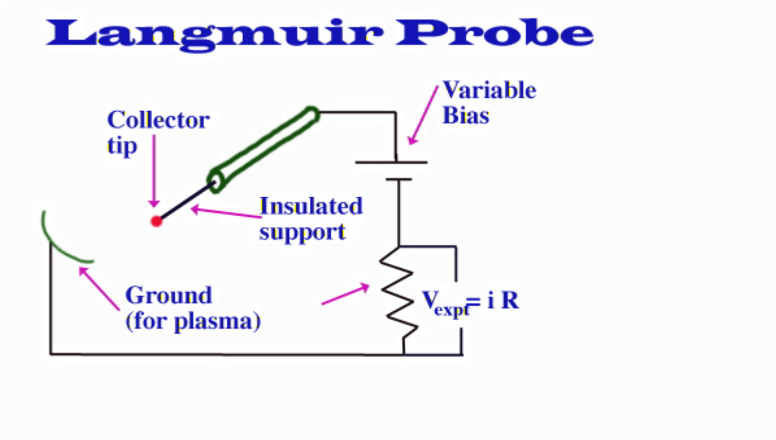
Langmuir Probe

This is the simplist diagnostic, everybody uses it, too bad it is nor super accurate. It is basically the tip of a wire, a small sphere or a disc immersed in a plasma. The tip is biased with respect to the plasma chamber wall or a grid or electrode in the plasma. Current is collected as the probe bias is changed:



When the bias is very negative it collects only ions, this is the ion saturation current. When there is no bias the probe is said to “float”. Since, per unit time, more of one species hits it than the other (why?) it charges up to the floating potential. When the probe is biased above the “plasma potential” it collects electrons. These regions are shown below:

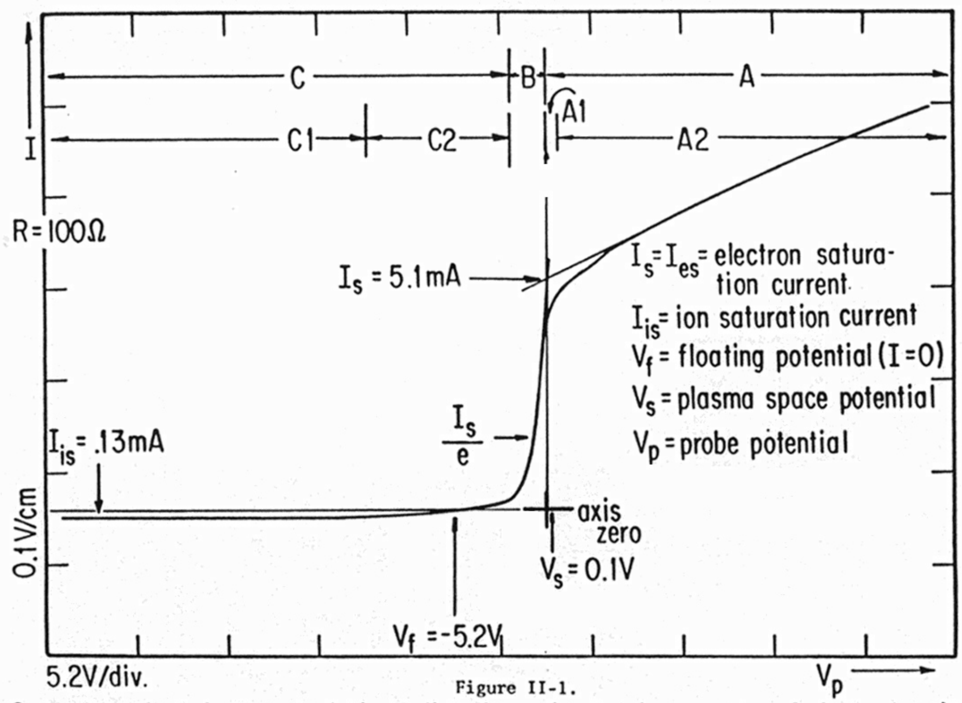


Figure II-1.

Sample Langmuir Probe Characteristic (Radial disc probe placed near center of single plasma): Region C1 - Ion saturation (electrons repelled); Region C2 - Ion saturation plus small primary electron current; Region B - Secondary electrons added to current of primaries and ions; X - Probe at space potential (zero electric probe field); Region A1 - Electron saturation with cooler ions being repelled; Region A2 - Electron saturation, no ion current. T_e (1.0 eV for this data).

The current to the Langmuir probe depends upon which region you are in
For the case where there is no magnetic field....

