Theory and demonstration of plasma measurement using Langmuir probe
電漿量測之蘭摩爾探針原理與實作

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2021 winter break

1/18(Mon.) – 1/22(Fri.) 14:00-17:40

http://capst.ncku.edu.tw/PGS/index.php/teaching/

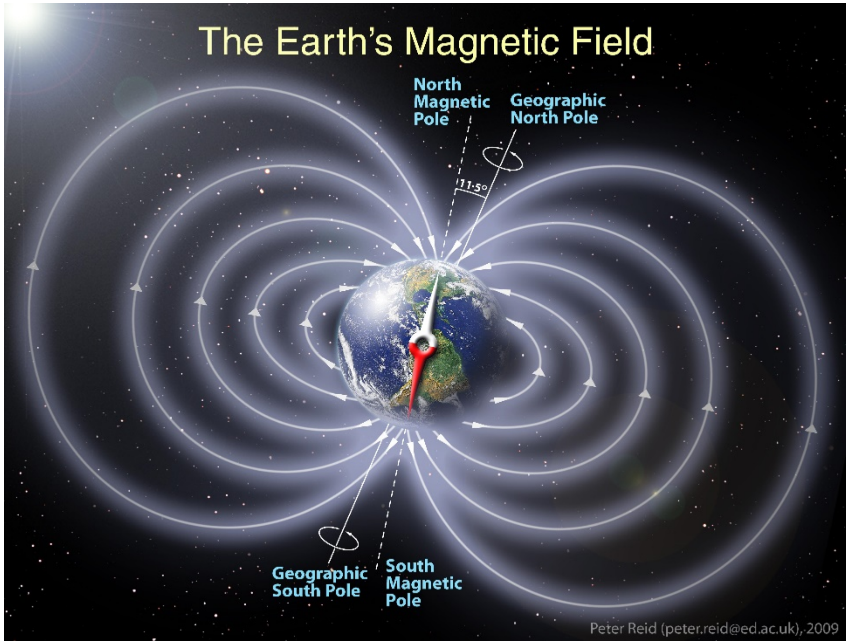
Lecture 3

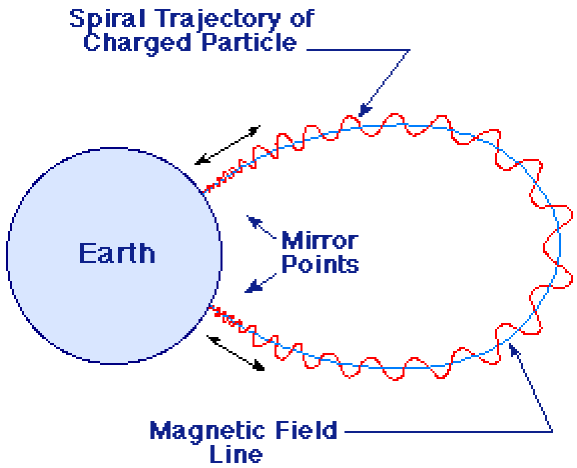
2021/1/20 updated

Applications of plasma

1. Material Processing
2. **Plasma in space**
3. Biomedical application
4. High energy particle accelerator
5. Electric propulsion
6. Controlled thermonuclear fusion

