Langmuir probes for low temperature plasma diagnostic

Laboratory Instructions (Lab. project)

Maria A. Ochando [1] and L. Conde [2]

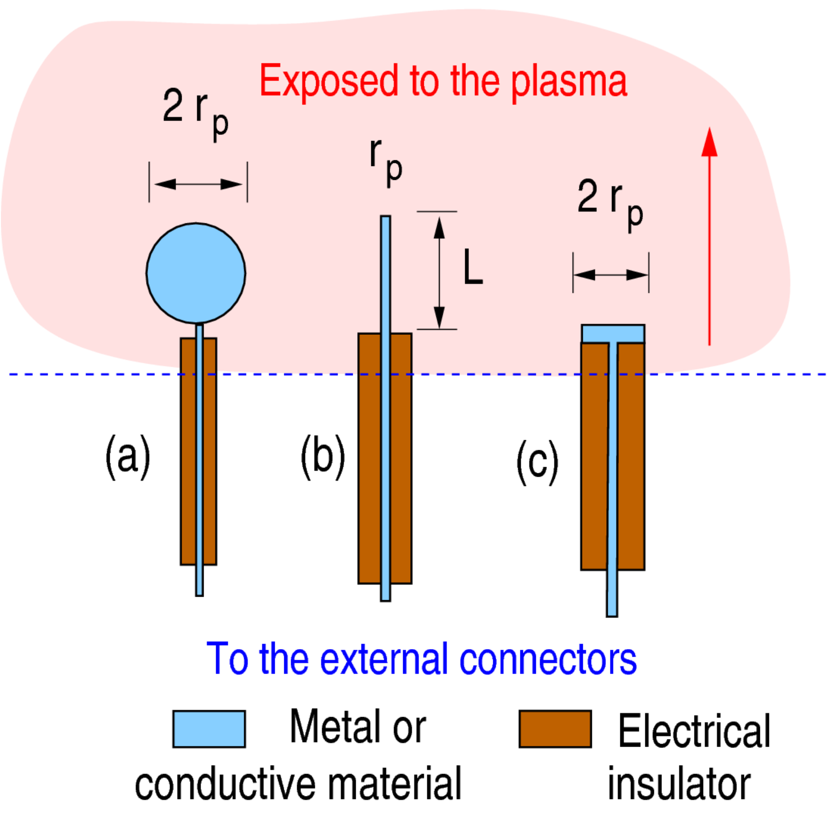
[1] Laboratorio nacional de Fusión. CIEMAT - Euratom

[2] Departamento de Física Aplicada.
E.T.S. Ingenieros Aeronáuticos.
Universidad Politécnica de Madrid

How Langmuir probes operate?

The collecting Langmuir probes are metallic electrodes with a well defined geometry (planar, cylindrical or spherical) immersed in the plasma.

The external surface is exposed to the plasma and externally biased to the potential V_p, different from the local plasma potential V_{sp}



According with the difference V_p-V_{sp} the electrons (or ions) are attracted (or repelled)

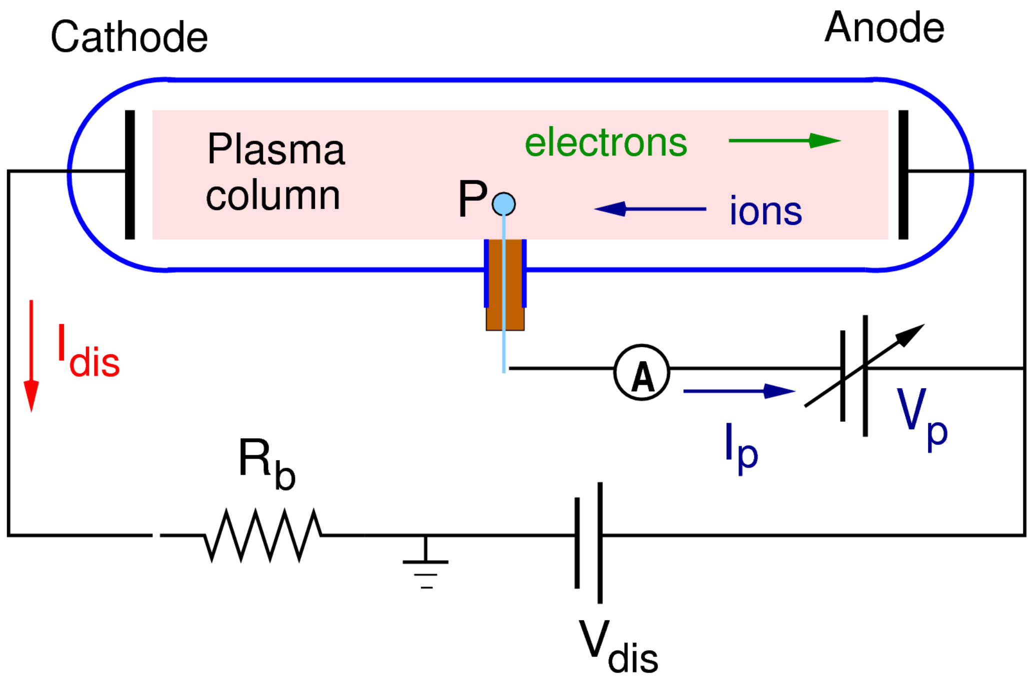
The plasma is locally perturbed by the probe