Ion saturation region:

$$I_{ion\_sat} \quad 0.5ne\sqrt{\frac{kT_e}{M}}\pi R^2$$

R = probe radius

n = density/cm^{-3}

There are other expression for cylindrical and spherical probes.

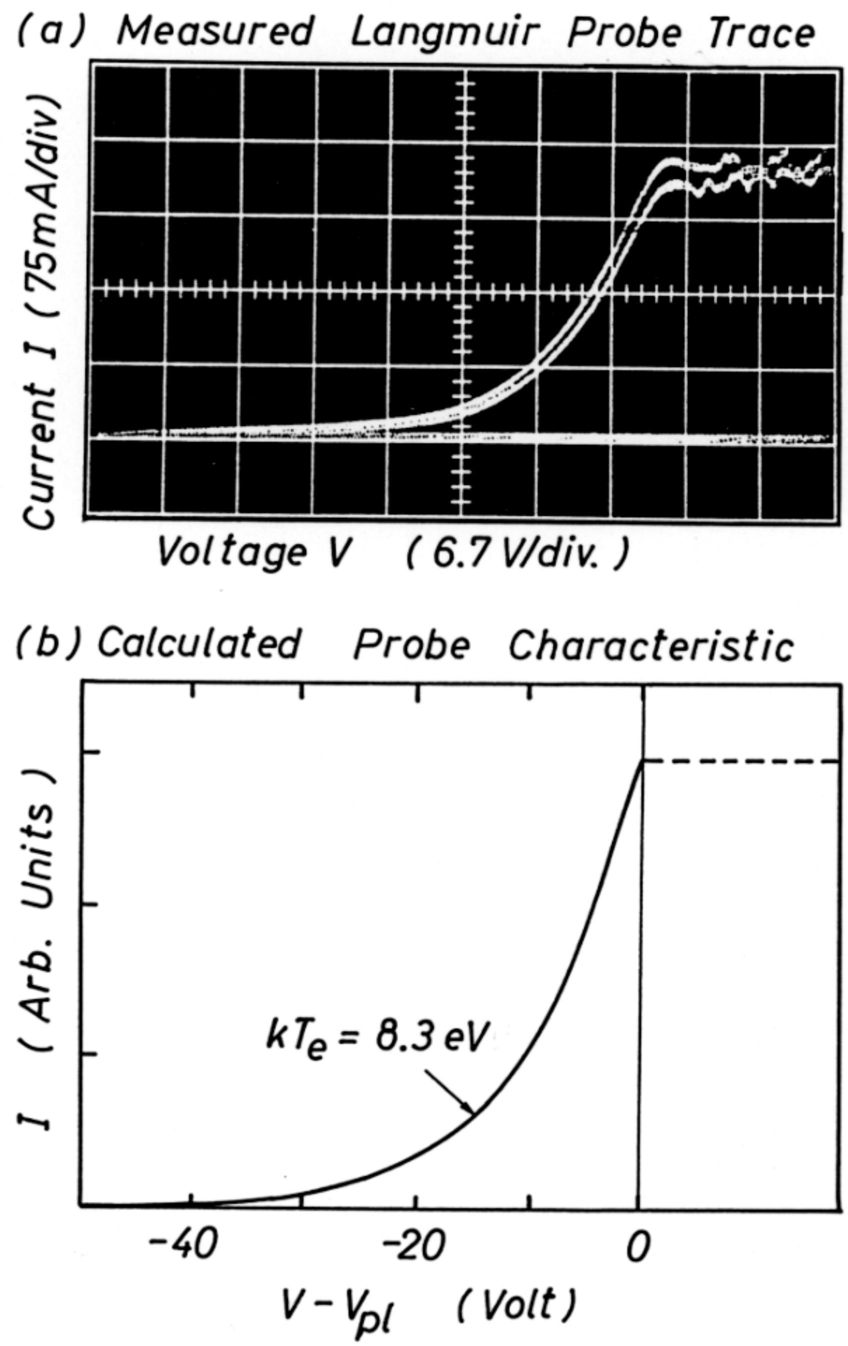
In the transition region let us neglect the ion current:

$$I_{probe} = eA\sqrt{1/2\pi mkT_e}\int_{E_{min}}^{\infty} ne^{-\frac{E}{kTe}}\,dE$$