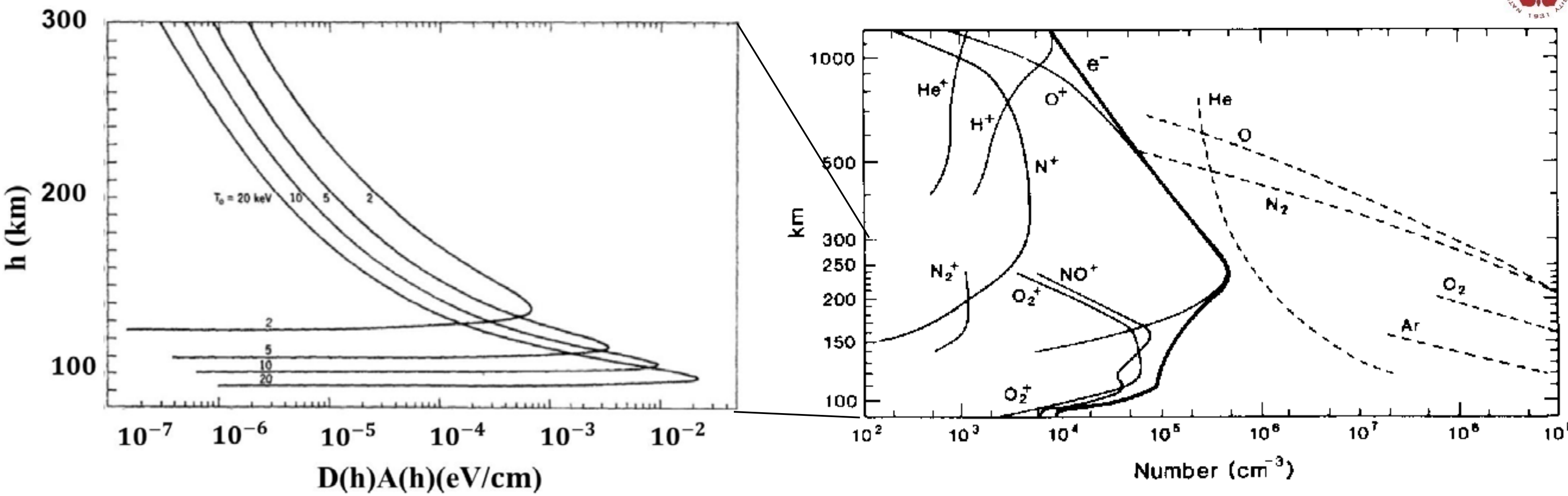
Earth’s magnetic field



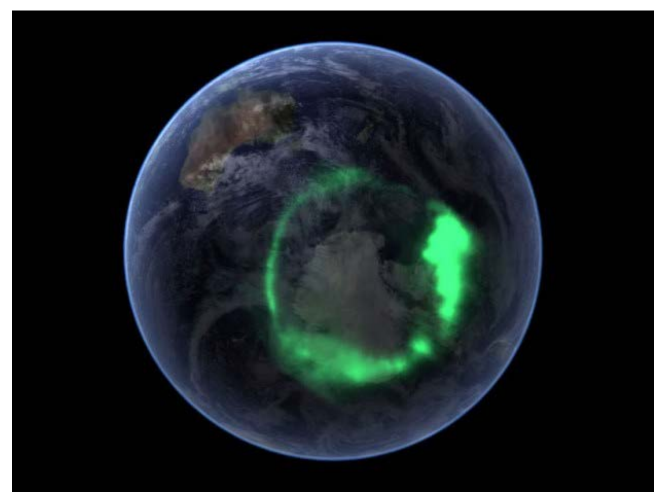


https://www.nasa.gov/mission_pages/sunearth/news/gallery/Earths-magneticfieldlines-dipole.html
http://www.pas.rochester.edu/~blackman/ast104/emagnetic.html

Aurora occurs when energetic electrons penetrating into atmosphere in the pole regions



- O_2: green or dark red
- N_2: blue or purple



J. Atoms Terr. Phys., **32** (1970) 1015-1045
Johnson, 1969; Luhmann, 1995

https://flashpack.com/insights/2014/11/20/aurora-australis-forget-the-northern-lights-have-you-heard-about-the-southern-lights/

