Langmuir Probe in Plasma Diagnostics

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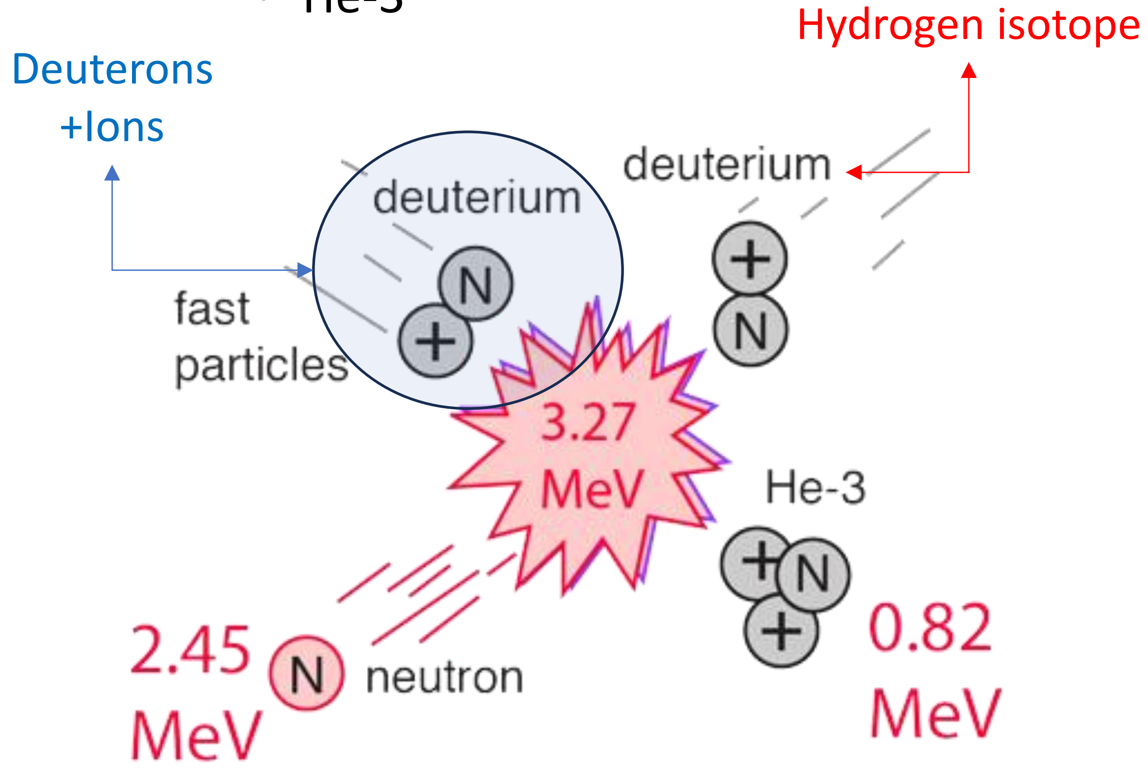
January 2025

Outline

1. Why are we here?
2. What is plasma?
3. Langmuir probe:
    1. I – V Curve
    2. Transition Region
    3. Electron saturation
    4. Floating potential
    5. Space potential
    6. Ion saturation current
4. Probe designing

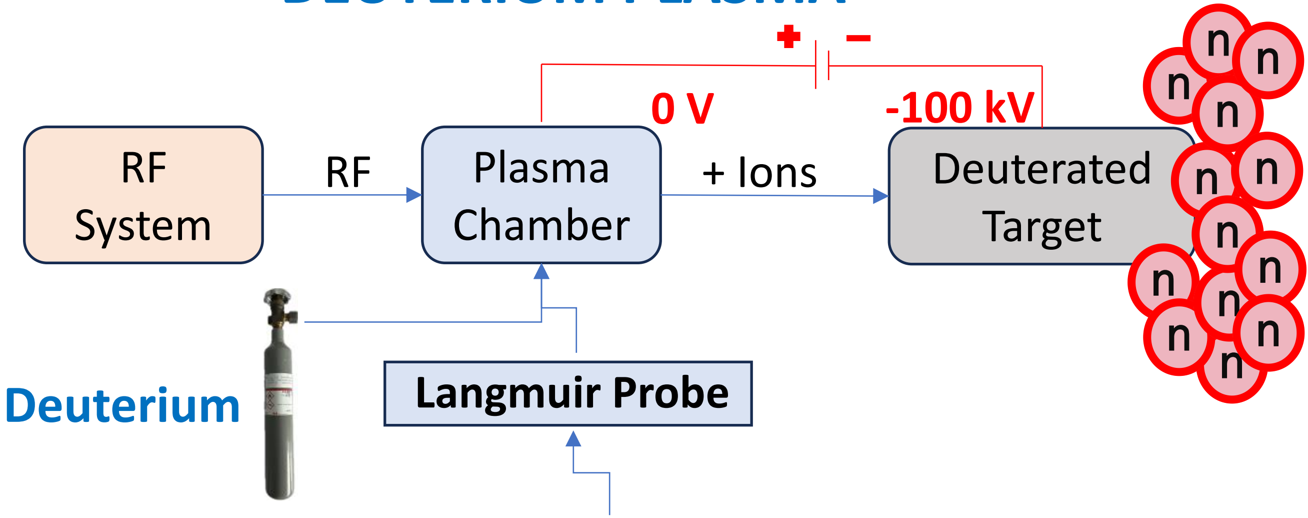
1. Why are we here?

