage values. A chi square goodness of fit test was used on the breakdown voltages between the theoretical and experimental data. This test resulted in a chi-square statistic of 1.97 with a P-value of 0.997. The uncertainty in the breakdown voltages was derived from the lowest scientific digit on the device divided by two resulting in an uncertainty of $\pm 5v$. The uncertainty in the pressure distance was calculated using the following equation where $\Delta p = 0.05hpa$ and $\Delta d = 0.0005mm$

$$\Delta(pd) = \sqrt{(\frac{\Delta p}{p})^2 + (\frac{\Delta}{d})^2} \tag{2}$$

With the experimental data, the value for the SEEC was calculated to be 1.0114 using the following equations,

$$c = (Bpd)/V_b - ln(pd) \tag{3}$$

$$\gamma = e^{\frac{A}{e^C}} \tag{4}$$

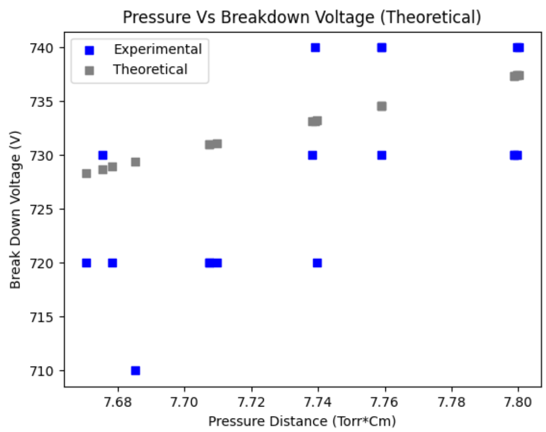

Figure 2: This is the plot of the uncertainties in both the breakdown voltages and the pressure distances for the gathered experimental data.

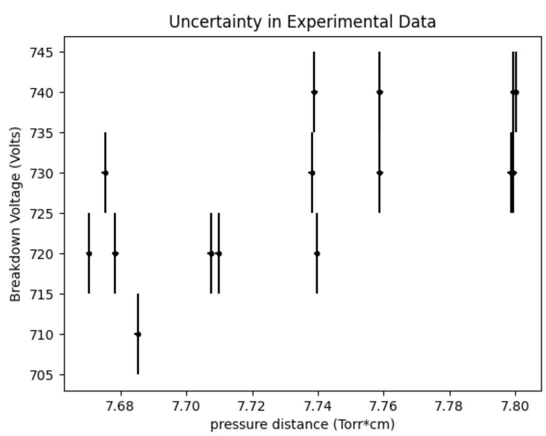

Figure 3: This is the plot of the uncertainties in both the breakdown voltages and the pressure distances for the gathered experimental data.

6 Discussion And Conclusions

Based on the high p-value for the chi square goodness of fit test, it can be seen that the experimental data is not statistically sound when compared to the theoretical data. This means that there is too much of a difference between the experimental and theoretical data to consider the experimental data as a good model for paschen's law. As a result of this the calculated value for the SEEC is incorrect by a wide margin. the calculated value was found to be 1.0114 where as the theoretical value for the SEEC is 0.1 .

This being the case the experimental data does appear to follow a similar positive trend to the theoretical data. The high uncertainty in the breakdown voltage is what likely caused this wide distribution of breakdown voltages. This large uncertainty comes from the lack of precision in the killavolt source used as the device only has three significant figures. Should a more precise killavolt source be used a much more fitted set of experimental data is likely to be taken.

Aside from the uncertainty in the breakdown voltages, the overall positive trend of the experimental data appears to be linear. A linear distribution of breakdown voltages compared to pressure distance is correct in this case as there is little variation in the pressure distance. If the separation distance for the spark gap were to be varied, then the resulting distribution of data would be more akin to a paschen curve.[1] When this curve is taken at a small range of pressure distance values then the resulting data will appear as a linear set of data.

In the future a new killavolt source along with varying separation distances would give more accurate results when compared to a Paschen curve. As well as a separate measurement could be made in order to record the SEEC before attempting to approximate it with the breakdown voltage data. This measurement could be done by measuring the discharge power across the electrode and the fraction of power carried by the ion to the cathode. Measuring the SEEC before will give another form of theoretical data point to test the experimental data.