Applications of plasma

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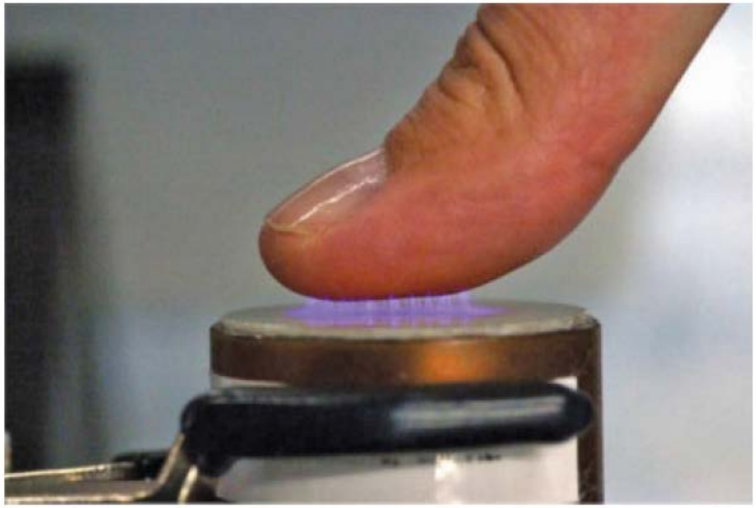
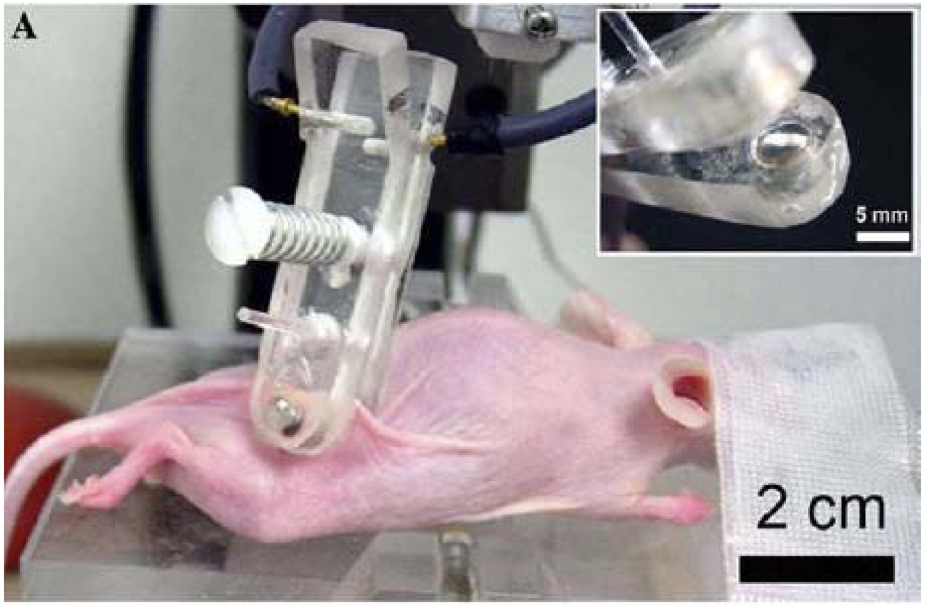
2. Plasma in space
3. **Biomedical application**
4. High energy particle accelerator
5. Electric propulsion
6. Controlled thermonuclear fusion