- **Thesis** → Design and construction of a D-D compact neutron source
- D-D **fusion** reaction:
  - **2.45 MeV** neutrons
  - He-3



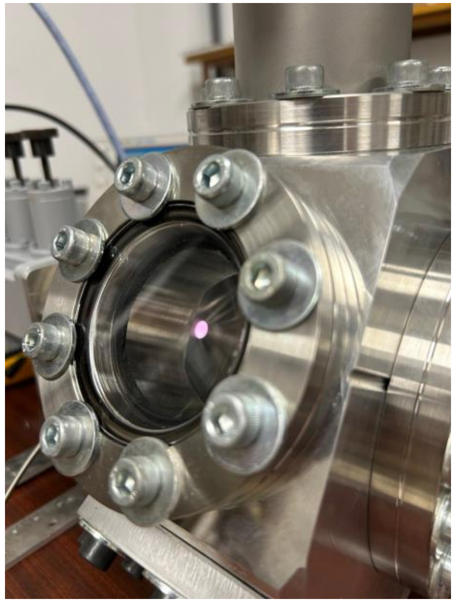
- Fusion reaction needs **high energy**
- Electrostatic acceleration → Uncharged particles / Charged particles (ions)
- Where do we find deuterium ions (deuterons)?

DEUTERIUM PLASMA

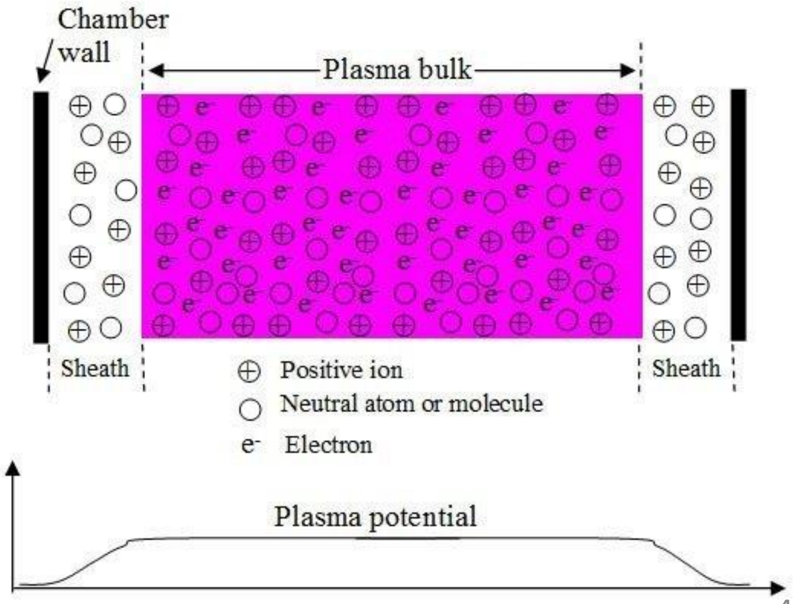


- Relevant to know the plasma characteristics as is the source of our deuterons.

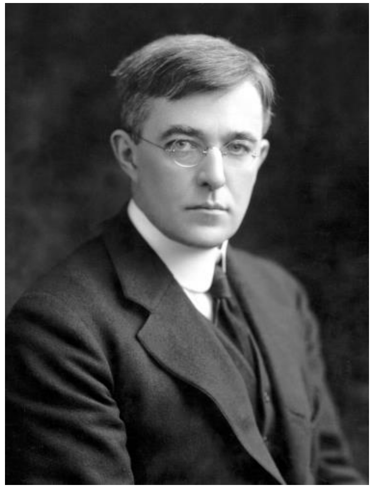
2. What is plasma?



