Properties of a DC Discharge Plasma

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Abstract

There have been Plasma is the ionization of a gas, meaning the separation of protons and electrons in a gas body. As a result, plasma often produces visible light from electrons accelerating. A common way to form a plasma is a dc discharge. In a dc discharge a gas body is present in between a cathode and a anode, voltage is applied releasing electrons to initiate a collision between particles to cause a plasma. Over years many publications have researched this process, leading to the study of properties of the dc discharge.

This paper walks through our research processes of discovering a correlation between cathode distance, pressure, and voltage in a dc discharge plasma formation. This required a configured an environment to replicated a dc discharge. Figure 1 on the following page is an image of our experiment layout. Our experiment setup uses a vacuum pump to extract air from a closed gas tube, resulting in a lower pressure. A fine adjust valve (pressure valve 2 in the figure) is used to keep the air between pressure valve one and pressure valve two as control air for pressure to be maintained. However, we could not adjust the valve efficiently to let minimal air into the tube to keep stable pressure. After the vacuum tube is at an ideal pressure, a high-voltage power supply is turned on and carefully adding voltage in between the cathode and the anode. At ideal pressure, voltage and distance dc discharge plasma is formed.

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 ex-

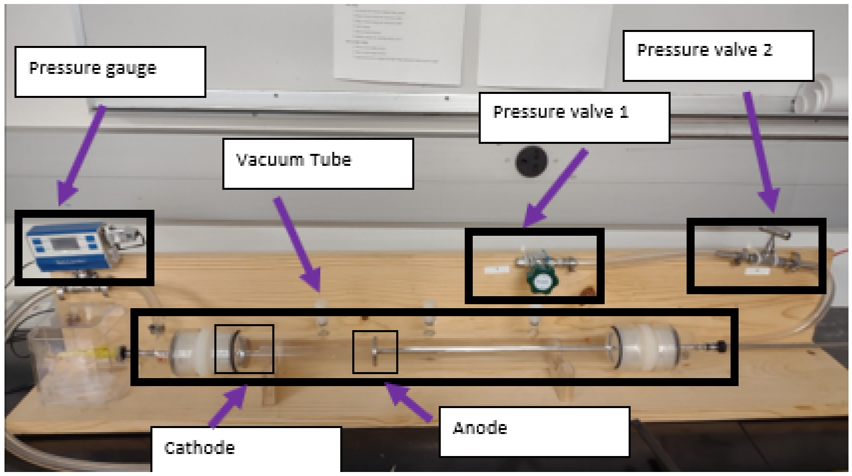

Figure 1: DC Plasma Formation Experiment Diagram

periment, 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 for a fixed discharge length L there is an optimum pressure for plasma breakdown." Therefore a breakdown voltage for a plasma can be found and represented using the Paschen Curve. Foundations of dc plasma sources 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.

To investigate if pressure multiplied by distance is related to voltage decrease we plotted seven distances and 3 data points at all distances. Designing and conducting an experiment to see whether our breakdown voltage patterns would match as stated in the Paschen Curve

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

Calculations

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

Figure 3: Milli Torr to Pascals Conversion Formula

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 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.

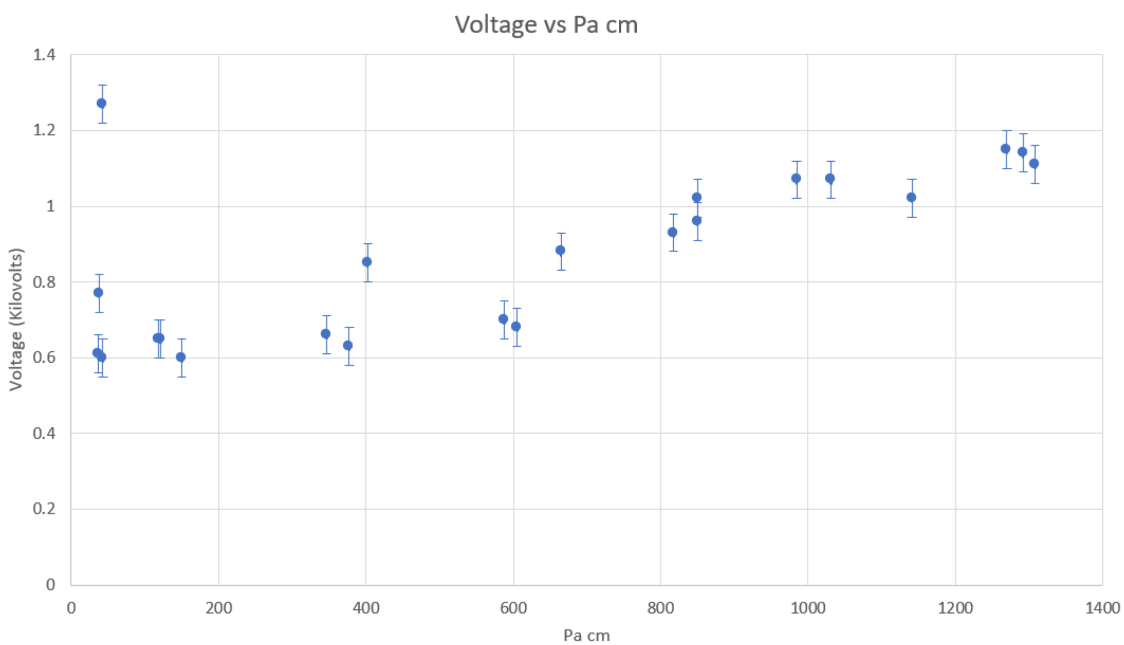

Figure 5: Voltage over Pa cm Graph

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

With our data collected from the experiment, a relationship was proved between pressure, electrode distance and voltage. As the pressure-distance product decreased, a lower the voltage was required to make plasma. Reasoning being that as distance between electrodes decreased, we get a higher chance of electron collision in the gas body. A lower pressure however would result in less force per area leading to less chance of collision therefore as the pressure-distance product decreased breakdown voltage did also increase. At a lower pressure and closer electrode distance we need a higher initial voltage to initiate a dc discharge breakdown of plasma. This would be due to at a lower pressure we have less chance for collision between the electrons and particles of our gas body. Calculations extracted from the data collected show that when the electrode distance decreased, and the pressure decreased in the containment tube, the required voltage to obtain plasma also decreased. Proving the paschen curve observations of a breakdown voltage. This idea of voltage decreasing as well as increasing due to environment changes draws ideas to additional study of this pattern. At what point does our breakdown voltage increase for a plasma breakdown? Would this act differently in a different gas body?

Future Experiments and Possible Alterations

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. Through this experimentation we were able to replicate a dc discharge plasma as well as compare our data to conclusion from fundamentals gas laws.

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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