An electric current composed of ions and electrons is drained from the plasma

$$I(V_p - V_{sp}) = I_i + I_e \quad \begin{cases} V_p - V_{sp} \ll 0 & I_p \simeq I_i \\ V_p - V_{sp} \gg 0 & I_p \simeq I_e \end{cases}$$

The electron temperature $K_B T_e$, the local plasma potential V_{sp} and the electron density n_e are calculated from the current-voltage characteristic curves $I(V_p)$

How are collecting Langmuir probes connected?



The connections for a *glow discharge*, the reference electrode is usually the anode

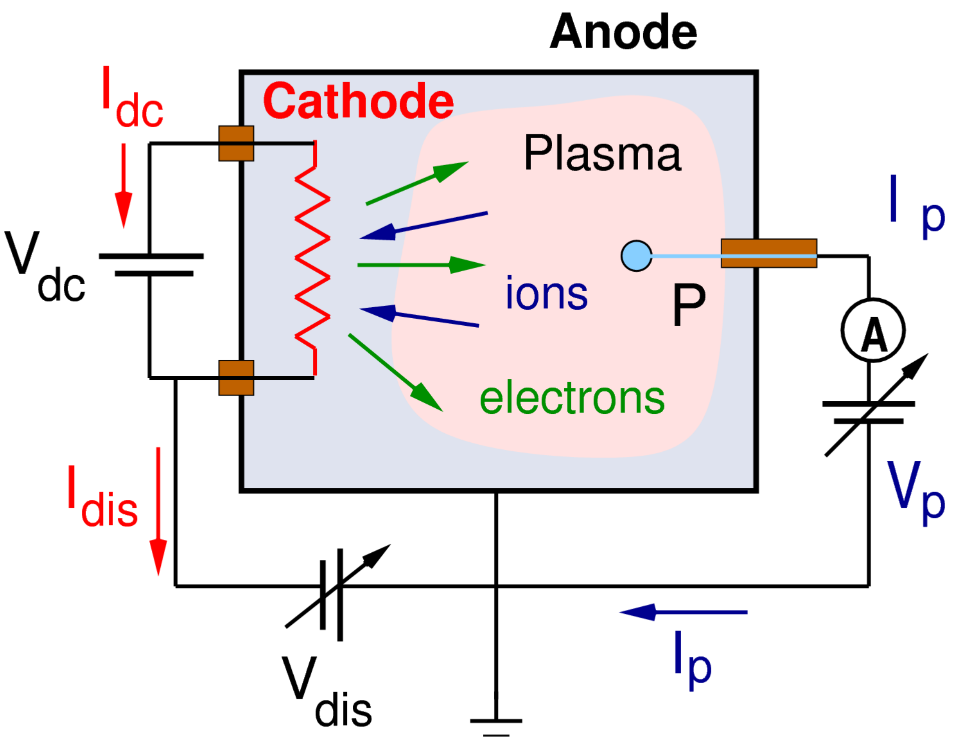
$$V_{dis} \simeq 400 - 500 \ V$$