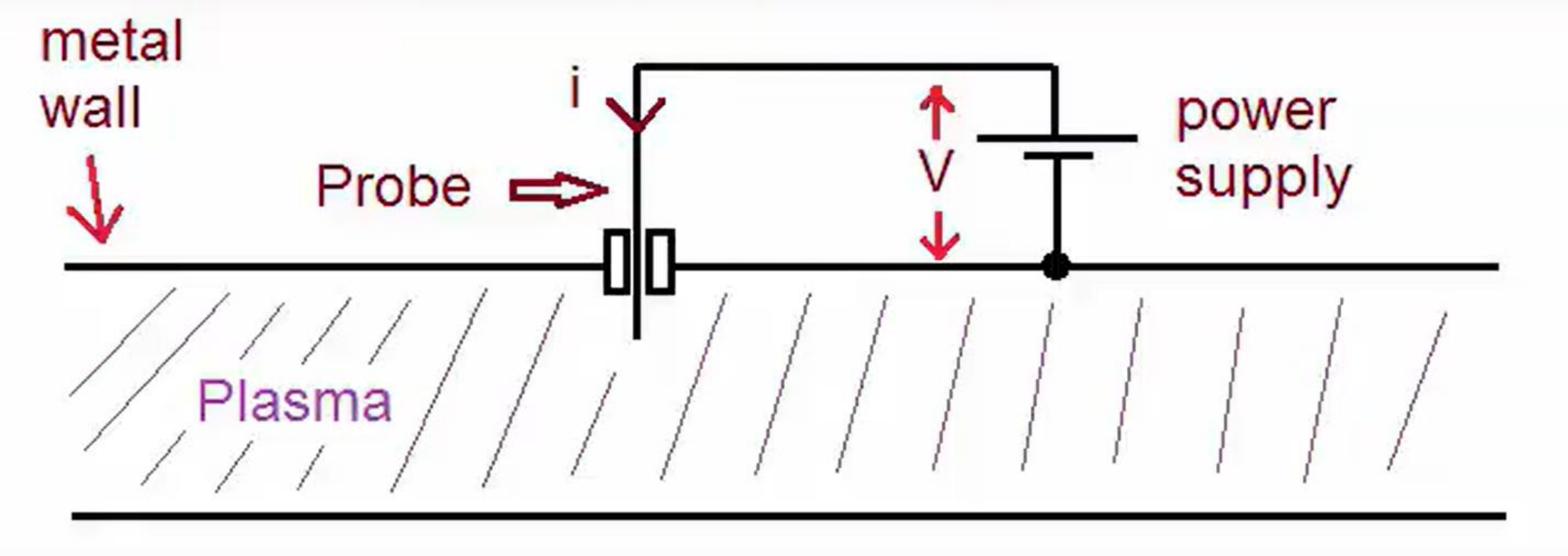
- 4th fundamental state of matter: solid, liquid, gas and **plasma.**
- It consists of ionized gas, where atoms or molecules have lost or gained electrons, creating a mix of free electrons and ions.
- **Parameters:**
  - *Density and ionization degree:* $\alpha = \frac{n_i}{n_i + n_n}$
    - n_i = ion density
    - n_n = neutral density
  - *Temperature (K, eV):* measure of the thermal kinetic energy per particle.
  - *Plasma potential:* The average potential in the space between charged particles is called the "plasma potential", or the "space potential".
  - *Sheath:* $T_e >> T_i$ because $m_e << m_i$. So, they can escape from plasma at a much faster speed than ions if there is no confining potential barrier. Once electrons are mostly depleted from the boundary interface between plasma and electrodes or samples, a region with only positive ions and neutrals will be formed.



3. Langmuir Probe



- Irving Langmuir → Electron temperature (T_e) 1924, Chemistry Nobel prize 1932
- A metal wire placed in a plasma to measure current and voltage to obtain:
  - T_e, T_i, n_e and n_i