7 Appendices

1	seperation distar	pressure (hpa)	humidty %	temperature (C)	breakdown voltage (V)
2	0.102	1000.8	53	21.5	0.73
3	0.102	1001.2	52	21.7	0.72
4	0.102	1000.16	52	21.8	0.72
5	0.102	1002.1	51	21.9	0.71
6	0.102	1005	41	21.8	0.72
7	0.102	1005.3	41	21.9	0.72
8	0.102	1005	40	22	0.72
9	0.102	1016.9	44	21	0.73
10	0.102	1017.1	44	21.3	0.74
11	0.102	1016.9	44	21.4	0.73
12	0.102	1017	44	21.5	0.74
13	0.102	1017	44	21.5	0.73
14	0.102	1011.7	49	22.2	0.74
15	0.102	1011.7	49	22.2	0.73
16	0.102	1011.7	49	22.3	0.74
17	0.102	1009	51	21.9	0.73
18	0.102	1009.1	50	21.9	0.74
19	0.102	1009.2	50	21.9	0.72

Figure 4: This is a graph of all the data taken for this capstone project.

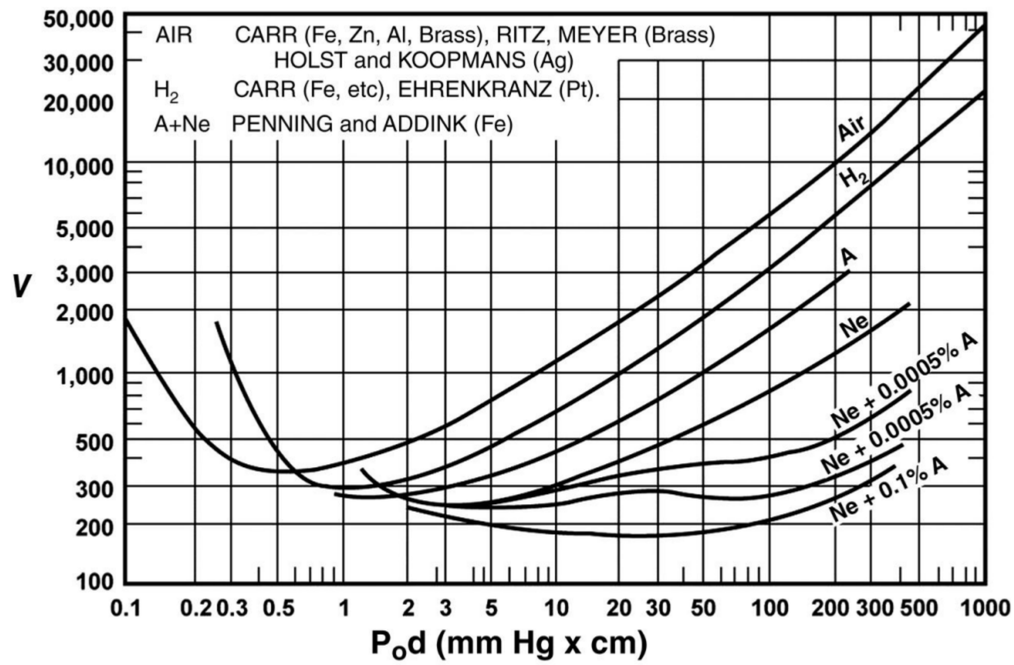

Figure 5: A graph of paschen curves for various types of gas

References

[1] K Philips Allen K R. Cloud chamber study of electron avalanche growth. *Proceedings of the Royal Society of London*, 274(1357,1963):163–86, 1963.

[2] Owen Richardson Gimpel, Irena. The secondary electron emission from metals in the low primary energy region. *Proceedings of the Royal Society of London*, 182(988):17–47, 20221943.

[3] Pralhad Ros Jane Lehr. *Foundations of Pulsed Power Technology*. John Wiley and Sons, Inc., 2017.