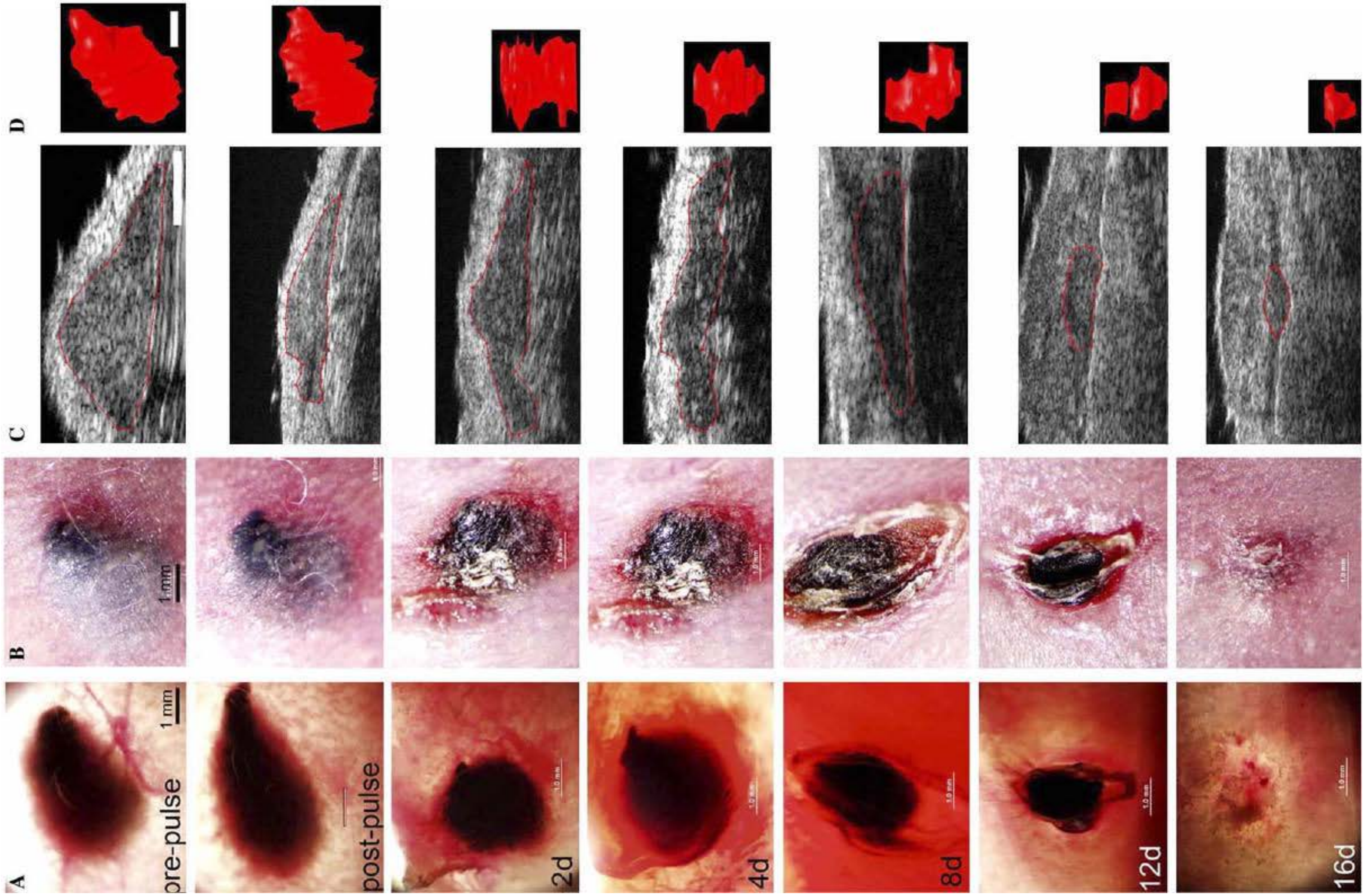
Biomedical applications of low temperature plasma





Plasma medicine, by Alexander Fridman and Gary Friedman
Biochem Biophys Res Commun. 2006 May 5; 343(2): 351–360.

Melanoma shrinks after the treatment



- **Day 0-3: 3 applications of 100 pulses (300 ns, 40 kv/cm, 0.5 Hz), 30 min apart**
- **Day 4: single application using 5 mm diameter parallel plate electrode**

Biochem Biophys Res Commun. 2006 May 5; 343(2): 351–360.

