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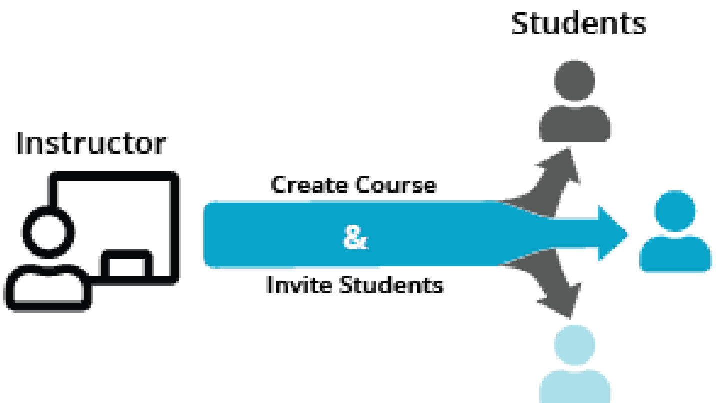

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Langmuir Probes Lab

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Attribution

Instruction Level

- Undergraduate, Upper Level (Junior, Senior)

Topic

- Active Circuits
- Langmuir Probes
- Plasma Parameters
- I-V Curves
- Ion Saturation Current
- Ion Density
- Electron Saturation Current
- Floating Space Potential
- Plasma Space Potential
- Electron Temperature
- Electron Density

Instruction Type

- Traditional

Timeline

- **Procedure:** 2-3 hours

Learning Objectives

- Students will construct an active circuit
- Students will measure the characteristic I-V curve at different discharge currents and to obtain a measure of the plasma parameters for each set of plasma conditions examined.

Additional Resources

- Alexeff, J. T. Pytlinski, and N. L. Oleson, Am. J. Phys. 45, 860 (1977).
- R. L. Merlino, Am. J. Phys. 75 1078 (2007).
- L. Conde, An introduction to Langmuir probe diagnostics of plasmas, available online at http://plasmalab.aero.upm.es/~lcl/PlasmaProbes/Probes-2010-2.pdf

Introduction

Background

Active Probe Circuits

An active circuit is one that contains op-amps or other elements that are powered. The most important active element for a Langmuir probe analysis is a differential amplifier which will subtract V_{probe} from V_1 and amplify the difference. Figure 1 shows a diagram of a successful active analysis circuit. This circuit can operate with dc bias voltages of more than ±1000V, can source or sink hundreds of milliamps and can accurately measure probe currents at the microamp level and probe voltages at the tens of millivolt level. The basic function and rationale for each element is described next.

The first element is the "sensing resistor", shown as four parallel R_s resistors and a switch. A small value for the resistor should be used when the current is very small. This produces a larger voltage which can be digitized. Too small a resistor, however, will allow too large a current to be drawn from the plasma when the probe is biased near the plasma potential. For that range of bias voltage, a large resistance is needed. A switch is provided for easy changes between several values of resistance depending on which portion of the I-V characteristic is to be measured. Resistors of 25, 100, 500, 2500 Ohms were used. If the whole I-V trace is to be mapped out at one time, the largest R_s should be used. However much more accurate measurements of the ion saturation region will be obtained with lower R_s.

The second element is the "differential amplifier" which measures the current across the sensing resistor, shown as OA3 in figure 10. The amplifier's power supplies are floating on top of V_B and are shown as the $\pm V_{s1}$ and $\pm V_{s2}$ sources on the side of the figure. In other words, the two power leads to the amplifier are at V_B +15V and V_B -15V. The resistor, R is added to give the proper output impedance for the device. The gain of this amplifier is 10. A Zener diode is placed between the inputs of the differential amplifier to prevent its destruction during an over voltage from the plasma. The third element provides a "high-input impedance" for measuring Vprobe· It provides overcurrent protection for the amplifier and the scope and is powered by the floating ±15 V power supply. Between these two elements of the circuit and the outputs are output amplifiers (OA4 through OA7) that subtract the de bias voltage from the signal and reamplify the remaining signal.