$$I_{dis} \simeq 10 - 100 \ mA$$

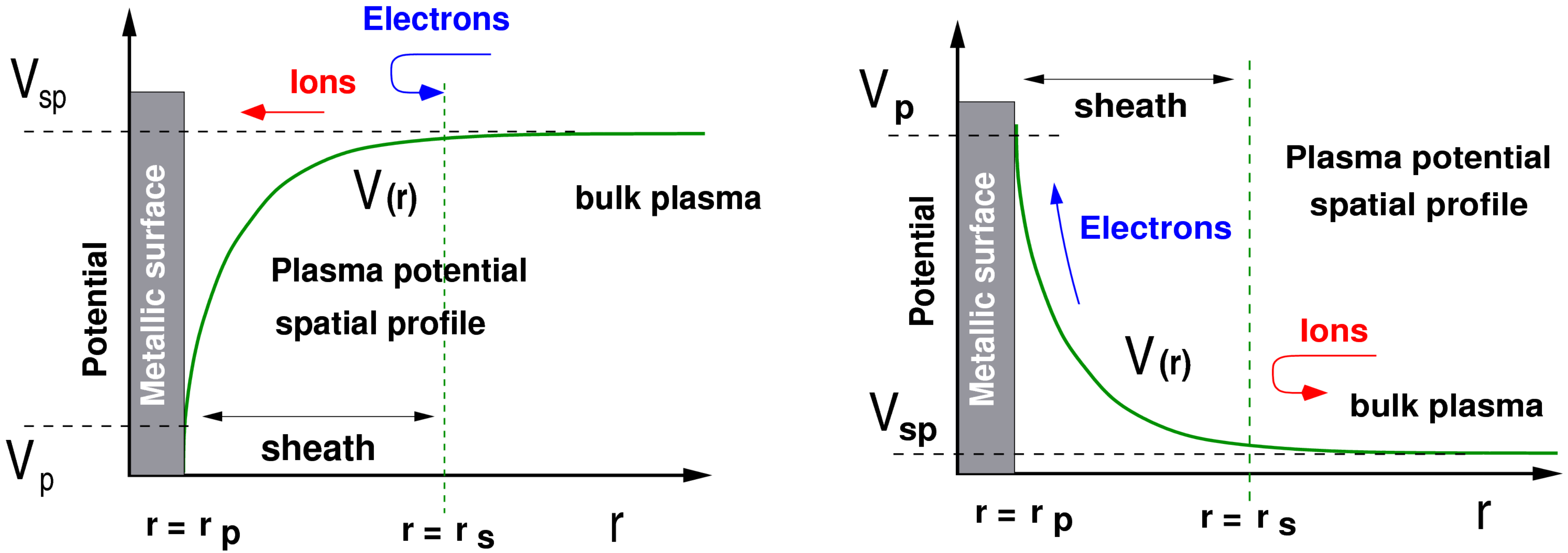
In plasmas produced by *boiling electrons* we have more possible choices

$$V_{dis} \simeq 50 - 80 \ V$$

$$I_{dis} \simeq 0.1 - 5 \ A$$



The *plasma sheath* represents the extension of the perturbation in the plasma caused by the probe potential V_p . The spatial plasma potential profile is non monotonic (*sheath and presheath*) and its typical extents is roughly 1-10 Debye lengths



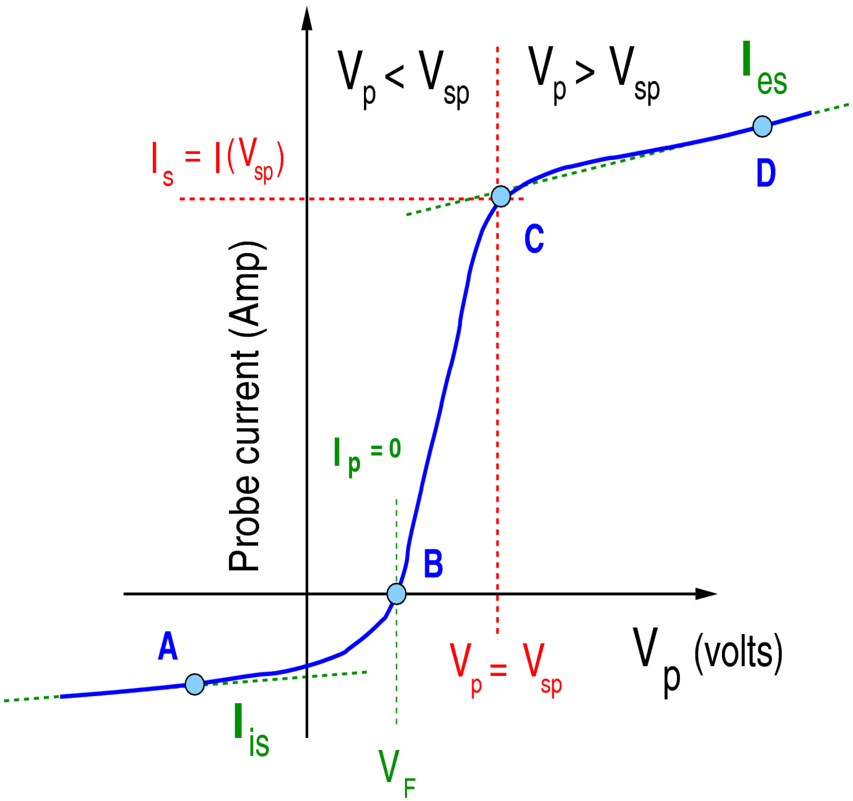
How repelled (or attracted) particles contribute to the drained current? → This is the key question of Langmuir probe theory

