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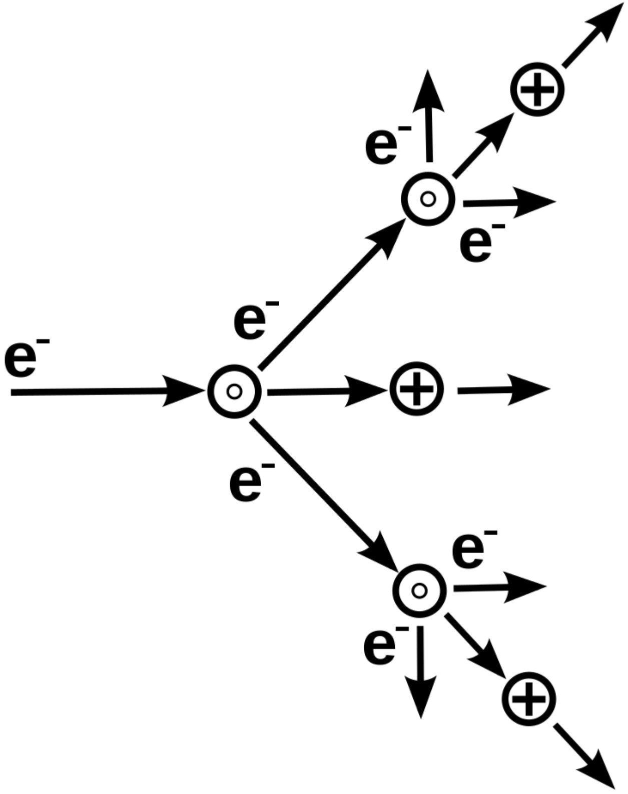
Langmuir Probe Experiment



Theory

- Plasma is an ionized gas that is composed of dissociated electrons and ions.
- Plasma is described in terms of macroscopic “plasma parameters”, including electron and ion temperature and density, and plasma potential.
- A Langmuir probe is a measurement device which is used to measure the plasma parameters in low temperature plasmas.
- By generating a plasma in a vacuum tube (<1 Torr), we are able to use a Langmuir probe to measure the I-V curve and derive the electron temperature, plasma potential, and floating potential.

$$f(x, y, z, v_x, v_y, v_z) = n(x, y, z)\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{m(\mathrm{v}_x{}^2+\mathrm{v}_x{}^2+\mathrm{v}_x{}^2)}{2kT}}$$

The Maxwell-Boltzmann distribution function describes the number density, temperature, positions, and velocities of particles in gas in terms of statistical quantities..

