Spectroscopic Analysis of Rubidium's absorption spectrum

Warren Mardoum[a], Monica Chrisholm[b], Kjell Hiniker[b]

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We used a Langmuir probe to analyze the properties of ion acoustic wave propagation. We find the Voltage-Current Characteristic relation for the plasma under varying neutral pressure and discharge current. We can use these characteristics to calculate the ion acoustic wave speed. We may then emit a potential pulse in the plasma, which creates an ion acoustic wave. We can manually adjust the postition of the Langmuir probe to obtain measured values for the wave speed. For our high pressure regime at 9.8×10^4 Torr, this yielded 3.8eV, which corresponds to a speed of 3030 ± 80 m/s, while at 2.4×10^4 Torr we found kT_e to be 3eV, which corresponds to a speed of $2691 \pm 90 m/s$ At high pressure, we measured the speed to be 2764m/s, while for our low pressure regime, propagation speed 1941m/s.

I. INTRODUCTION

Plasma is an ionized gas, meaning that valence electrons have been disentangled from their respective atoms, creating a mix of positively charged ions and negatively charged electrons. Plasmas are by their nature unstable on earth, because they are in a high state of disequilibrium. Like charges repel each other and opposite charges tend to rejoin unless the temperature is kept high enough such that thermal energy is higher than the ionization potential. In space, plasma is the most common state of matter, as stars are made primarily of unbound ions, and interstellar space retains a low density of free ionic particles. In a laboratory setting, we use a complex chamber to create a steady-state plasma.

To measure ion fluxes under given conditions, we embed a metal plate in the plasma called Langmuir probe, named after Irving Langmuir who is considered one of the fathers of plasma physics. Today plasma physics finds application in the creation of the microscopic circuits which have given truth to Moore's Law. The fusion of hydrogen ions may yet provide inexpensive clean energy, and a detailed understanding of plasma physics is vital to overcoming the instabilities and creating the conditions necessary for hydrogen fusion to work on Earth.

Section 2 will describe plasma theory relevant to our experimental goal, Section 3 will discuss our methods and apparatus, Section 4 will delve into our results and their implications, and Section 5 will discuss how the experiment could be improved.

II. THEORY

As we sweep the voltage of the probe, we are manipulating its interactions with ions and electrons. A positively charged probe will repel ions while a negatively charged probe will repel electrons. The current through the probe arises from ions or electrons interacting with the probe and "donating" their charge to it, which induces a current. The current induced can be written as

$$I_p = \frac{1}{4} n_3 v_{th} A_p, \tag{1}$$

where n_e is the electron density, A_p is the probe area andv_{th} is the thermal velocity. We can solve for v_{th} of an electron as

$$v_{th} = \sqrt{\frac{8kT_e}{\pi m_e}(2)}$$

Thus we should be able to solve for each of these terms while knowing the other three. To find the ion acoustic wave speed, we use the following relation

$$\frac{KT_e}{e} = \frac{2(V_p V_f)}{ln(\frac{2Mi}{\pi m_e})}$$

(where M_i is the ion mass) to isolate the electronic thermal energy KT, which we may in turn plug into

$$C_s = \sqrt{\frac{KT_e}{M_i}} \tag{3}$$

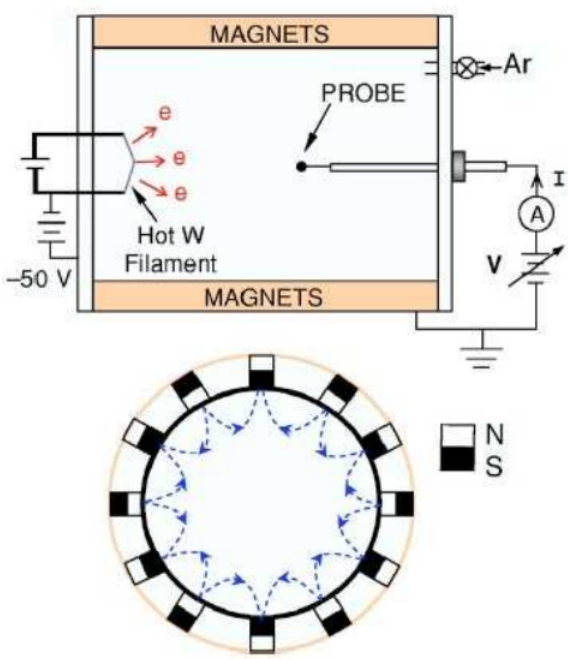
to find the ion acoustic wave propagation speed C_s.