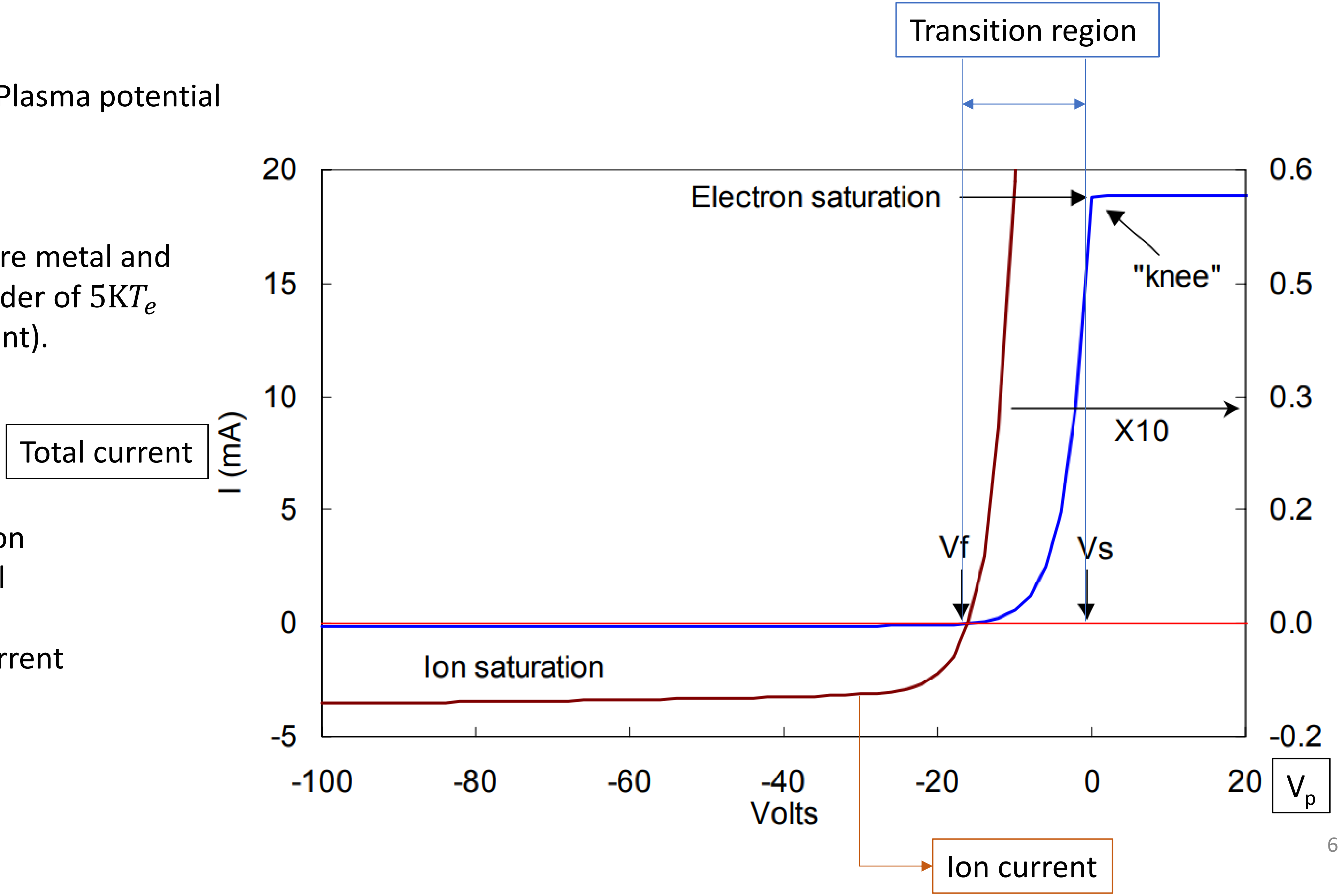


3. Langmuir Probe. I – V Curve

- V_s = Space potential / Plasma potential
- V_p = Probe potential
- V_f = Floating potential

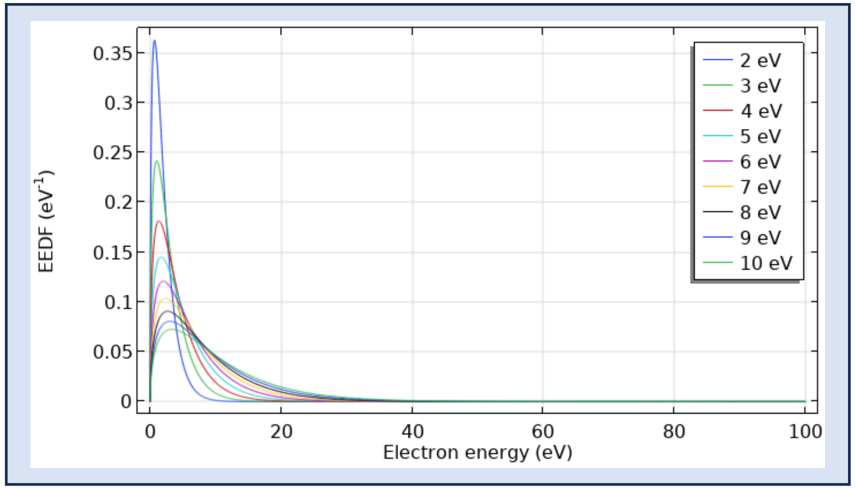
- If the chamber walls are metal and grounded, V_s of the order of $5KT_e$ (K = Boltzmann constant).

