Properties of a DC Discharge Plasma

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Abstract

What is plasma? Plasma is the ionization of a gas, meaning we are separating the protons and electrons from one another. As a result, plasma often produces visible light from electrons accelerating.

This paper walks through our research processes of discovering a correlation between cathode distance, pressure, and voltage in a dc discharge plasma formation. Figure 1 on the following page is an image of our experiment layout. Additionally, we have a vacuum pump on the floor to the left of the pressure gauge. Our experiment setup uses a vacuum pump to extract air from our gas tube, resulting in a lower pressure in our glass tube. We installed a fine adjust valve (pressure valve 2 in the figure) to keep the air between pressure valve one and pressure valve two as control air so that we could enter our glass tube to maintain a stable pressure. However, we could not adjust the valve efficiently to let minimal air into the tube to keep stable pressure. After the vacuum tube was at our ideal pressure, we turned on the high-voltage power supply and carefully added voltage until we saw a plasma breakdown in the vacuum tube.

During the preliminary investigation, we had a breakdown of plasma at a 23.35 cm distance between the cathode and anode, approximately 600 millitorr pressure, and 1.02 kilovolts of power from the anode and cathode. With our given setup, we can change three variables of our experiment, the distance between our anode and cathode, pressure in our glass tube, and voltage applied to the anode and cathode. Initial research prompted experimenting with the idea of the Paschen curve. According to “Foundations of dc plasma sources” by J.T Gudmundsson and A. Hecimovic, “This curve shows that

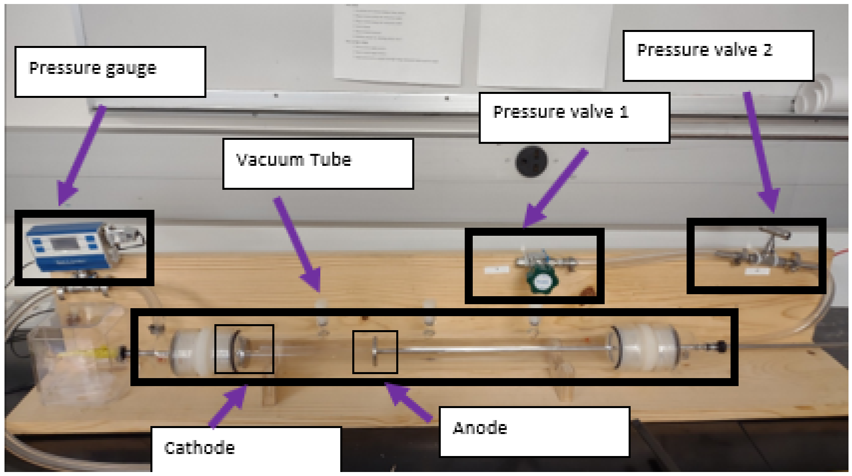

Figure 1: DC Plasma Formation Experiment Diagram

for a fixed discharge length L there is an optimum pressure for plasma breakdown." The source also states, "At lower pressures, the ionization process is ineffective due to the low electron-neutral collision probability, while at higher pressures, elastic collision prevents the electrons from reaching high enough energy." Explaining how at lower pressure, the distance between cathode and anode needs to be longer to produce a discharge similar to that of high pressure and low distance between cathode and anode. Our purpose was to safely ionize air into a plasma and investigate the relationship between breakdown voltage and pressure multiplied by distance between cathode and anode.

Given this correlation, we had a working hypothesis relating all components distance, pressure, and voltage. Pressure multiplied by distance is related to voltage by decreasing our pressure-distance ratio, which leads to less voltage required to produce plasma. Once we had this working hypothesis, we plotted seven distances and 3 data points at all distances. Besides the lowest distance of 1.01cm, we acquired five points. After finding all this data, we could relate the pressure multiplied by the distance to a voltage by the given equation.

$$\boxed{Y = -1E - 09X^3 + 3E - 06EX^2 - .0013x + 0.8273}$$

Figure 2: Y is breakdown voltage (kV)and X electrode distance (cm)

Data

Electrode Distance (cm)	Pressure Reading (mTorr)	Plasma Breakdown Voltage (kv)
23.50	365	1.02
23.50	330	1.07
23.50	315	1.07
28.50	345	1.11
28.50	335	1.15
28.50	341	1.14
18.52	345	1.02
18.52	345	0.96
18.52	332	0.93
13.51	370	0.88
13.51	337	0.68
13.51	327	0.7
8.52	355	0.85
8.52	333	0.63
8.52	306	0.66
3.51	321	0.6
3.51	260	0.65
3.51	255	0.65
1.01	320	0.6
1.01	281	0.77
1.01	768	0.38
1.01	317	1.27
1.01	273	0.61

Figure 3: Recorded milltorr of pressure, electrode distance (cm), and breakdown voltage (kV)