The fourth element in the circuit is a "probe driver" which includes OA!, Tl, and T2 in figure 1. The feedback resistor has the same value as the input coupling resistor to maintain a similar magnitude of the voltage ramp. The voltage signal input can be a function generator or any ±V ramp or triangle wave generator.

The value of R depends on the maximum de-bias voltage, VDC_{max}, applied to the system. R should be greater or equal to VDC_{max} x 400, but at least 40kOhms. The wattage of the R resistors (and the 4kOhm resistors) should be two or three times greater than $VDC_{max}/400$. The resistors, R, should have 1% or better tolerances.

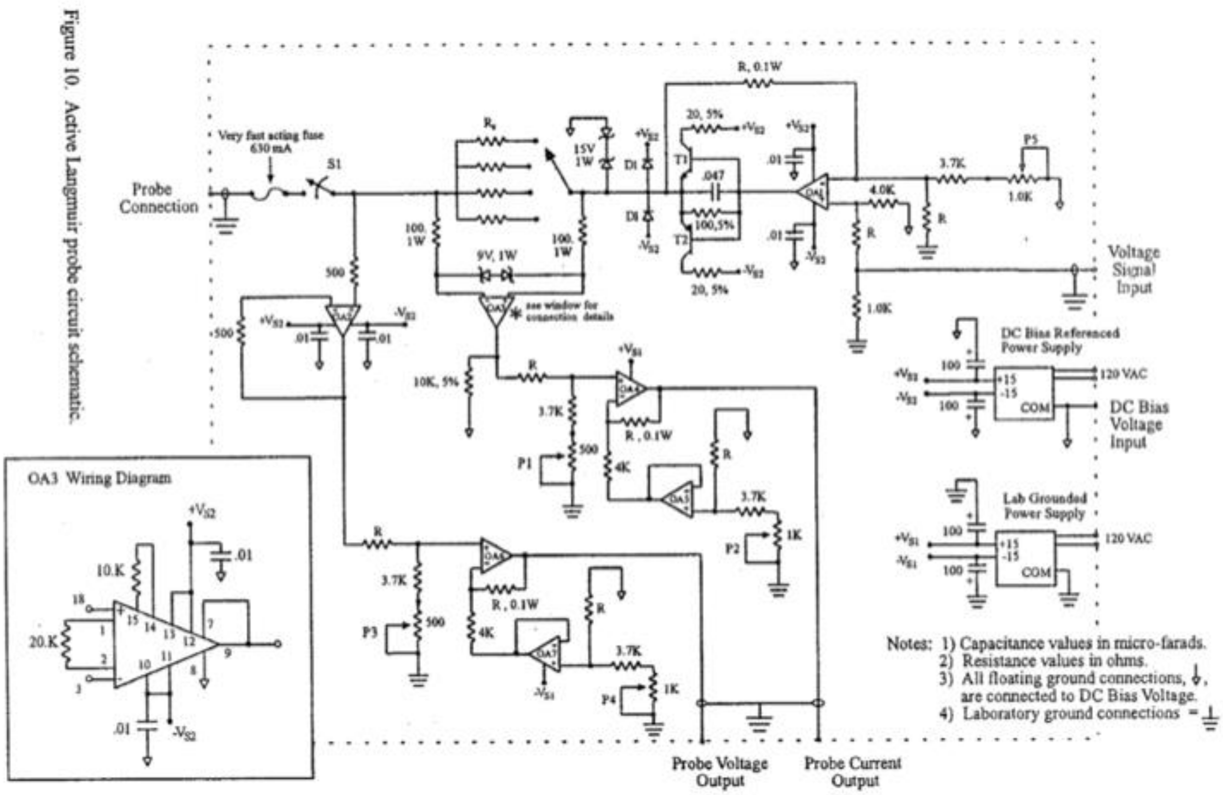


Figure 1: Diagram of an active circuit

Plasma Physics

When one typically considers a gas, one thinks of a collection of neutral particles whose dynamical behavior is governed by local interactions (i.e. collisions). This picture, however, is not entirely accurate because there is always some degree of dissociation – which is to say there are some electrons have been separated from neutral atoms, resulting in some number of free electrons and positive ions. At room temperature, the degree of dissociation (ionization) is so low that molecular and atomic properties dominate. As the temperature increases, the ionization increases and at some point, the behavior of the system is governed not only by local interactions but also by long-range electromagnetic forces. Typically, this happens when the thermal energy, k B T, approaches the ionization energy, E i (the energy needed to free the outermost electron). When this occurs, one moves into the plasma state. In general, the degree of ionization necessary to enter the plasma state can be quite low (~0.1%). As a result, there is not a sharp boundary that denotes the transition into the plasma state.

