Memorandum

To: William Saucier

From: Bryce Ipson, Connor Lane, Steven Sharp

Date: June 1, 2022

Subject: AERO 356 Langmuir Probe Experiment

Background:

We successfully conducted the Langmuir probe experiment on Wednesday, May 25, 2022, ending the experiment with a workable data set. The purpose of the experiment was to determine the properties of a plasma emitted by an electric thruster under low pressure, including the electron temperature and density of the plasma. This was accomplished by applying various voltages to the charged Langmuir probe and observing the response in current. We also analyzed another set of data collected by industry professionals for comparison with our data.

Nomenclature:

A_{probe} - Collecting Area of Probe

I - Current

K_B - Boltzmann's Constant

m_e - Electron Mass

n_e - Electron Number Density

q_e - Electron Charge

T_e - Electron Temperature

V - Voltage

$V_{e,th}$ - Electron Thermal Velocity

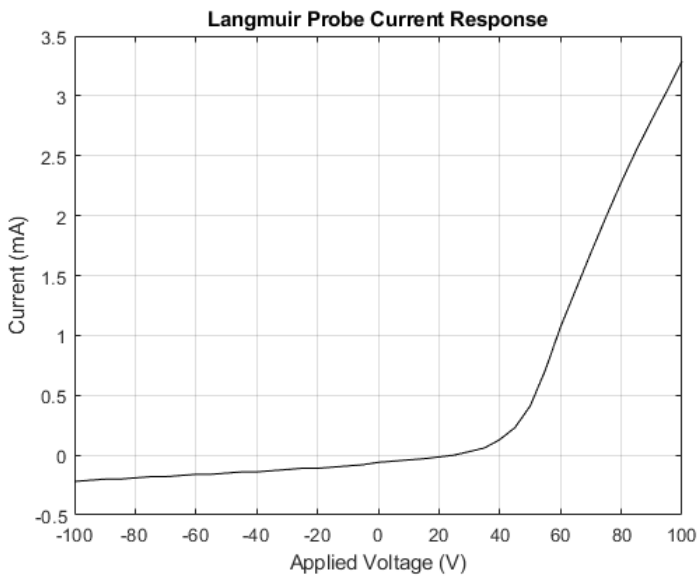
Λ - Plasma Parameter

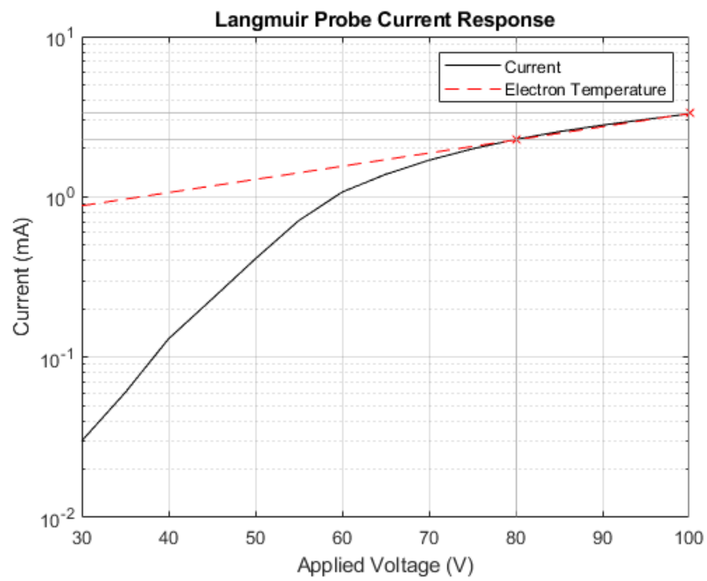
Methodology and Procedure:

We were given a pre-assembled setup consisting of an electric thruster inside the vacuum chamber connected to an external argon tank and a Langmuir probe connected to the external power supply and two external multimeters, with one multimeter measuring the voltage applied to the probe, and the other measuring the current response. In order to best understand the probe in vacuum conditions, we brought our pressure down to about 1.7 Torr, then measured the current response as we increased our applied voltage in 5 V increments from -100 V to 100 V.