The space plasma potential profile around the probe is unknown and affected by particle collisions?, magnetic field, ...etc. ... This is not fully solved yet

The idealized voltage-current curve

In collisionless unmagnetized plasmas, according to the difference V_p-V_{sp} the ions and electrons could be *attracted* or *repelled*

$$\begin{cases} V_p - V_{sp} < 0 & \text{Electrons are repelled and ions are attracted: C-D} \\ V_p - V_{sp} > 0 & \text{Ions are repelled and electrons are attracted: A-C} \end{cases}$$



I (V_F) = 0 defines the floating potential V_F

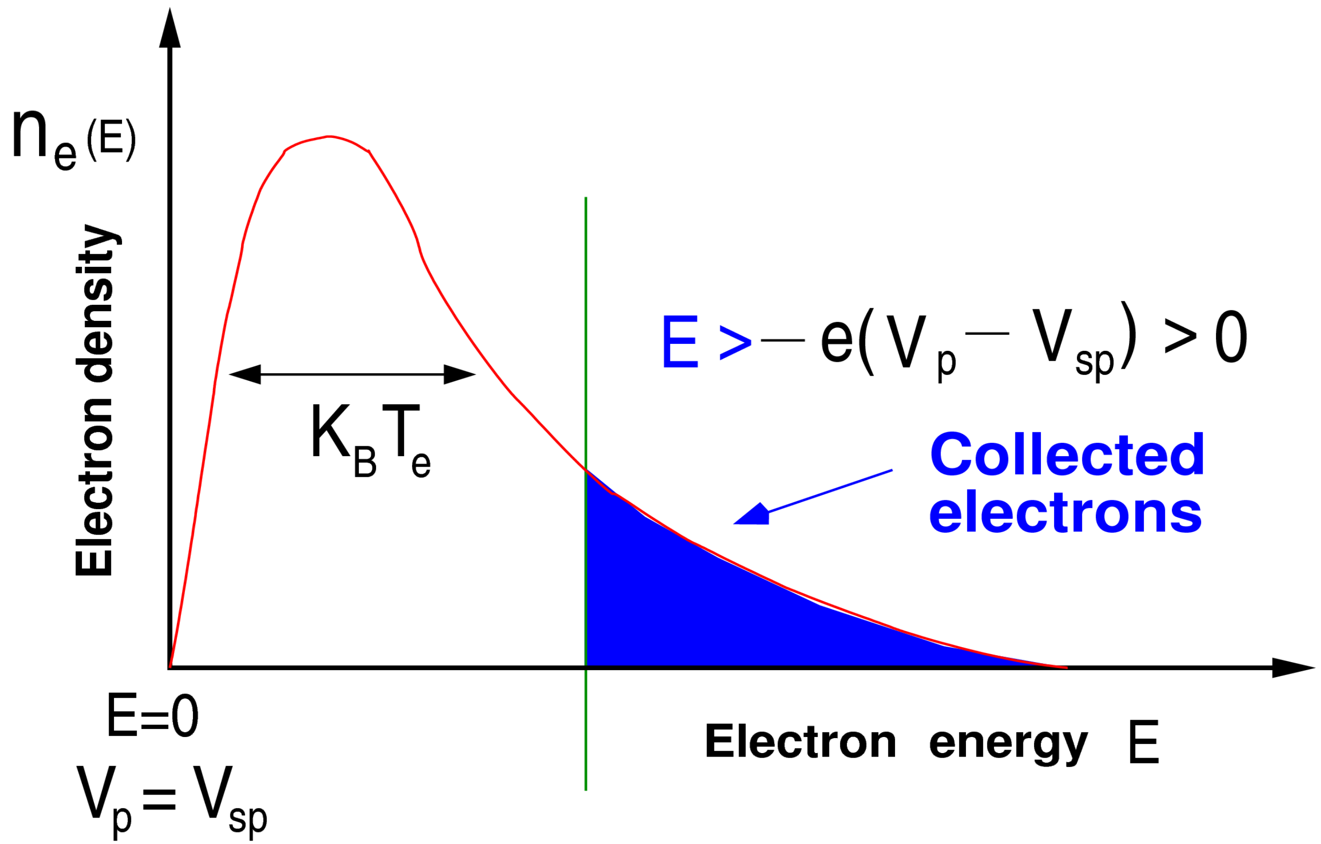
I_{es} defines the electron *saturation current (for V_p>>V_{sp})*

I_{is} defines the *ion saturation current (for V_p <<V_{sp})*

In B-C the increment in the collection of repelled electrons is exponential

The collection of repelled charges

Because of the *finite electron (or ion) temperature* $K_B T_e \neq 0$ $(K_B T_i \neq 0)$ a repelled electron (or ion) group has energy enough to reach the probe surface.