Applications of plasma

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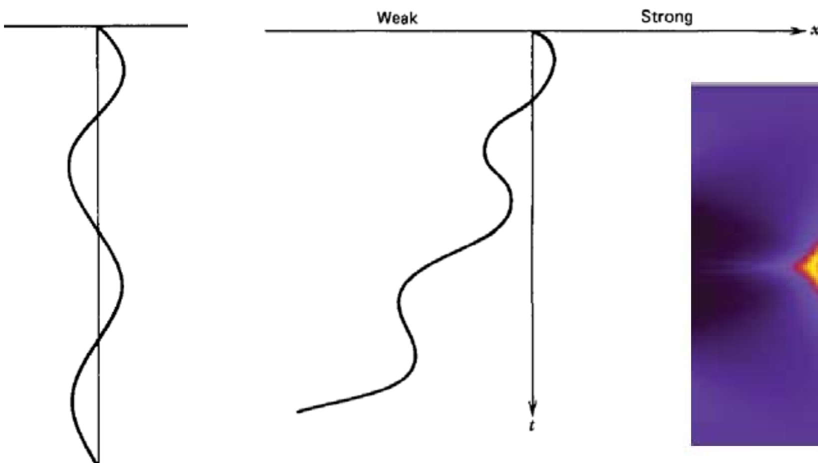
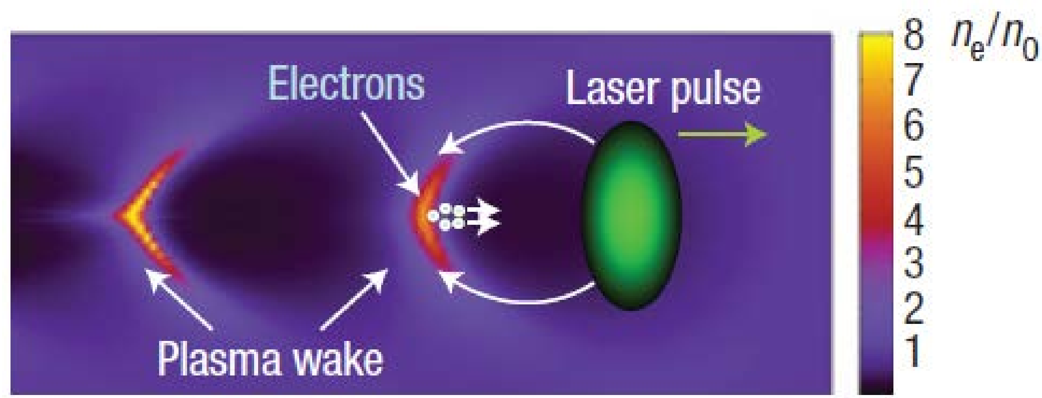
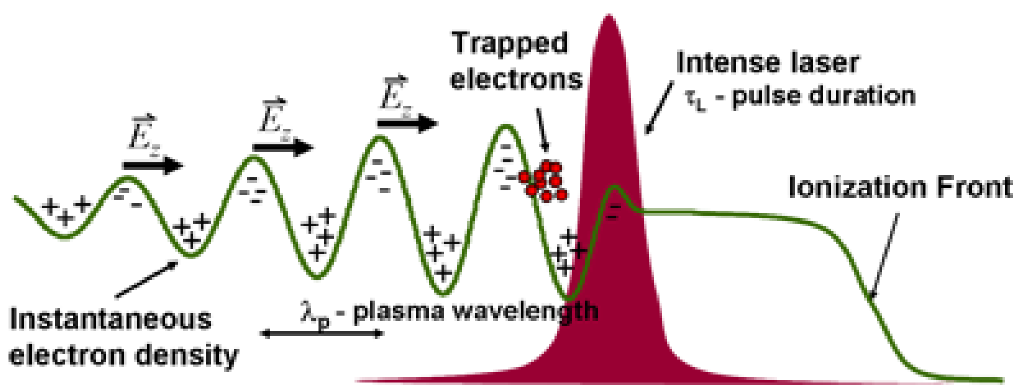
Electrons can be accelerated by a plasma wake generated by a short pulse laser

$$\frac{dE_0}{dx} = 0 \qquad \frac{dE_0}{dx} > 0$$







V. Malka, *et al.*, Nature Physics **4**, 447 (2008)
http://cuos.engin.umich.edu/researchgroups/hfs/research/laser-wakefield-acceleration/
https://i.ytimg.com/vi/CA-SDf1wvTQ/maxresdefault.jpg