- Five main parts:
  - Transition region
  - Electron saturation
  - Floating potential
  - Space potential
  - Ion saturation current



3. Langmuir Probe. I – V Curve

- **Transition region:**
  - $V_f < V_p < V_s$
  - Ion current is negligible and the electrons are partially repelled by the negative potential $V_p - V_s$
  - Exponential part of the I – V curve only if electrons follow a Maxwellian energy distribution
  - In this region the I_e can be described as:

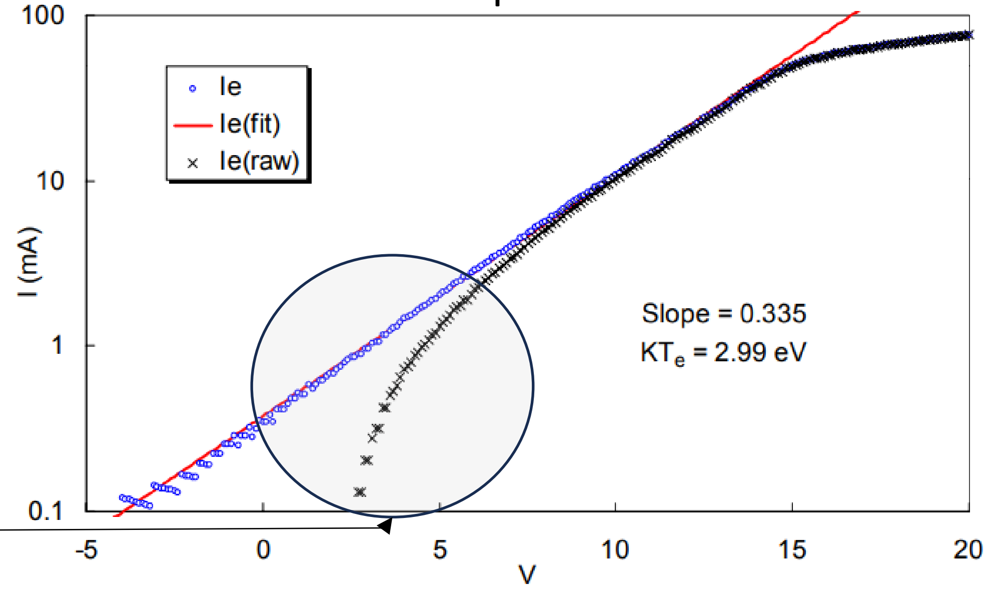


$$I_e = I_{es} \exp[e(V_p - V_s)/KT_e)]$$

Area of the probe tip dependent

  - The slope of $\ln(I) - V$ curve is $\frac{1}{T_{eV}} = \frac{e}{KT_e}$
  - T_e is the easiest parameter to obtain from a probe
  - $I_e = I - I_i$
  - The EEDF (Electron Energy Distribution Function) can be determined from the shape of this curve