Thus, along B-C the electrons with kinetic energy *E* over the probe potential $E > -e\,(V_p - V_{sp})$ reach the probe surface and are collected. The effective collection surface is the metallic surface of the probe: *no sheath effect for repelled particles.*

The results from the simplified theory

The elementary theory applies for collisionless and unmagnetized plamas and assumes that, both electrons and ions, have a Maxwellian energy distribution function with finite temperatures: $K_B T_e >> K_B T_i \approx K_B T_a$

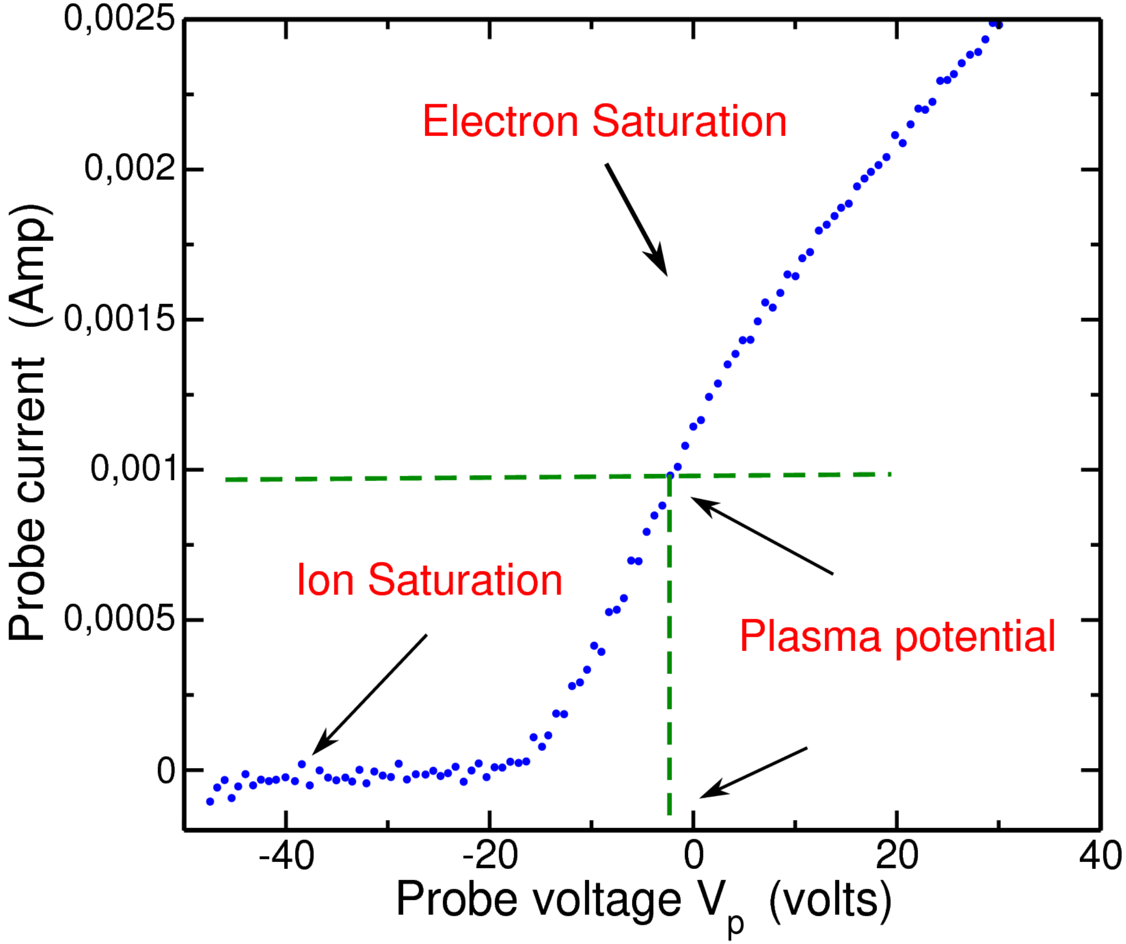
$$I_{BC} = I_s \exp\left(\frac{e(V_p - V_{sp})}{K_B T_e}\right)$$

$$v_{th} = \left(\frac{8 K_B T_e}{\pi m_e}\right)^{(1/2)} \qquad I_{es} = \frac{1}{4} S n_e v_{th} \qquad \begin{cases} S = 4\pi r_p^2 \\ S = 2\pi r_p \; L \end{cases}$$