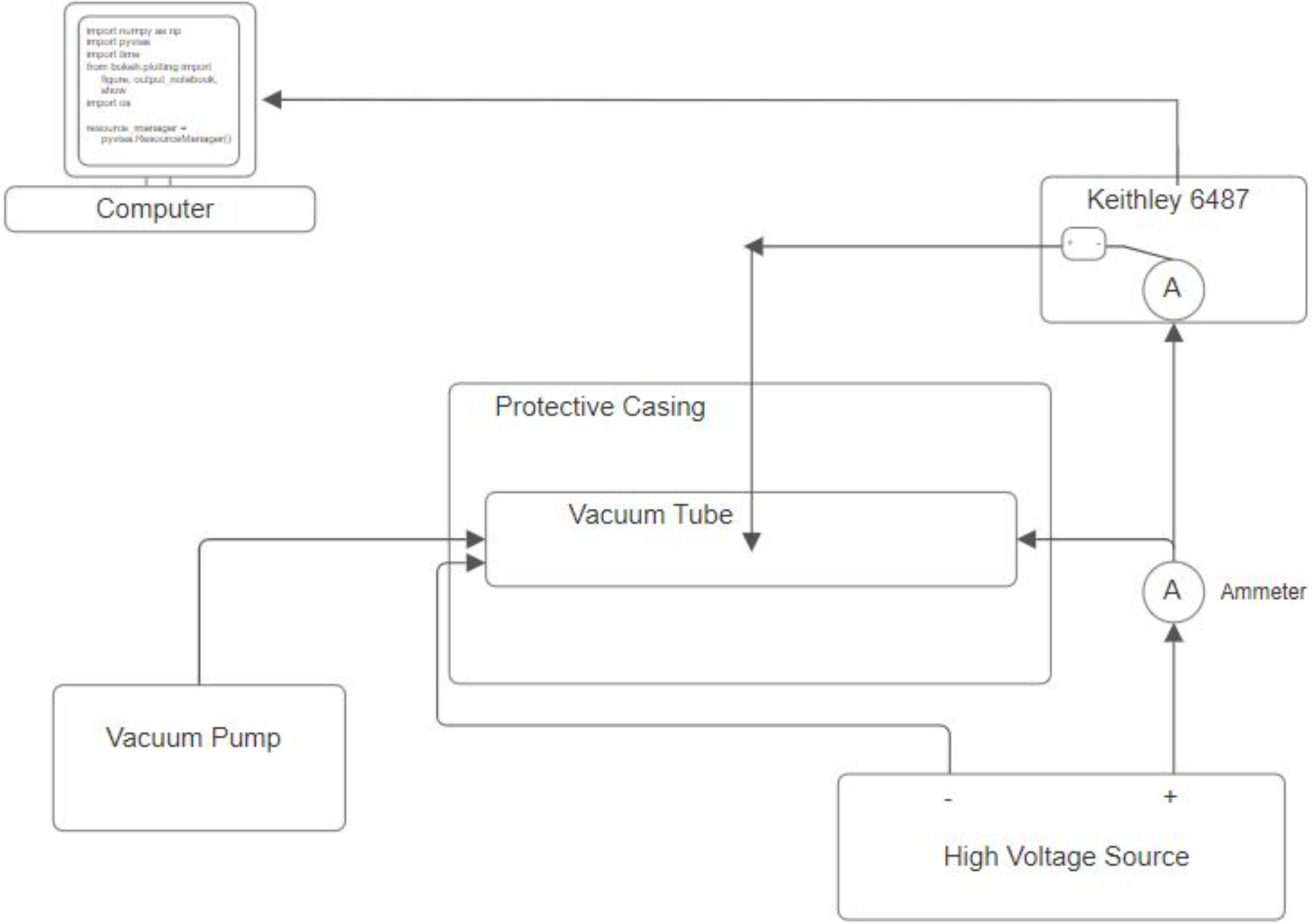


Figure 2. Block diagram of experimental setup.

Instrumentation

- The probe's bias potential was set by the Keithley 6487 picoammeter/voltage source.
- The 6487 is a feedback picoammeter; a design that reduces the voltage burden by several orders of magnitude, resulting in behavior much more like that of an ideal ammeter than a more traditional shunt picoammeter.
- The 6487 was used to perform a sweep across a set voltage range, as well as to measure the current generated by the plasma.
- Stability of measurement is maintained by a process called "autozeroing", where the 6487 measures its own internal voltages, which are then used in the algorithm to calculate the reading of the input signal.
- The 6487 is connected to a computer and controlled using a python script with which the voltage range of the sweep can be set.

Figure 3. Circuit for a feedback ammeter.

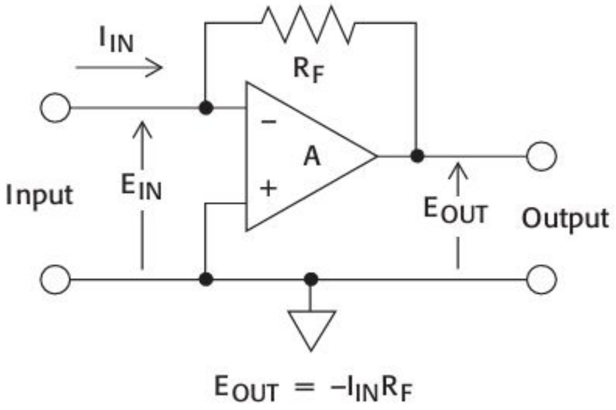
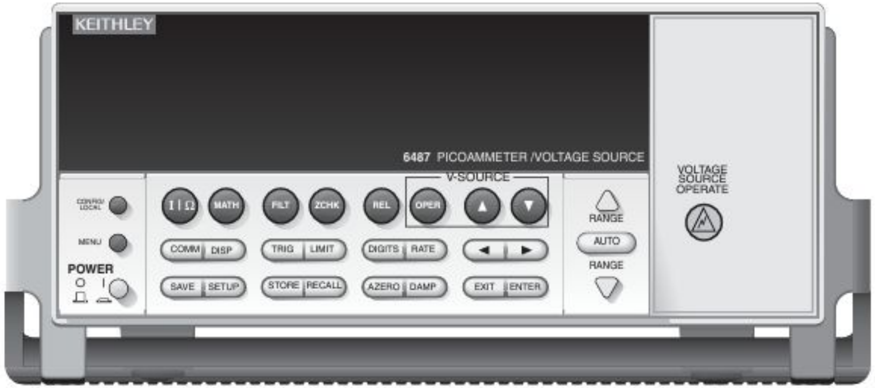