Applications of plasma

1. Material Processing
2. Plasma in space
3. Biomedical application
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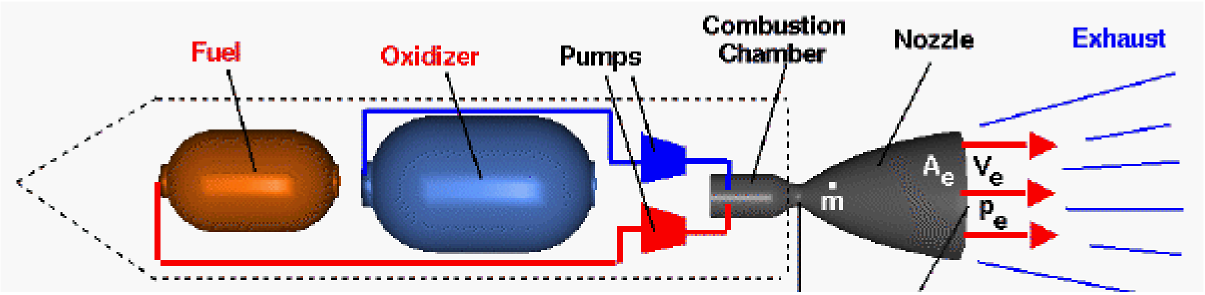
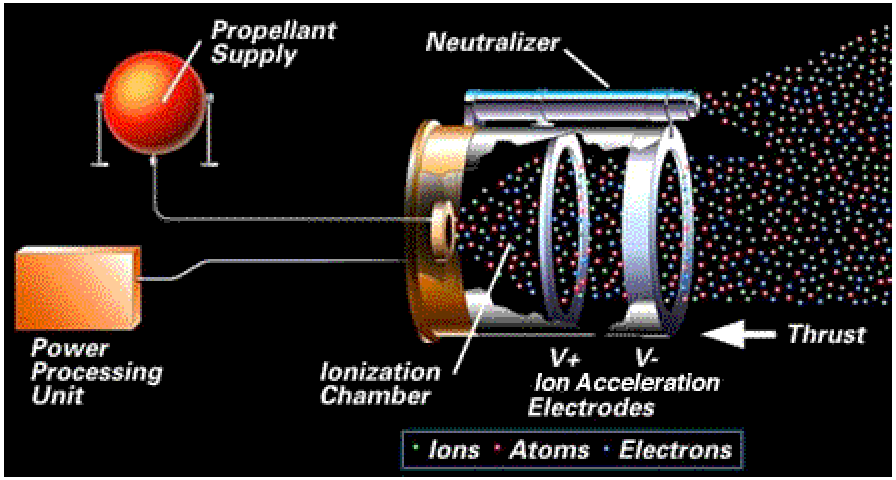
5. **Electric propulsion**
6. Controlled thermonuclear fusion

Comparison between liquid rockets and ion thrusters

- Liquid rockets
  - u~4500 m/s
  - Isp~450 s
  - Energy ~ 100GJ
  - Power ~ 300MW
  - Thrust ~ 2x10^6 N
- Ion thrusters
  - u~30000 m/s
  - Isp~3000 s
  - Energy ~ 1000GJ
  - Power ~ 1kW
  - Thrust ~ 0.1 N





