Core Concepts

**Plasma Electron Temperature**

Plasmas consist of both ions and electrons acting as a semi-coherent system. Using the common definition of temperature, the ions and electrons should be at the same temperature. However, because the electrons have much smaller mass than the ions, they have greater thermal velocity. This means that their motion due to temperature is greater. Also because of this lower mass, when we introduce a floating potential, the electrons respond more strongly than the ions. This results in the electrons’ effective temperature being higher than the ions’ effective temperature, even though they are part of the same body of plasma. The electrons’ temperature is dependent on pressure and the gas that has been ionized. We also found an inverse relationship between changes in the base voltage and the temperature.

**Plasmas: Ions and Electrons**

Plasmas are quasi-neutral gasses. This means that the gas consists of ions and electrons, so the overall charge is neutral, but the ions and electrons exist separately within the system, so it behaves as a charged system. The plasma reacts to the electrical current; because plasmas are quasi-neutral, they behave as primarily positive or negative depending on the external charge. The main idea of this experiment was to see that charges’ thermal energy has an important role in the plasma’s behavior and was controlled by the electrical potential. The plasma ions and electrons have an important role in our modern days because it help us understand the theory behind it and help us replicate the experiment in the laboratory setting. With modern technology we can go one step up by computing the data we collect in the experiment for further study.

Equipment

**The Langmuir Probe**

The Langmuir probe we used inserts an electrode into a plasma and runs a varying electric potential through the system. By observing the resulting current, the plasma’s temperature can be determined, among other things. The Keithley device was set up to control the bias, or sweeping, potential. Early physicists thought the plasma potential to be very similar to, if not the same as, the probe’s floating potential — the potential at which the probe sits if there is no bias potential being added. However, a floating probe by definition doesn’t receive any net contribution from the plasma, so this isn’t necessarily correct. The Langmuir probe instead measures the current in the plasma by comparing the potential inside the tube containing the plasma with the potential on the outside of the tube to calculate the plasma potential, then converting that data to current data.

**Keithley Integration/Python Setup**

We used the Keithley device to simultaneously vary the floating potential within the plasma and measure its current. We have Keithley tethered to the computer where the computer collects the data and commands the Keithley device to run a different current through the probe. The data we collected were generated by Python and saved as .csv files. Python is a high-level programming language that can read various file types, control devices and analyze large quantities of data. Python was created in 1991 and has many different libraries, most of which are open source. For this experiment we used several libraries, including matplotlib, NumPy, and SciPy. Python is free and powerful for data analysis and research.

Data Analysis

**Plasma Temperatures at Varying Pressures**

By increasing the pressure of the plasma, we would expect the electron temperature to decrease. Our measurements confirmed this, and the graphs show an associated steeper slope for the electron-dominated current. We started this experiment with our hypothesis that as we increase the pressure of the plasma there will be some effect on the temperature. We tried different pressures, and, through different data analysis and long hours of observation, we concluded that pressure does inversely affect the temperature of the plasma. We plotted the data to the Python program using the libraries matplotlib and bokeh. The experiment can be replicated, and our data are available for further analysis if wanted.

**Plasma Temperatures at Varying Base Voltages**

We had initially hypothesized that increasing the base voltage of the plasma would increase the electron temperature. However, we found through observation that the slope of electron-dominated current increased as our base voltage increased, indicating that the temperature was decreasing. The plasma temperatures did not noticeably change with sweeping voltages, but this was likely due to the comparatively small range over which we could sweep our voltage; it took a change of a few hundred volts in base voltage to see a noticeable difference in temperature. It seems odd that electron temperature would decrease when voltage increases, since we should expect our energy to increase, but electron temperature is most relevant to thermal energy, so it could be that temperature is decreasing because more energy is being allocated toward flow of current than thermal movement of particles.

Sources

In addition to the sources provided as part of the lab, we drew information from the following:

<http://home.sandiego.edu/~severn/langmuir_probes_amjp.pdf>