Results and Discussion:

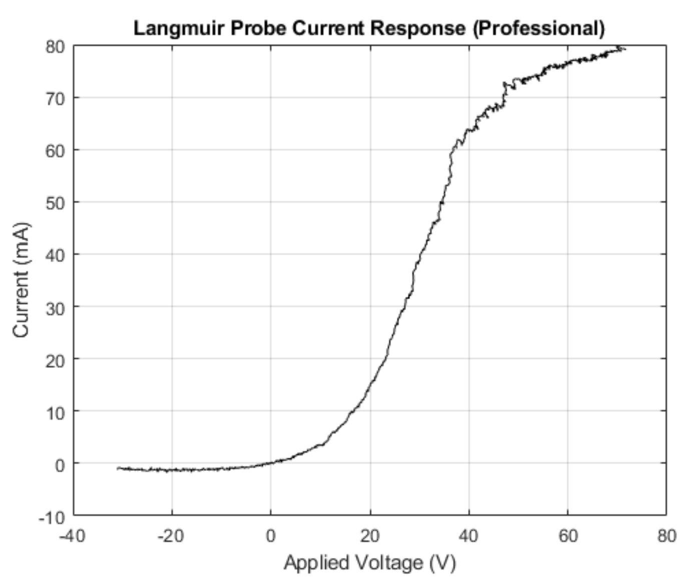
<u>Student Data</u>

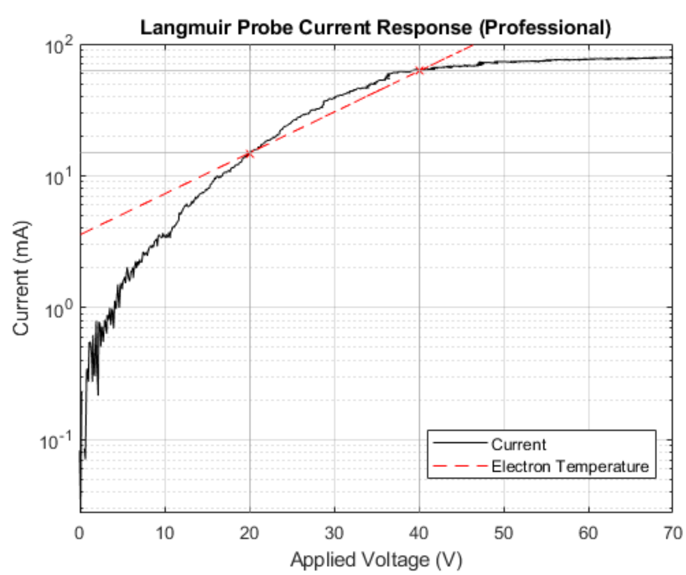




The floating voltage was recorded as 25 V.

<u>Professional Data</u>





The floating voltage was recorded as 549 mV.

Calculations

Student

$$T_e = \frac{V_2 - V_1}{\ln\left(\frac{I_2}{I_1}\right)} q_e$$
$$= \frac{100\,\mathrm{V} - 80\,\mathrm{V}}{\ln\left(\frac{0.00329\,\mathrm{A}}{0.00228\,\mathrm{A}}\right)} q_e$$
$$= 54.5387\,\mathrm{eV}$$
$$= 632{,}919.8\,\mathrm{K}$$

Professional

$$T_e = \frac{V_2 - V_1}{\ln\left(\frac{I_2}{I_1}\right)} q_e$$
$$= \frac{40\,\mathrm{V} - 20\,\mathrm{V}}{\ln\left(\frac{0.0634\,\mathrm{A}}{0.0147\,\mathrm{A}}\right)} q_e$$
$$= 13.6835\,\mathrm{eV}$$
$$= 158{,}796.3\,\mathrm{K}$$