RF plasma



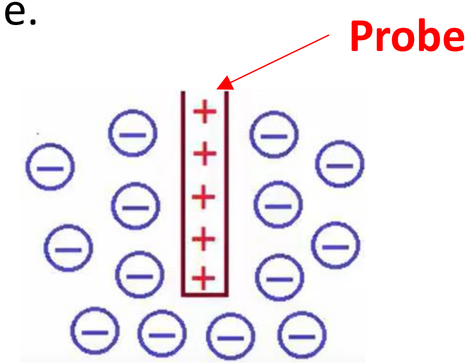
Ion contribution

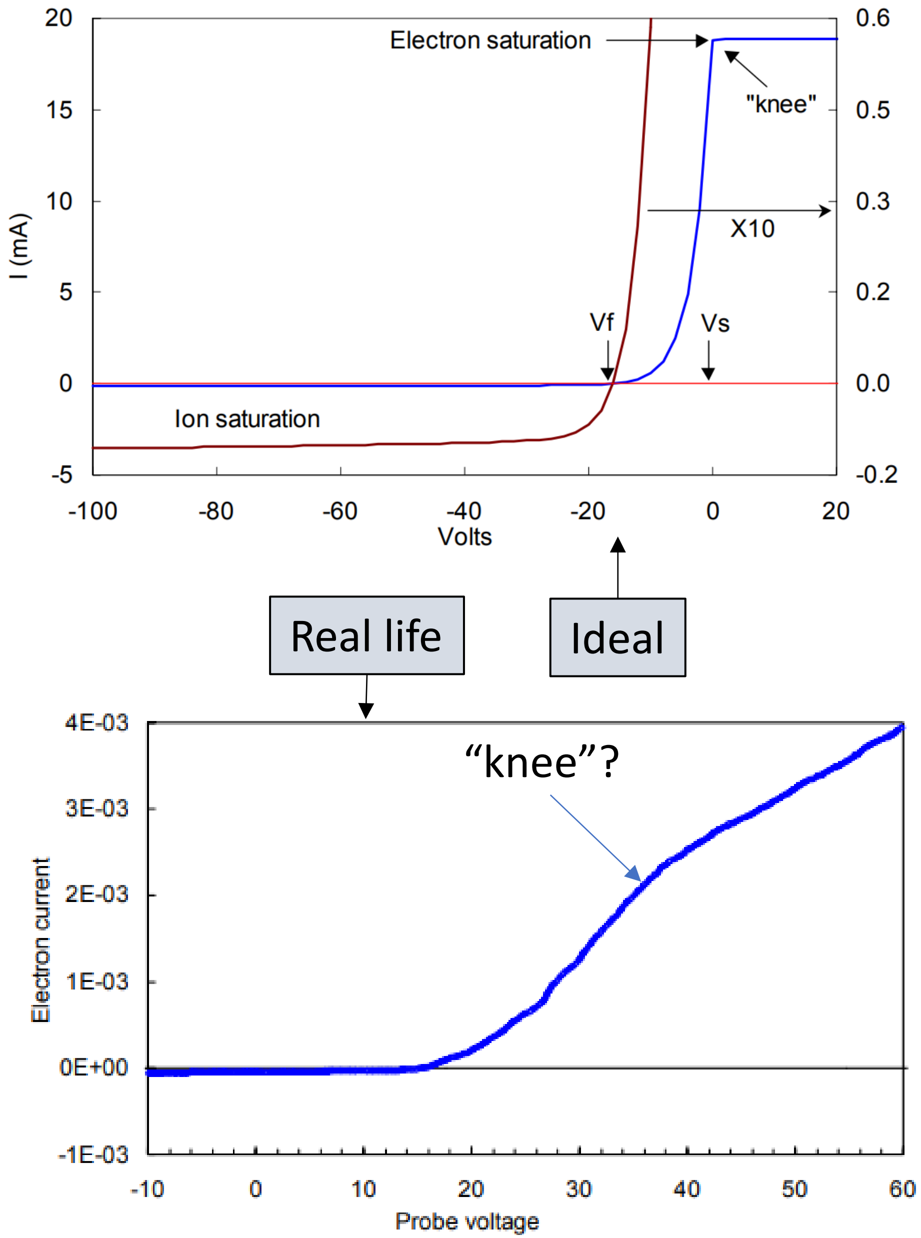
3. Langmuir Probe. I – V Curve

- **Electron saturation:**
  - $V_p \geq V_s$
  - At $V_p = V_s$,none of the electrons is repelled by a negative potential. The I_e saturates.
  - It is recommended to avoid collecting I_{es} as it can damage the probe.

  - I_{es} only gives information about the electron density in low pressure plasmas where the free path is very large.

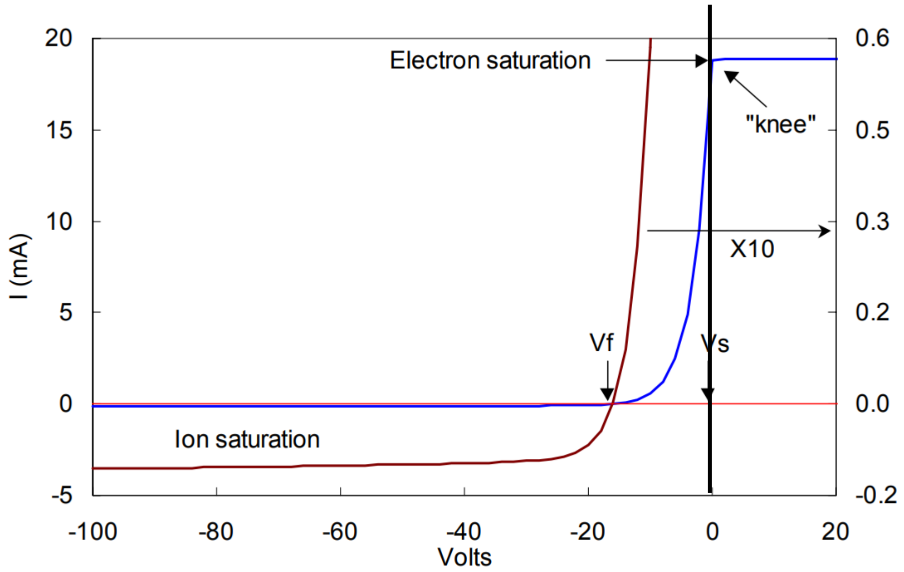
  - Collisions and magnetic fields will lower the magnitude of I_{es} and round off the “knee” so V_s is hard to determine.