III. EXPERIMENT

Plasma behaves much like a gas, but is susceptible to a medley of effects arising from the coulombic effects of the ions and electrons. Each ion retains an electric field and produces magnetic fields when moving, all of which affect the movements of every other ion and electron in the vicinity. This gives rise to many runaway instabilities, many of them having runaway effects. To do experiments on plasma, we must first contain it. To do so, our vacuum chamber is lined with permanent magnets of successively opposite alignments (see figure 1), assuring that both electrons and ions will encounter diverting forces before reaching the chamber wall. We induce a strong negative charge in a tungsten filament, then run a powerful current through it to induce thermionic emission of electrons. These "primary" electrons have high kinetic energy and are able to interact with argon atoms to overcome the ionization potential and produce ion electron pairs as such:

$$e_p + Ar = Ar^+ e^- + e_p \tag{3}$$

The high-energy primary electrons will escape, leaving a plasma of Argon ions and ionized electrons. Since our containment is imperfect, some ions and electrons will escape or be vacuumed out, so we constantly pump in Argon atoms to maintain a constant pressure. The rate at which we allow Argon atoms into the plasma chamber determines the neutral pressure p_o of the plasma. To continually ionize the incoming Argon atoms, we continually produce primary electrons by passing current through the low potential tungsten filament. In order to complete the circuit between the chamber wall, where the primary electrons escape to ground, and the tungsten filament, we use a "discharge" power supply to pump electrons from the ground and chamber wall back to the filament. Our first goal is to measure the effects that the discharge power supply and the neutral pressure will have on the plasma's voltage current characteristic.

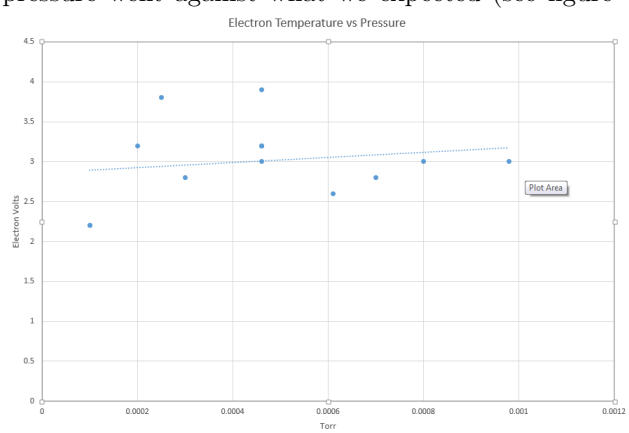


(Figure 1) Notice that the magnets which line the cylindrical chamber are successively anti-aligned.

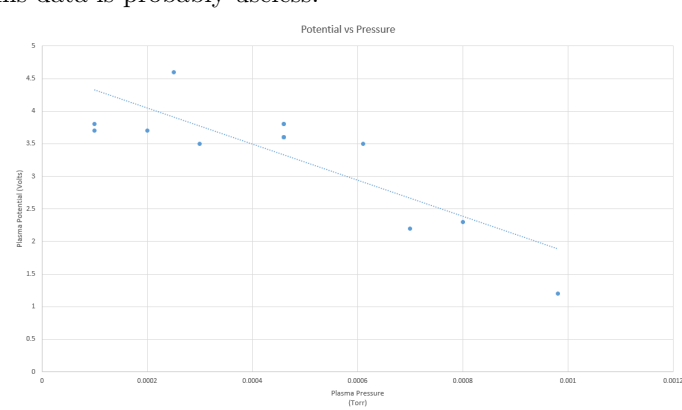
We use a planar Langmuir probe inserted through the chamber wall which we may manually and electronically manipulate. By sweeping the voltage of the probe, and measuring the current flowing through it at each voltage, we obtain a trace of the Voltage-Current characteristic (see figure 2), which may be interrogated to find the kinetic energy, density, potential, and other plasma characteristics. In particularly we are interested in the speed of propagation of ion acoustic waves. We may predict this speed theoretically using the relations described in Section 2 EQUATION. We may also measure this value directly by creating a potential pulse and varying the space between the origin of the pulse and the probe, and measuring the time taken for the potential fluctuation transmitted via the ions and electrons to reach the probe.