$$V_{e,th} = \sqrt{\frac{8K_B T_e}{\pi m_e}}$$

$$\text{(Student) } V_{e,th} = 4,942,353.8\ \frac{m}{s}$$

$$\text{(Professional) } V_{e,th} = 2,475,595.5\ \frac{m}{s}$$

We also will need the electron number density for later calculations. Assuming that the area of the probe used in each scenario is equal, we can determine the electron density by graphically determining the electron saturation current and using the following equations:

$$I_{es} = \frac{q_e n_e V_{e,th} A_{probe}}{4} \qquad \Rightarrow n_e = 4\frac{I_{es}}{q_e V_{e,th} A_{probe}}$$

$$\text{(Student)} \qquad I_{es} = 3.096\,\mathrm{mA}$$
$$\text{(Professional)} \quad I_{es} = 59.684\,\mathrm{mA}$$

Thus the electron number densities for each situation are:

$$(\text{Student})\ n_e = 4.823 \times 10^{15}\ \frac{1}{m^3}$$

$$(\text{Professional})\ n_e = 1.856 \times 10^{17}\ \frac{1}{m^3}$$

Note that the plasma potential corresponding to the electron saturation currents are 97 V for the student data and 38 V for the professional data.

From the two electron temperatures and the electron number densities, we can determine the plasma parameter for each test using the following equation:

$$\Lambda = \frac{4\pi}{3}\left[\frac{\varepsilon_0 K_B T_e}{e^2 n_e^{\frac{1}{3}}}\right]^{\frac{3}{2}}$$

$$= \frac{4\pi}{3}\left[\frac{(8.85418782 \times 10^{-12}\frac{s^4A^2}{kg*m^3})*(1.380649 \times 10^{-23}\ \frac{kg*m^2}{K*s^2})*(632{,}919.8\ K)}{(1.60217663 \times 10^{-19}A*s)^2*(4.823\times10^{15}\frac{1}{m^3})^{\frac{1}{3}}}\right]^{\frac{3}{2}}$$

$$= 9.981*10^6\ (\text{Student})$$

$$= \frac{4\pi}{3}\left[\frac{(8.85418782 \times 10^{-12}\frac{s^4A^2}{kg*m^3})*(1.380649 \times 10^{-23}\ \frac{kg*m^2}{K*s^2})*(158{,}796.3\ K)}{(1.60217663 \times 10^{-19}A*s)^2*(1.856\times10^{17}\frac{1}{m^3})^{\frac{1}{3}}}\right]^{\frac{3}{2}}$$

$$= 2.022*10^5\ (\text{Professional})$$

These plasma parameter values are important because they tell us the general qualities we can expect when using the plasma. As the parameter increases, we can expect hotter, less dense, faster material which directly impacts the efficiency and effectiveness of certain mechanisms (like electronic thrusters). Some machines can't handle higher value parameters while some need more diffuse material like the materials with lower parameters. So what we see here is a numerical representation of the fact the students' material was warmer and less dense than the professionals' material.

One interesting observation was that the student data produced a significantly higher electron temperature than the professional data. Any number of typical experiment variables could have influenced this outcome. We believe our sources of error to be minimal since no issues occurred during the experiment however some differences between our experiment and the professional experiment did exist. For instance, our pressure was not strictly controlled during the test and as such our values may have varied slightly due to this. The probe was also not calibrated between tests and this may have led to the setup shifting slightly which would have changed the placement of our measurement tools. However, we have no specific evidence which proves this was an issue and due to any other lack of problems, we conclude our data was accurate.

Conclusion:

Plasma can often cause severe damage to a spacecraft, so understanding the properties of plasma is crucial for designing a spacecraft to withstand the plasma environments, such as the ionosphere and magnetosphere. As such, the Langmuir probe served to collect information about the currents of electrons and/or ions present in the plasma and determine the plasma's debye number (plasma parameter). Determining the plasma parameter for each experiment served to characterize the plasma and from there design considerations can be made to counteract the effects of the plasma on a spacecraft, such as grounding surface metallic parts, insulating key electronic components, etc.

References:

[1] Saucier, William, "High Voltage Considerations in a Plasma Environment," Space Environments II, California Polytechnic State University, 2022.