1 Dimension:

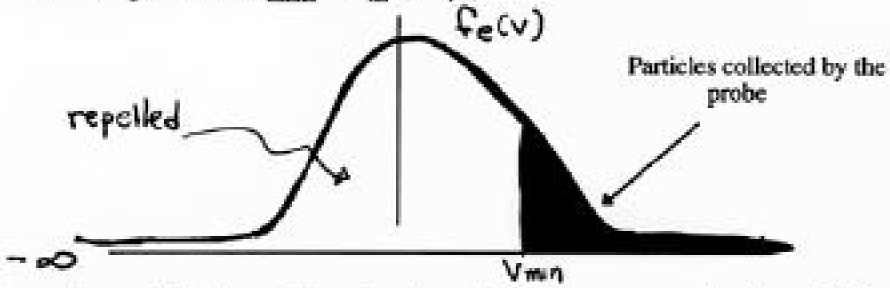
Langmuir Probe Data:

The following curve is an experimental current-voltage Langmuir probe trace:



Langmuir Probe currents:

Suppose we bias the probe in the circuit shown above to collect electrons in the "transition region" Here $I_{electron} >> I_{ion}$ (Why?)



Let us also consider the one dimensional case. Particles can approach or be repelled only along the x direction.

$$I_{probe} = j \cdot A = -\left(\frac{m_e}{2\pi kT_e}\right)^{1/2} neA \int_{v_{min}}^{\infty} v_x e^{-\frac{1}{2}m_e v_x^2/kT_e}\, dv_x$$

Area

If Φ is the bias potential applied to the probe electrons with energy $\frac{1}{2}mv^2 \geq e\phi$ will get to it (ϕ is negative so is e)

Converting to energy $mvdv = ed\Phi$ we get:

$$I_p = -\frac{ne^2A}{m_e}\left(\frac{m_e}{2\pi kT_e}\right)^{1/2} \int_{\phi_{min}}^{\infty} e^{-e\phi/kT_e}\, d\phi \quad ; \quad \int e^{-\alpha x} dx = -\frac{1}{\alpha} e^{-\alpha x}$$

$$I_p = -ne^2A\left(\frac{1}{2\pi m_e kT_e}\right)^{1/2} \left(-\frac{kT_e}{e} e^{-e\phi/kT_e}\right)\Bigg|_{\phi_m = \phi_B}^{\infty}$$

; ϕ_{min} is your probe bias also the probe bias

$$I_p = +\frac{ne^2}{e}A\left(\frac{kT_e}{2\pi m_e}\right)^{1/2} e^{-e\phi/kT_e}$$

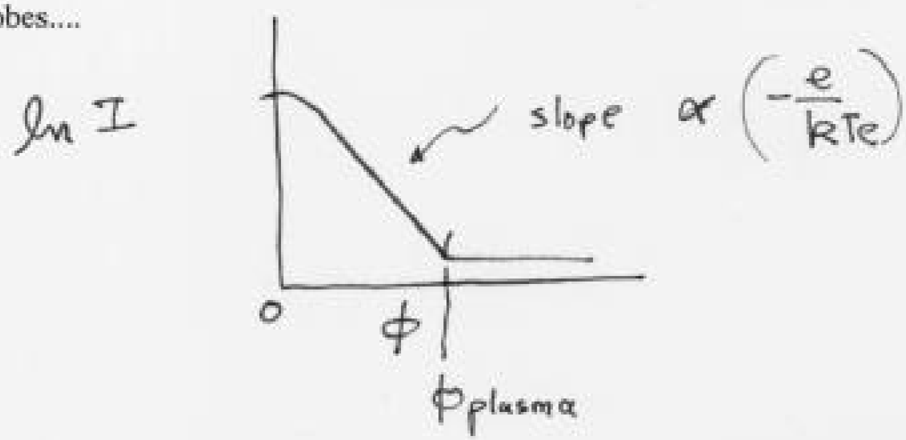
then $\ln(I_p) = \ln\left(neA\sqrt{\frac{kT}{2\pi m_e}}\right) (e\phi/kT_e)$

Note this is of the form

$$y = m\phi + b \quad \text{with} \quad m = -\frac{e}{kT_e}$$

Langmuir probes....

Thus



Therefore in this simple approximation (**NO** magnetic field, collisions with like or neutral particles)

We get the electron temperature proportional to the ln of the slope of the current in the "transition" region.

For an Early article on Langmuir probes which is still highly quoted
F.F. Chen, *Electric Probes*, Chapter 4 of Plasma Diagnostic Techniques, Huddlestone and Leonard, Academic Press

If particle orbits and a magnetic field near the probe is included the one can only find the current verses voltage curve numerically. This has been done over the years by Lamfromboise, a Canadian plasma theorist specializing in Langmuir probes. He is still at it.

More current articles may be find in Plasma Diagnostics Ed. by Noah Hershkowitz, Chapter 3, *How Langmuir Probes Work.*, by Noah Hershkowitz (who is coincidentally the Langmuir Professor of Physics at the University of Wisconsin !)