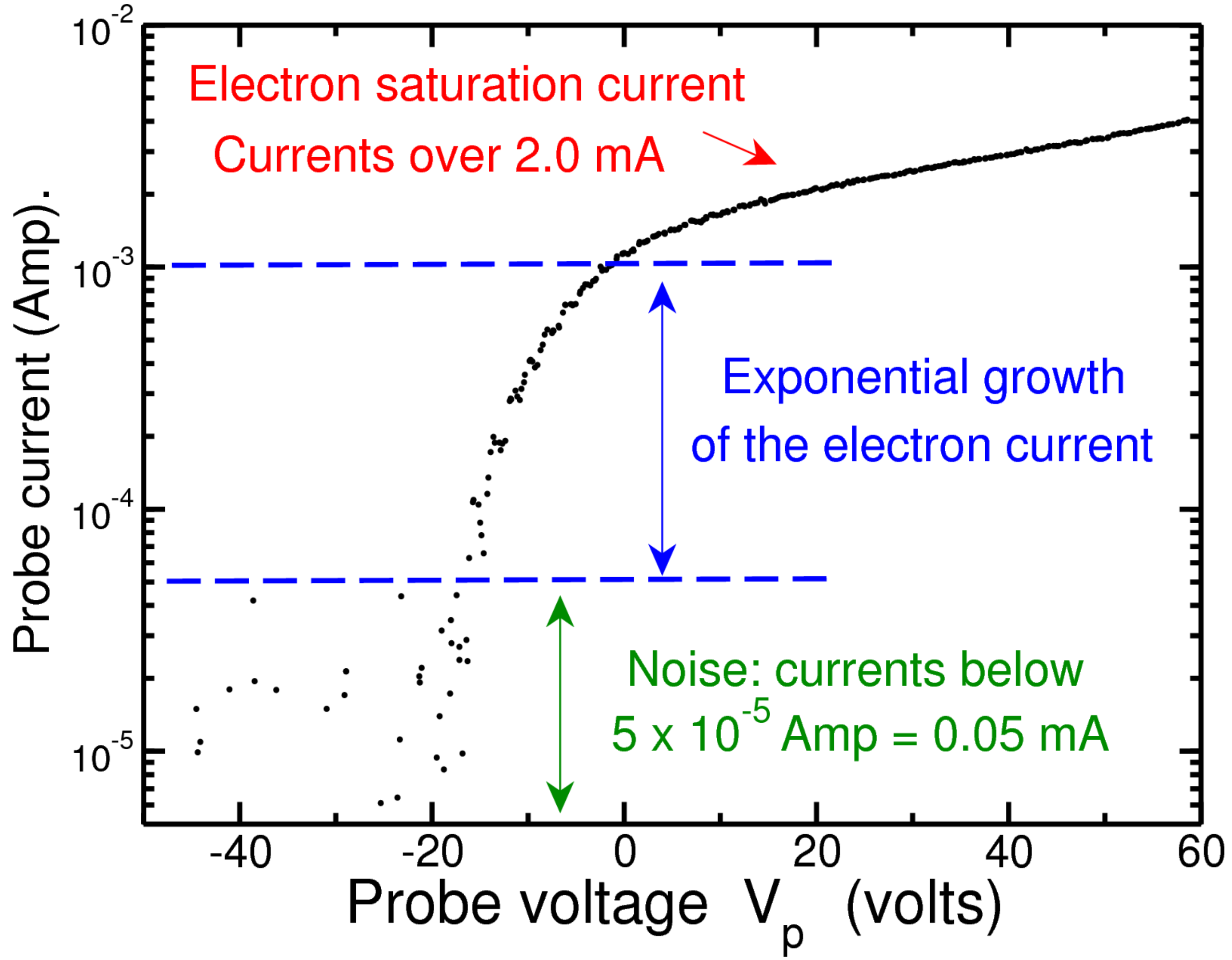
The second derivative of the current for *repelled* particles is proportional to the electron energy distribution function *g(E)*