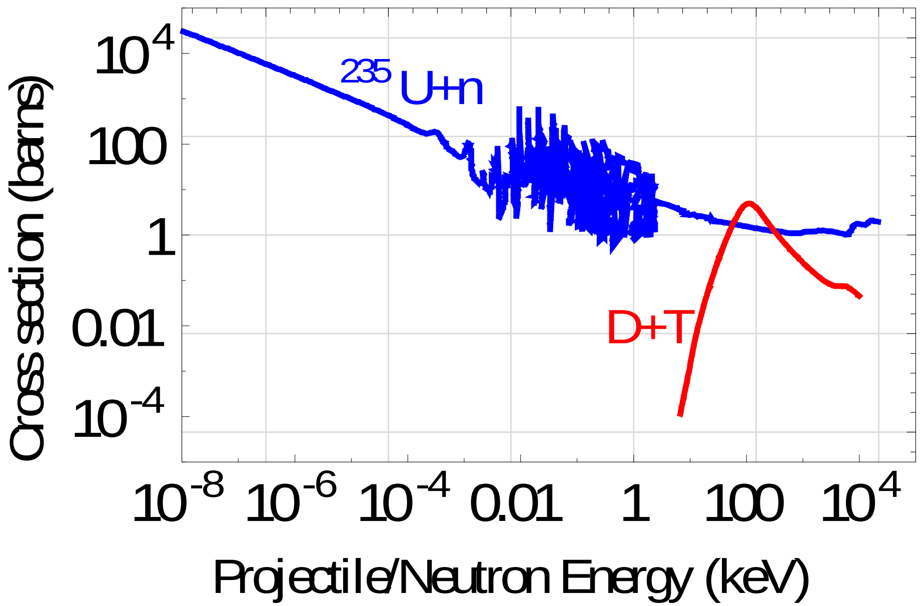
https://www.grc.nasa.gov/WWW/K-12/airplane/lrockth.html
https://defence.pk/pdf/threads/isro-to-test-electric-propulsion-on-satellites.411176/

Applications of plasma

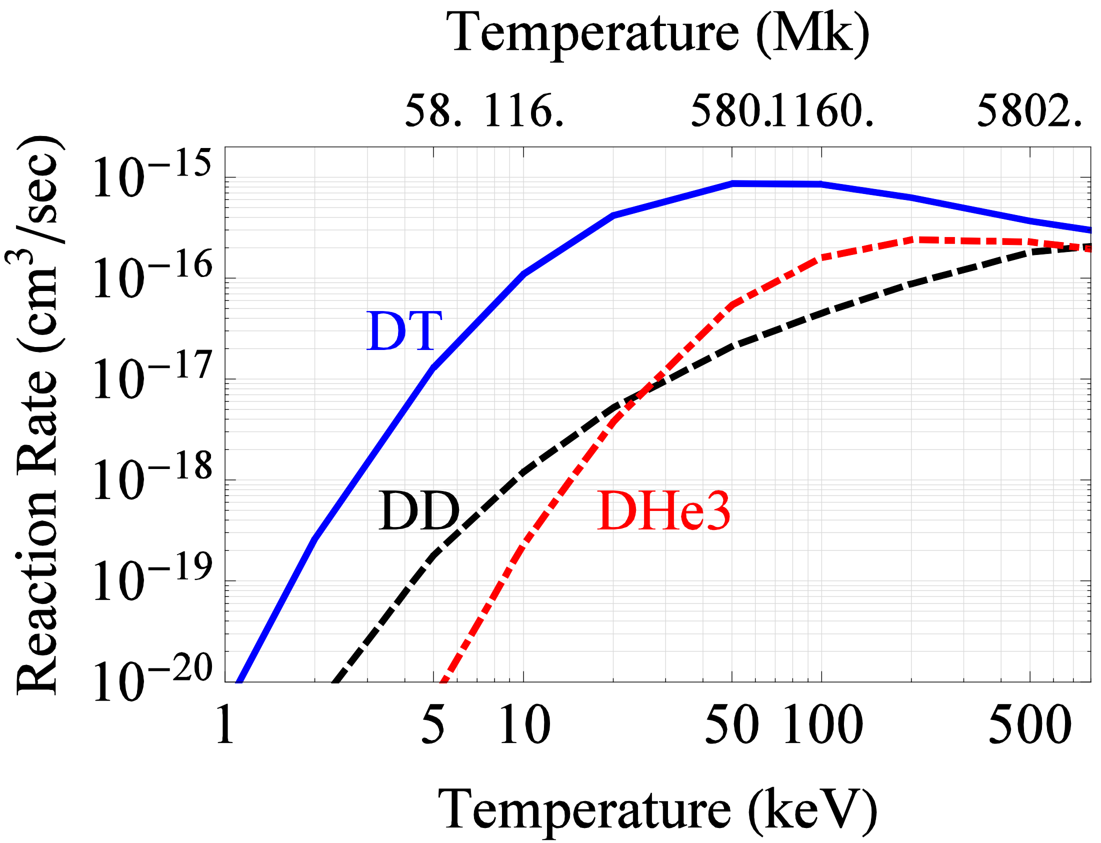
1. Material Processing
2. Plasma in space
3. biomedical application
4. high energy particle accelerator
5. Electric propulsion
6. **Controlled thermonuclear fusion**

