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Langmuir Probe Paragraphs

Theory

Plasma is a state of matter defined as an ionized gas. Specifically, it is a gas where the electrons have become disassociated from the molecules and atoms within, resulting in a combination of negatively charged electrons and positively charged ions moving around freely. These free charged particles make plasma conductive, meaning that the plasma itself is sensitive to external electromagnetic fields. Plasma is described in terms of macroscopic “parameters”, including the electron and ion densities and temperatures, and the plasma potential. One of the oldest and simplest devices to measure these parameters in the Langmuir probe. A Langmuir probe consists of a bare wire and metal disk which is inserted into the plasma and electrically biased with respect to a reference electrode to collect electron or ion currents. When we plot the current data with respect to the voltage, we get a characteristic I-V curve, from which we are able to derive many features through inspection and manipulation. In order to do this, we run a current across a low pressure, vacuum tube filled with gas to generate a plasma. We then perform a sweep of probe bias voltages and measure the change in current across the voltage range. From this data, we then derive several important plasma parameters.

Instrumentation

Our experimental setup starts with a high voltage source, run across two electrodes in the gas filled vacuum tube, in order to generate a plasma. In the tube, a Langmuir probe is placed about half way. We then use a Keithley 6487 picoammeter/voltage source to perform a “sweep” of voltages to bias the probe relative to the plasma, and also to measure the electron current that gathers on the probe's surface. The 6487 is a feedback type ammeter which allows for extremely accurate low current measurements. In the feedback type configuration, an input current flows into a high gain amplifier with a negative corrective feedback voltage which serves to minimize the input voltage burden to be near zero. The input current also flows across a feedback resistor connected in parallel. The sensitivity of the feedback resistor, together with the input current is what determines the output voltage. This is compared to the shunt ammeter configuration, in which the input current runs across a shunt resistor, which sets the sensitivity and serves to reduce the input voltage burden. One additional process used by the 6487 to improve the accuracy of low-current measurements is called “autozeroing”. Simply, to help maintain stability and accuracy over times and changes in temperature, the 6487 periodically measures internal voltages corresponding to offsets (zero) and amplifier gains. These measurements are then used in the 6487 algorithm to calculate the reading of the input signal. The 6487 was connected to a computer and controlled using a python script which allowed us to set the range and step size of our voltage sweep.

Data Analysis

The data were collected for three large voltages generated across the vacuum tube: 1200 V, 1300 V, and 1400 V. For each large voltage, the probe was biased over a range of -450 V to -120 V. Once the data were collected, the I-V curve was plotted and used to identify several parameters. From the unaltered I-V curve, we were able to immediately identify the ion saturation current (the initial negative current), the electron saturation current (the final positive plateau), and the floating potential (the voltage where the current crosses the x axis). The gradient of the total current with respect to the probe bias voltage and selected the voltage value where the gradient reached its maximum. This gave us the plasma potential. Lastly, the ion saturation current was subtracted out of the total current on the I-V curve to obtain the electron current. In order to linearize the electron current, we took the natural log in order to obtain a linear relationship with the bias voltage. This was then plotted as a semi-log plot with the probe bias. From this new curve, the linear segment was selected and a linear fit function was used to obtain a fit equation. The error in this fit was determined using the variance in the fit function. The slope was then used to solve for the electron temperature. Our calculated values for the electron temperature were substantially higher than seemed reasonable, being 294,038 K +/- 6999 K (25.34 eV +/- 0.60 eV) at 1200 V, 299,393 K +/- 7114 K (25.80 eV +/- 0.61 eV) at 1300 V, and 294,587 K +/- 6854 K (25.38 eV +/- 0.59 eV) at 1400 V. From the literature we were given, we would seemingly expect values about an order of magnitude lower. As of now, we have not determined any convincing reasons for the error in these values. We spoke with several other students about which values they calculated, and it seems as though calculating electron temperatures at this order of magnitude was by no means uncommon. As of now, I would say that I'm inclined to believe it is due to some error in the calculations themselves, rather than in the data or measurement.

Langmuir probe for atmospheric measurements

Langmuir probes are one of many devices used to take in situ measurements of plasma in the Earth's atmosphere, in particular of the upper atmospheric region known as the ionosphere. The ionosphere is a region of ionized gas, caused by incident solar winds, ranging from roughly 50 km to 1000 km above sea level. Satellites equipped with Langmuir probes can be useful in measuring the I-V curve of the ionospheric plasma, from which plasma parameters can be derived. One example of a particularly useful characteristic of the ionospheric plasma to measure is the critical frequency, which itself is proportional to the maximum electron density. This is an important quantity to measure when trying to establish intra-planetary, as well as extra-planetary communication via radio waves. Any radio waves with a frequency less than the plasma’s f_c will be reflected back towards the Earth, allowing for the bouncing of radio signals off of the ionosphere. Alternatively, any radio wave with a frequency greater than the plasma’s f_c will penetrate the ionosphere, allowing for the transmission of radio waves through the ionospheric plasma medium. The electron density can be derived from the I-V curve returned by the Langmuir probe. Specifically, this can be done by solving for the electron current and the electron temperature.