Figure 4. Front of Keithley 6487



Data Analysis

- Data was taken for three voltages across the plasma: 1200 V, 1300 V, and 1400 V.
  - For each voltage, the probe bias was swept over the range -450 V to -120V.
- Once the data was collected, the I-V curve was plotted.
  - With the I-V curve, the ion saturation current, the electron saturation current, and the floating potential were found.
  - The gradient of the total current with respect to the voltage was plotted to find the plasma potential.
- The ion saturation current was subtracted from the total current in the I-V curve, and the natural log of the remaining electron current was plotted.
- The linear range of the log of the electron current was selected and fit with a linear fit function.
  - The slope of the linear fit was used to determine the electron temperature.

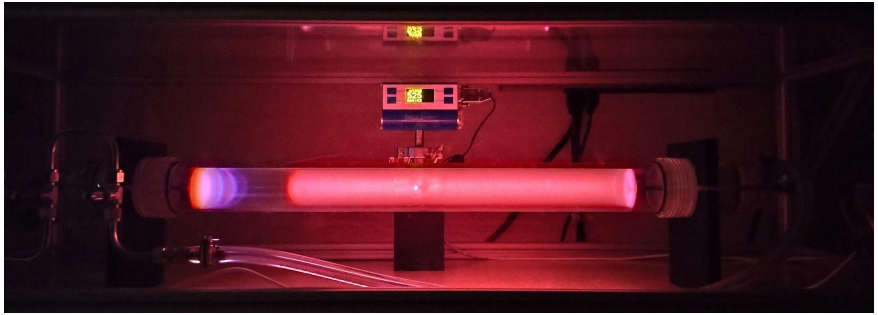


Figure 5. PIcture of plasma generated in low pressure tube.

$$I_e(V_P) = I_{es} e^{\frac{-q_e(V_P - V_B)}{kT_e}}$$

$$ln(I_e) = \frac{q_e V_B}{kT_e} - \frac{q_e V_P}{kT_e} + ln(I_{es}) = \frac{q_e V_B}{kT_e} + b$$

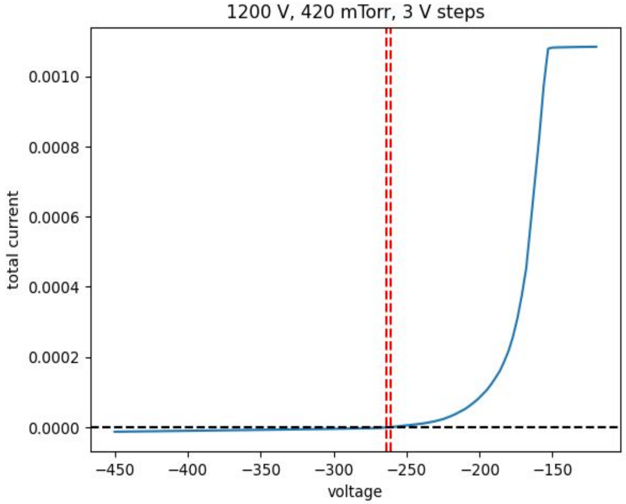


Figure 6. The probe bias vs. the total current. The red lines show the floating potential.

```
V_f_max = -261.0 V
V_f_min = -264.0 V
V_f = -262.5 V +/- 1.5 V

I_is_min = -1.478699e-05 A
I_is_max = -1.307172e-05 A
I_is = -0.00001392935 A +/- 0.00000085763 A

I_es_min = 0.001080552 A
I_es_max = 0.001082654 A
I_es = 0.001081603 A +/- 0.000001051 A
```