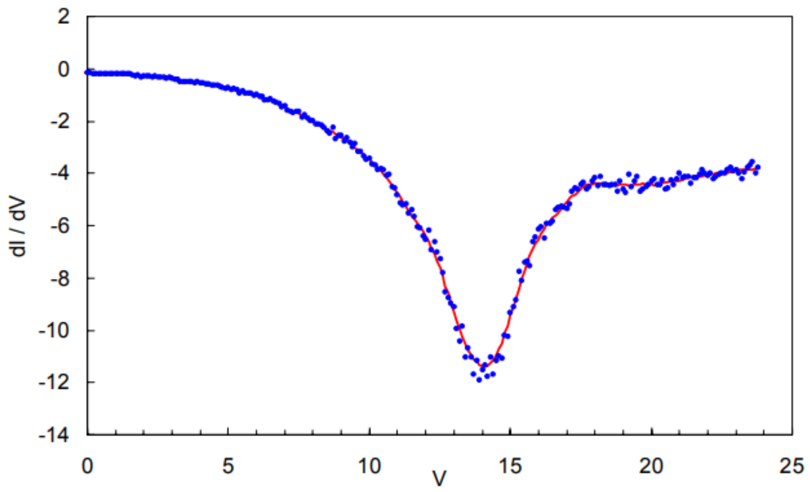


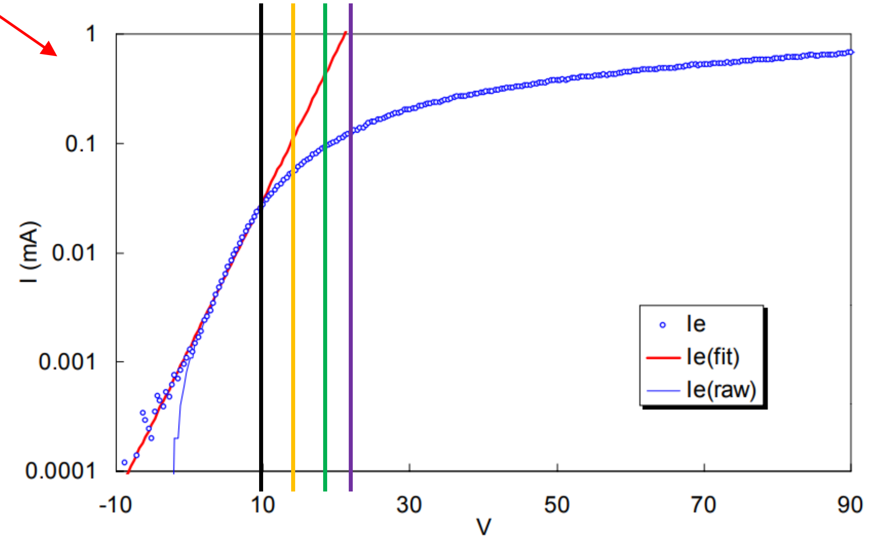


3. Langmuir Probe. I – V Curve

- **Floating potential:**
  - $V_f \rightarrow I_i = I_e$
- **Space potential:**
  - The conventional way to obtain V_s is to draw a vertical line just in the "knee". Not working in *curved* I_{es}.
  - We select as V_s the point where I_e starts to deviate from exponential growth.
  - Where $I'_e(V)$ is maximum.







3. Langmuir Probe. I – V Curve

- **Ion saturation:**
  - Measure n_e with I_{es} can lead to probe damage.
  - I_{is} is much smaller and because of plasma's quasineutrality we can consider $n_e = n_i$.