$$\frac{d^2 I}{dV_p^2} = -(e^2 \pi r_p^2) g(E) \sqrt{\frac{2e}{m_e V_p}}$$

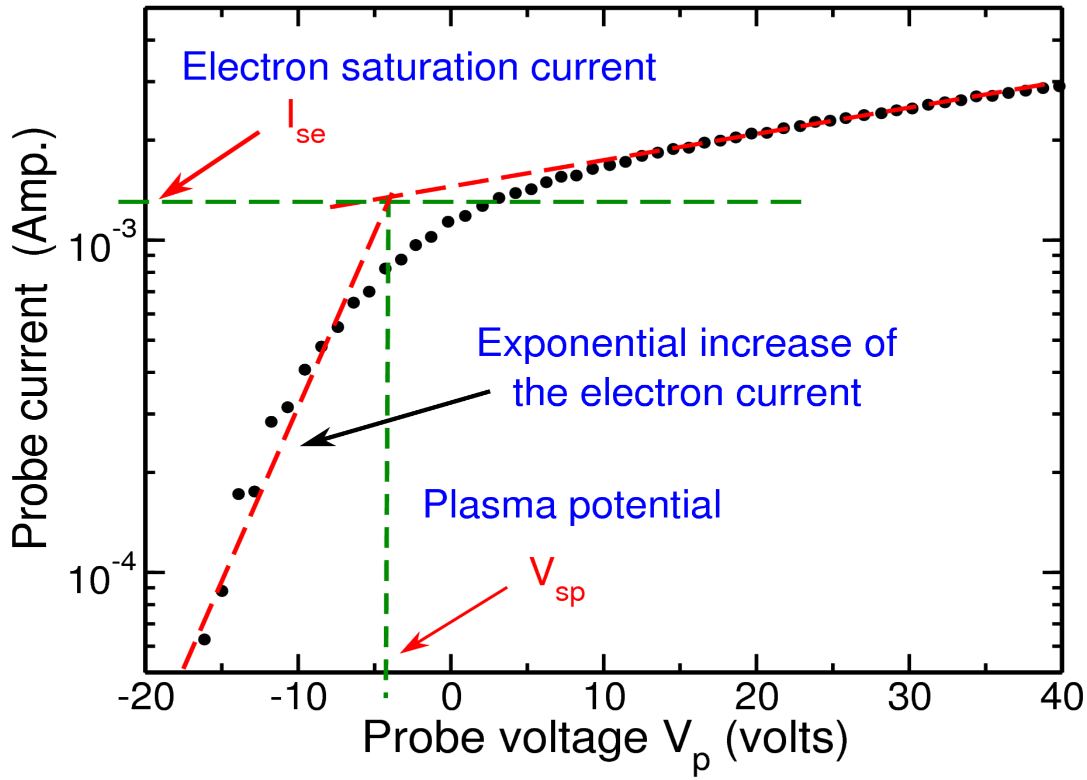
The actual experimental data in linear scale



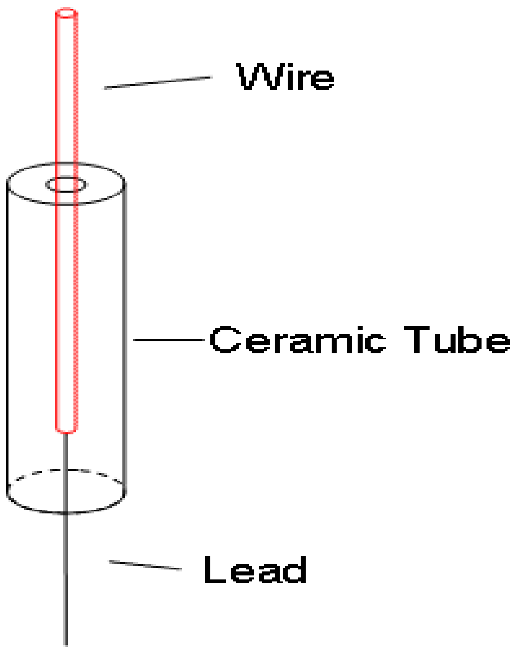
The experimental data in logarithmic scale