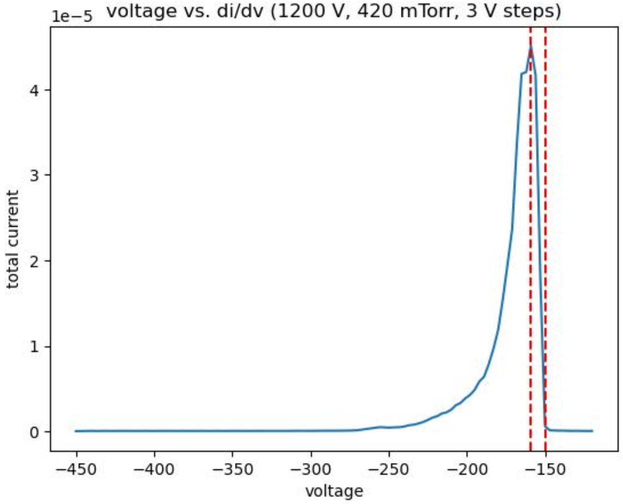


Figure 7. The probe bias vs. the gradient of the total current with respect to the voltage. The red lines show the plasma potential.

```
V_P_max = -162.0 V
V_P_min = -156.0 V
V_P = -159.0 V +/- 3.0 V
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Electron temperature: 294587 K +/- 270 K
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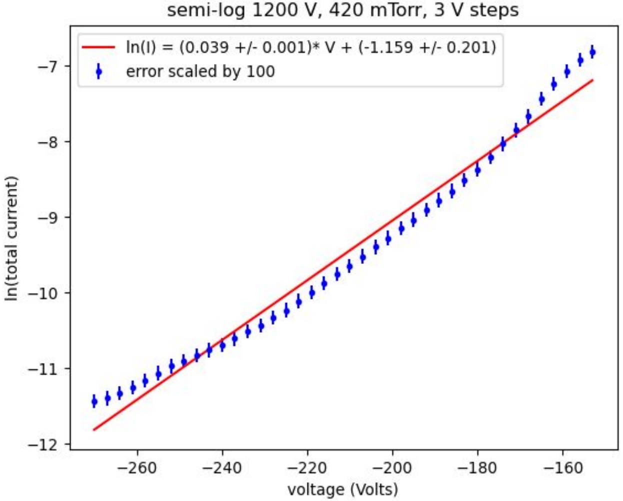

Figure 8. Selected range of the probe biasl vs. the natural log of the electron current with fit.

Langmuir probe in atmospheric measurements

- Langmuir probes are used take in situ measurements of plasma parameters in the atmosphere.
- Monitoring the plasma parameters in the upper atmosphere helps to predict geomagnetic storms and ionospheric disturbances which can affect radio and satellite communications.
- The critical frequency f_c of a plasma is proportional to the maximum electron density.
    - Radio waves with a frequency less that the ionospheric plasma’s f_c will be reflected back towards the Earth.
    - Radio waves with frequencies greater than f_c will penetrate the ionospheric plasma and be scattered.
- This makes the electron density in particular an important plasma parameter to understand when attempting to communicate via radio wave signal.
- The electron density can be derived from the I-V curve measured by the Langmuir probe.

$$I_{es} = \frac{1}{4} e n_e v_e A_{probe} = e n_e \left(\frac{kT_e}{2\pi m_e} \right)^{1/2} A_{probe}$$

$$n_e = e I_{es} \left(\frac{kT_e}{2\pi m_e} \right)^{1/2} A_{probe}$$

$$f_c = 9\sqrt{n_{e,max}}$$

(critical frequency in terms of the maximum electron density)

References

Merlino, R. L. (2007). Understanding Langmuir probe current-voltage characteristics. *American Journal of Physics*, 75(12), 1078. https://doi.org/10.1119/1.2784725

Tektronix. (2011). Model 6487 Picoammeter/Voltage Source Reference Manual. Retrieved from https://download.tek.com/manual/6487-901-01(B-Mar2011)(Ref).pdf

Keithley. (2012). Low current measurements (Application Note Series No. 1671). Retrieved from https://download.tek.com/document/LowCurtMsmntsAppNote.pdf

Bunker, K., & Bauman, A. (2022, January 27). Advanced Physics Lab 3711/3721: Plasma Physics - Langmuir Probe.

Tagg, R. Langmuir Probe Experiment.

(Title slide picture) Wikipedia contributors. Plasma (physics) [Illustration]. Retrieved from https://en.wikipedia.org/wiki/Plasma_(physics)#/media/File:Cascade-process-of-ionization.svg