IV. RESULTS

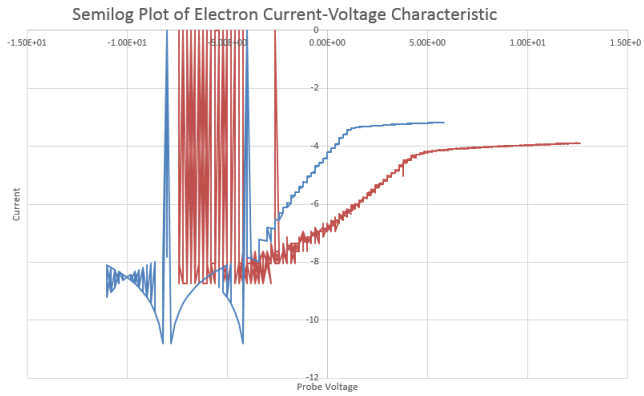
To find the electronic thermal energy kT_e, we begin by subtracting the I_i ion current from our IV characteristic. We can find the I_i-V characteristic by dialing the probe voltage low enough such that it repels and thus receives no electrons. We then take the semi-log plot of our result, and find the voltage difference between the electron saturation current I_e and $I_e/exp(1)$. See figure 4 For our high pressure regime at 9.8×10^4 Torr, this yielded 3.8eV, which corresponds to a speed of 3030 ± 80 m/s, while at 2.4×10^4we found kT_e to be 3eV, which corresponds to a speed of $2691 \pm 90 m/s$ At high pressure, we measured the speed to be 2764m/s, while for our low pressure regime, propagation speed 1941m/s. The disagreement between theory and measurement is especially stark in the low pressure case. The error is likely in the theoretical prediction, since the measurement formed a perfect line, and the theoretical relationships between potential, temperature and density similarly fell away from expectation. While the potential calculation shows a negative relationship between potential and pressure (see figure 3), the relationship between the electron temperature and pressure went against what we expected (see figure 4).



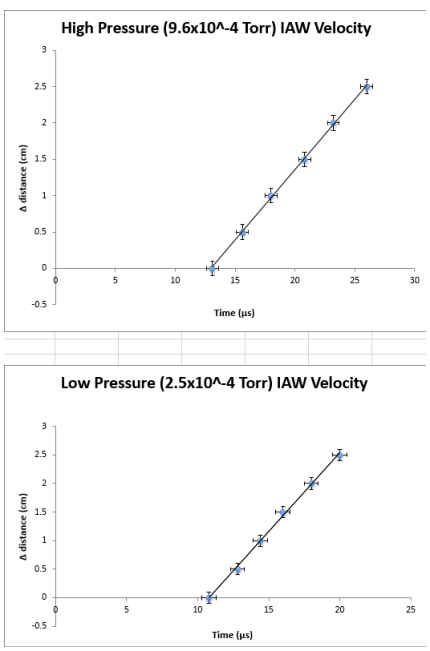
(Figure 2) The relationship between the fit is tenuous at best and data is tenuous at best. In fact we expect the electron temperature to be higher at low pressures because at high pressure they are more likely to interact and relinquish energy to ions. Thus we conclude that this data is probably useless.



(Figure 3) We expect plasma potential to drop with pressure, however the relationship between the data and the line of best fit remains tenuous.



(Figure 4) The linear "zigzag" sections which cross zero voltage represent the semilog-linear IV characteristic. It was difficult to exactly distinguish the Electron saturation point, and especially same divided by e, since the length of said characteristic is unclear.



(Figure 5) These are our measured X-T values for the ion acoustic wave propagation. We assume these values are good because they are near perfectly linear.

V. CONCLUSION

We used voltage fluctuations in an Argon plasma to explore the relationships between pressure and ion acoustic wave propagation. We interrogated the IV characteristic to find ion acoustic wave propagation speed, electron temperature, plasma pressure, and plasma potential. We examined these values relationships to plasma pressure, and found that only plasma potential agreed with expectation. We also compared values of ion acoustic wave propagation speed with values predicted from the Current-Voltage characteristic, and found the relationship to be loose. We are reluctant to say that our experiment shows that theory is wrong as much as that we must reevaluate our experiment to excise the errors. Fortunately, we found that in the high and low pressures that we took measurements for, pressure and ion acoustic wave propagation are negatively related, albeit with a significant deviation from theory in terms of slope. Once the data of the IV trace has been processed, it is difficult to pinpoint exactly where the ion current takes over, thus it is difficult to exactly define $I_e/exp(1)$. See figure 4. Even then, that specific current corresponds to a range voltages, so much so that the uncertainty is difficult to ascertain for the same reason that it is known to be high. We assumed it to be 0.2 volts because this is the finest resolution possible in the data, however the uncertainty is larger, closer to an electron Volt, for which the theory will of course agree with measurement better, but still they do not overlap.

VI. ACKNOWLEDGEMENTS

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1 Understanding Langmuir probe current-voltage characteristics, R. Merlino, Am. J. Phys. 75, 1048, (2007). *Phys. Rev. Lett. 93* (2004)'Waves in Plasmas', Ch.4 in Introduction to Plasma Physics and Controlled Fusion Vol.1, Chen, 2nd Ed., Plenum Press (1984). Controlled Landau Damping of Ion-Acoustic Waves I. Alexeff, W. D. Jones, and D. Montgomery Phys. Rev. Lett. 19, 422-425 (1967).