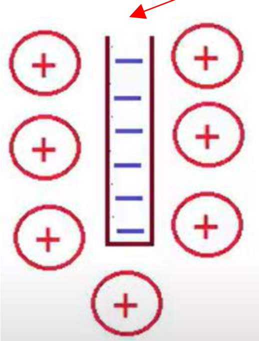
- $J_i = \frac{I_i}{A} = e n_s u_B$

  - u_B: Bohm speed (T_e)
  - n_s: Ion density at sheath edge

- $n_s = 0.5 n_i$

- $I_i = \frac{1}{2} e n_i A \left(\frac{K_B T_e}{m_i}\right)^{\frac{1}{2}}$

Probe



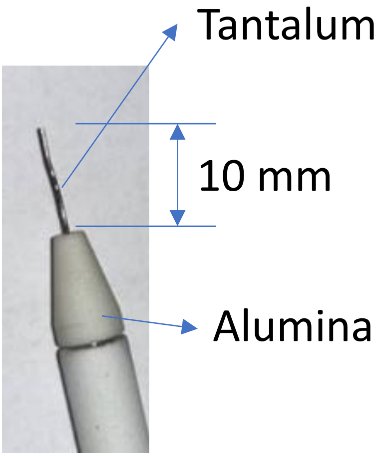
https://youtu.be/XiNE-H_g9t8

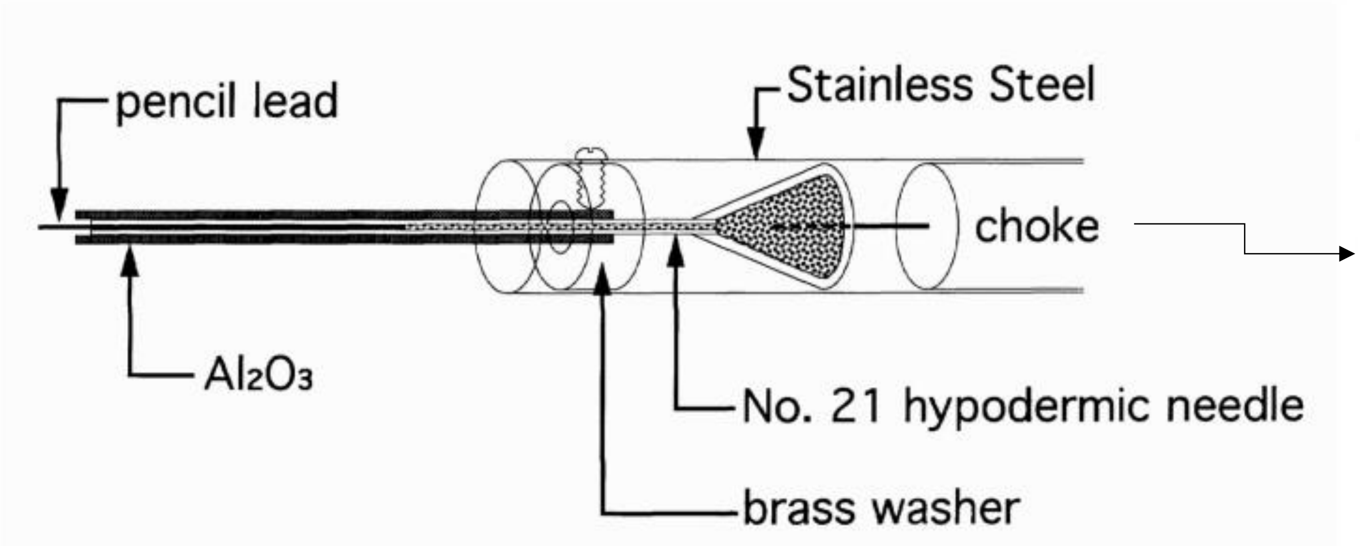
Key Differences:

Aspect	OML Theory	ABR Theory
Sheath Consideration	Assumes a thin sheath.	Accounts for finite sheath effects.
Object Size	Valid for small objects ($r \ll \lambda_D$).	Applicable to larger objects.
Plasma Collisions	Assumes a collisionless plasma.	Can include collisional effects.
Complexity	Simpler, based on particle orbits.	More complex, includes sheath dynamics.

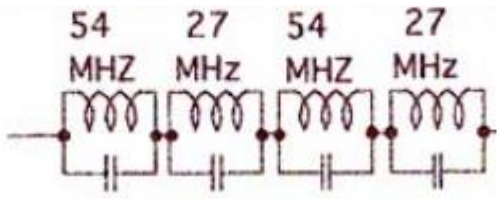
4. Probe Designing

- The design process is critical to obtain a precise I –V curve as the probe will be inmersed in a harsh environment.
- The probe tip is made of a **high-temperature material**, usually a tungsten rod or wire. Ø = 0.1 – 1 mm.
- To insulate the the probe from the plasma, except the tip, **ceramic tubes** (alumina) are used. They need to be as thin as possible to avoid disturbing the plasma, < 1 mm.
- When in the ion current region, the probe can be eroded by sputtering which could modify the collection area. Minimized by using carbon as tip material.





RF Chokes



Not for **ECR** plasmas

Thank you for your attention