As with any state of matter, it is important to be able to quantify that state. In the case of the plasma state, the typical parameters that are used include the ion and electron densities, the electron temperature and the electron distribution function, that is the distribution of electron velocities. The simplest method to accomplish this involves inserting a small metal electrode (Langmuir probe) into the plasma and then measuring the electrons and ions (currents) that are collected by the probe as the voltage applied to the probe was varied with respect to the plasma space potential 1 , V p .

Langmuir Probes

The Langmuir probe is a common diagnostic technique in low temperature plasmas (e.g. plasmas with Te ~ a few eV) and is used to measure the plasma density, electron temperature, and the plasma potential. Typically, a Langmuir probe consists of a bare wire (or metal disk/sphere) that is inserted into a plasma. When a bias is applied to the probe, the probe will collect electrons and ions from the plasma in the area surrounding the probe. At negative (positive) biases, protons (electrons) and only the electrons (protons) with sufficient energy to overcome the potential barrier of the probe are collected. As the probe bias is varied, the fraction of the electron and ion distributions that are collected varies. The resulting I-V trace will resemble what is seen in Fig. 2.

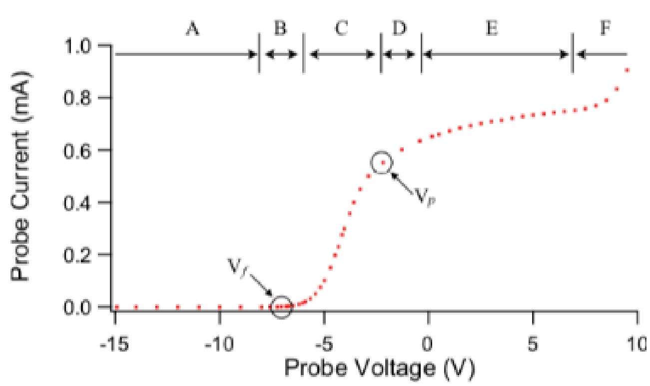
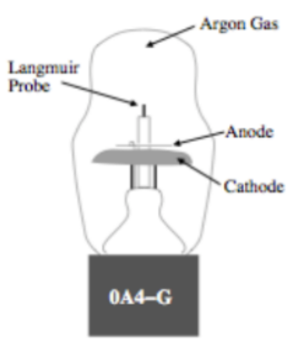


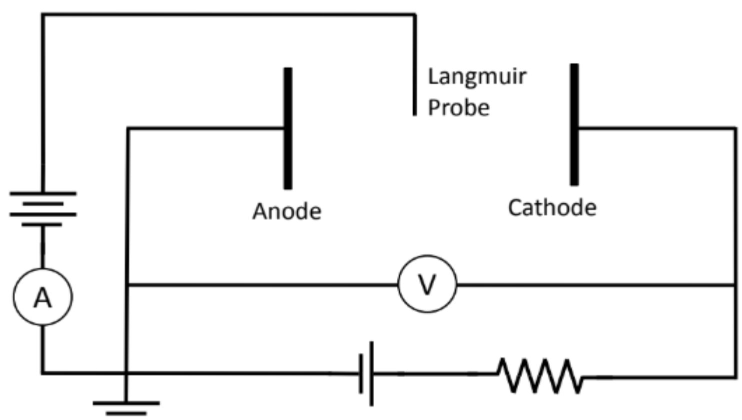
Figure 2: A representative Langmuir probe trace with different regions of interest indicated.