Calculations

$$\boxed{1\text{Pa} = 0.33\text{mT}}$$

Electrode Distance (cm)	Pressure Reading (mTorr)	Plasma Breakdown Voltage (kv)	P (Pa)	$P \cdot D$ (mTorr*cm)	$P \cdot D$ (Pa*cm)
23.5	365	1.02	48.55	8578	1140
23.5	330	1.07	43.89	7755	1030
23.5	315	1.07	41.9	7403	985
28.5	345	1.11	45.89	9833	1310
28.5	335	1.15	44.56	9548	1270
28.5	341	1.14	45.35	9719	1290
18.52	345	1.02	45.89	6389	850
18.52	345	0.96	45.89	6389	850
18.52	332	0.93	44.16	6149	818
13.51	370	0.88	49.21	4999	665
13.51	337	0.68	44.82	4553	606
13.51	327	0.7	43.49	4418	588
8.52	355	0.85	47.22	3025	402
8.52	333	0.63	44.29	2837	377
8.52	306	0.66	40.7	2607	347
3.51	321	0.6	42.69	1127	150
3.51	260	0.65	34.58	912.6	121
3.51	255	0.65	33.92	895.1	119
1.01	320	0.6	42.56	323.2	43
1.01	281	0.77	37.37	283.8	37.7
1.01	317	1.27	42.16	320.2	42.6
1.01	273	0.61	36.31	275.7	36.7

Figure 4: Calculations table of conversions

Error Discussion

Uncertainty and Error

The tools we used for measurements, a ruler down to the mm allowing for a $\pm$1mm error. We also used the Pressure gage which to the millitorr allowing for a $\pm$1millitorr. The object with the most error was the power supply which a $\pm$,0.01kv error, shown in Figure 2.

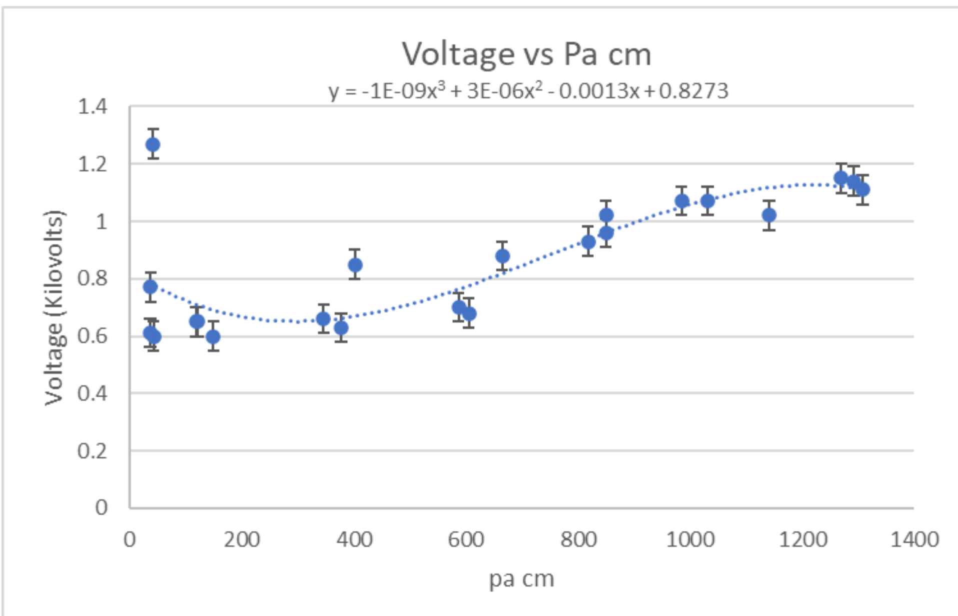

Figure 5: Voltage over Pa cm Graph

Mistakes/Blunders

In our experiment we are not able to keep the pressure constant in our plasma tube which lead to vary in our data however did create plot our data with pressure multiplied by distance.

Result

During this experiment it was quite apparent that we had close to zero control over a stable pressure. Another topic of reflection would be to organize a another experiment with more control on our variables in order to which shows the Pachens Curve. With our data collected from the experiment we found the relationship between pressure, electrode distance and voltage. The relationship found was that as the pressure-distance ratio decreased, the lower the voltage was required to make plasma. This matched our hypothesis, and the experiment data supported it.

Result Statement

The calculations show that when the electrode distance decreased, and the pressure decreased in the containment tube, the required voltage to obtain plasma also decreased.

Future Experiments and Possible Alterations

Looking into the possibilities of the experiment, one of the biggest prospects is a different vacuum tube setup. Possible shapes for a new containment chamber can be dome like or if the tube shape is retained, possible concave or convex portions of the tube can alter the experiment. To further the observation ability of the plasma different apparatuses can be placed into the containment chamber for voltage application or magnetic application. An example of this can be a coil to change the movement of the plasma, and to further observe the effect of magnetism on the plasma you can input magnets into or around the containment chamber. With the current setup it is possible to analyze the same pressure-distance ratio and how that affects plasma, however now we can run the experiment with different gases, for example, the element Argon. This will allow for a new range of data to create and compare it to the other tests. Looking into the issues we had, something that needs to be resolved is the lack of pressure control. A possible solution to this would be access to a pressure valve between the vacuum pump and the containment tube. This would allow the user of the system to isolate the system of the plasma experiment and hopefully have a stable pressure inside the system. The only concern with this is that the new stable vacuum would have to be carefully released when the desired tests have been completed

References

Gudmundsson, J. T., & Hecimovic, A. (2017). Foundations of DC plasma sources. Plasma Sources Science and Technology, 26(12), 123001. https://doi.org/10.1088/1361-6595/aa940d

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