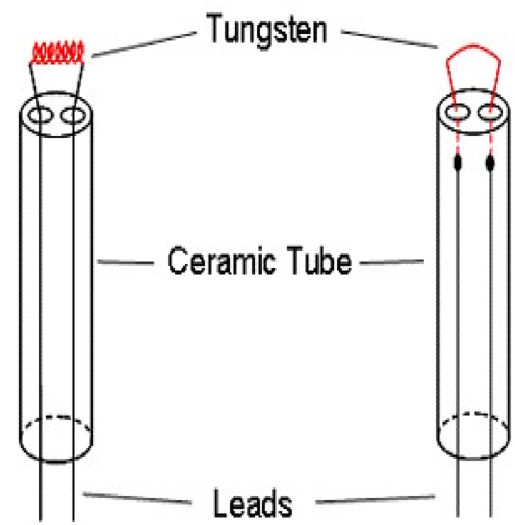


The analysis of the current voltage curve

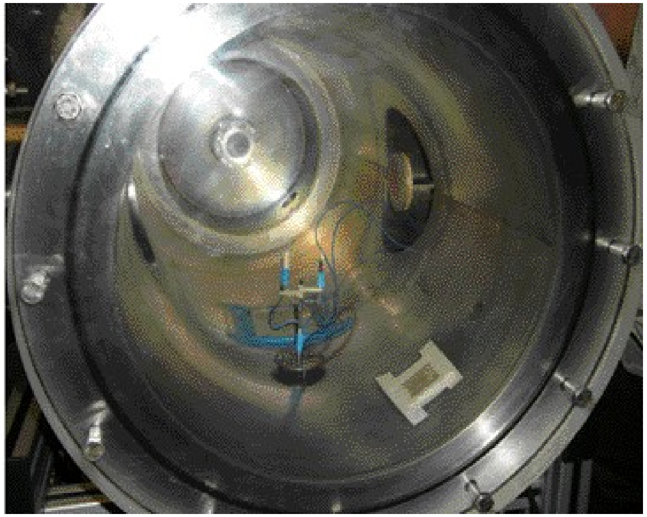


The actual collecting and emissive Langmuir probes employed in the experiments

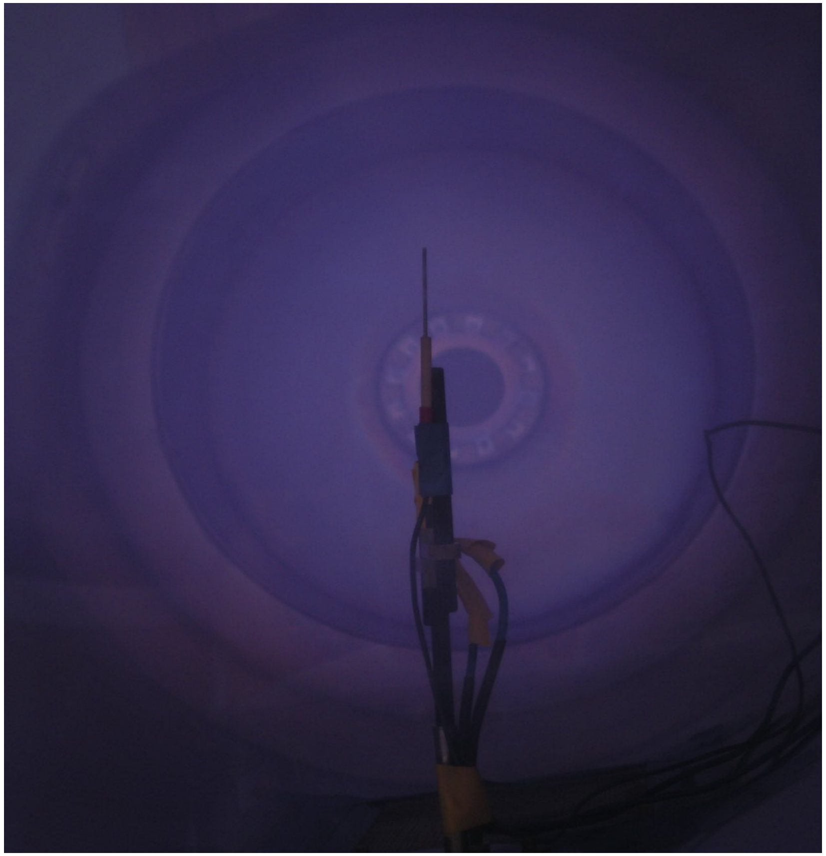




The plasma chamber with the probe support

The support for the collecting and emissive Langmuir probes in the plasma chamber



The probes immersed into a glow discharge plasma in an actual experiment.

Laboratory Project: Objectives.

The main objective is to calculate the plasma parameters using actual experimental data of collecting and emissive Langmuir probes.

Check if the measured plasma properties are independent of the geometry of the *collecting* probe.

To verify if the collecting probes operate in the *thick sheath -orbital motion limited-* approximation (see the notes) using the experimental data.

Determine the electron emission current for different *emissive probe* temperatures from the voltage current characteristic curves.

Check if the floating potential of the emissive probe approaches the plasma potential as the probe is heated.