Each of the regions indicated in Fig. 2 corresponds to unique populations being measured. At large negative biases (region A), only ions are collected by the probe. This is known as the ion saturation current,Iis. In region B, the ion saturation current plus a small amount of the electron distribution is measured. The voltage when the net current collected is zero is known as the floating potential, Vf . In region C, an increasing fraction of the electron distribution is measured. At the knee of the curve, known as the plasma potential (Vp), you are now measuring the entire electron distribution and some of the ion population is being repelled (region D). In region E, only electrons are collected by the probe and this is known as the electron saturation current, Ies. In region F, the probe is beginning to act as a source of electrons. The electron temperature and density can be found from region C and E respectively, while the plasma potential can be found from the intersection of these regions. It should be noted that under some experimental conditions, it is possible to not observe Regions D and E. In this case, you can only find the electron temperature from the I-V trace obtained with a Langmuir Probe.

Experimental Overview

To examine the plasma state, you will be using a cold-cathode, gas filled triode, the OA4-G.This tube is filled with argon gas at a pressure of 1 Torr and contains three electrodes: a metal disc cathode (pin 2), a wire tip electrode (pin 5) and a trigger anode (pin 7). You will generate a plasma by applying a voltage across the metal disc cathode and wire tip electrode and then measure the parameters of the resulting plasma using the trigger anode, which will function as a Langmuir probe. This is seen in the circuit schematic in the figure below. To protect the gas tube, a resistor is used to limit the current in the discharge.





<u>Pre-Lab Assignment</u>

1. *Purpose Statement:* In one or two sentences, specifically describe the purpose of the day's experiment/lab work. What are you trying to learn or achieve, and how?

2. Why can't a passive circuit be used in this experiment?

3. What is the purpose of a Langmuir probe?

4. How is a plasma different than an ordinary gas?

Procedure

Safety

Use caution when working with power supplies.

Protocol

Data Collection

1. Assemble the apparatus found in the Experimental Overview section of the Background

2. Ignite the plasma by turning on the power supply and increasing the voltage until you see a purple glow inside the tube.

3. Adjust the discharge current to the desired value. You will be measuring the characteristic I-V curve for at least 3 discharge currents between 20 and 120 mA.

4. Vary the voltage applied to the Langmuir Probe (pin 5) using the second power supply, which provides voltages from -15V to 15V, and measure the current that is collected by the probe. As you are taking data, be sure to makes sure that you have enough data in the areas of interest.

Finding Plasma Parameter

1. Find the ion current by performing a linear fit to the ion saturation region of your data. Subtract this from the total current to find the electron current.

2. Plot the natural log of the electron current as a function of probe voltage and fit the electron retardation and saturation region to a line. The slope of the best fit line in electron retardation region is the inverse of the electron temperature in eV.

3. Use these results to find the relevant plasma parameters (with their associated uncertainties). These include:

- the ion and electron saturation currents
- the floating (I_{probe} = 0) and plasma space potential
- the electron temperature
- the ion and electron density
- Debye Length

Results

1. Input the I-V curve over the various discharge currents you measured below:
2. Input the plasma parameters into the table below:

Ion Saturation Current	
Electron Saturation Current	
Floating Space Potential	
Plasma Space Potential	
Electron Temperature	
Ion Density	
Electron Density	
Debye Length	

Post-Lab Assignment

1. How do you Langmuir probe traces for different discharge currents compare?

2. Is there a relationship between the parameters you found and the discharge current?

3. How do the ion and electron densities compare? Is the condition of quasineutrality ($n_i \approx n_e$) satisfied? What is the ionization fraction?

4. How does the electron temperature compare with room temperature? What is the thermal velocity of the electrons?

5. Over time, the glass tube does get warm. However, it doesn't melt. On the surface, this seems somewhat surprising given the electron temperatures that you measured. Why doesn't the glass melt?

6. How does the Debye length compare to the size of your probe? The mean free path of an electron?