Fusion is much harder than fission

- **Fission:** $n +^{235}_{92} U \rightarrow^{236}_{92} U \rightarrow^{144}_{56} Ba +^{89}_{36} Kr + 3n + 177\ \mathrm{MeV}$
- **Fusion:** $D + T \rightarrow He^4\,(3.5\ \mathrm{MeV}) + n\,(14.1\ \mathrm{MeV})$



Fusion doesn't come easy

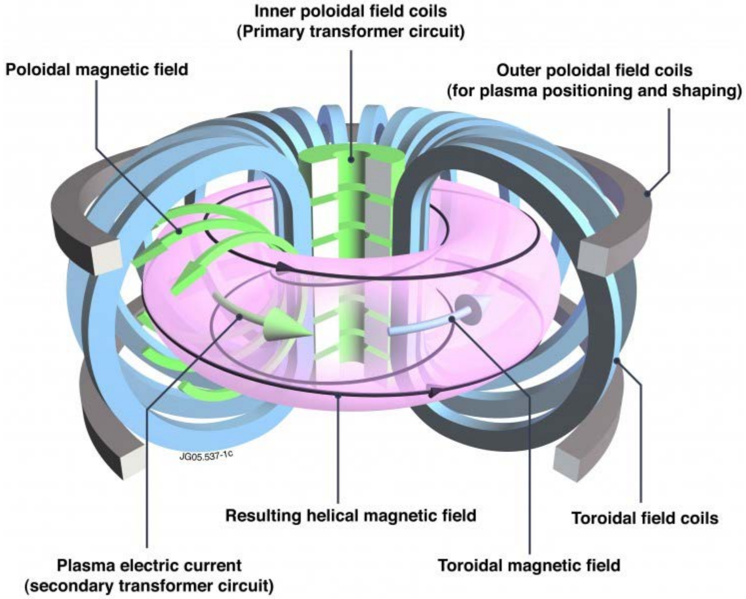


*NRL Plasma Formulary, Naval Research Laboratory, Washington, DC 203785-5320

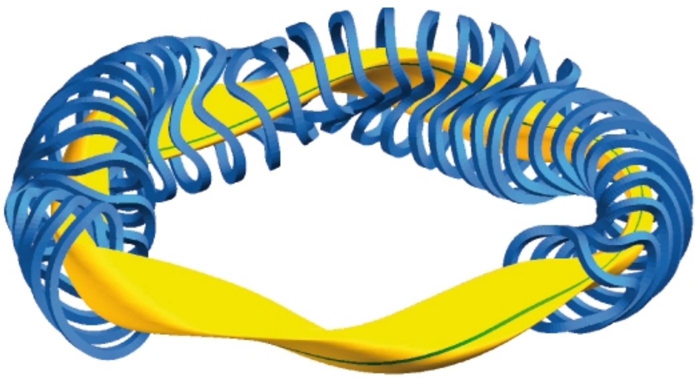
The plasma is too hot to be contained

- **Solution 1: Magnetic confinement fusion (MCF), use a magnetic field to contain it. P~atm, τ~sec, T~10 keV (10^8 ºC)**

Tokamak

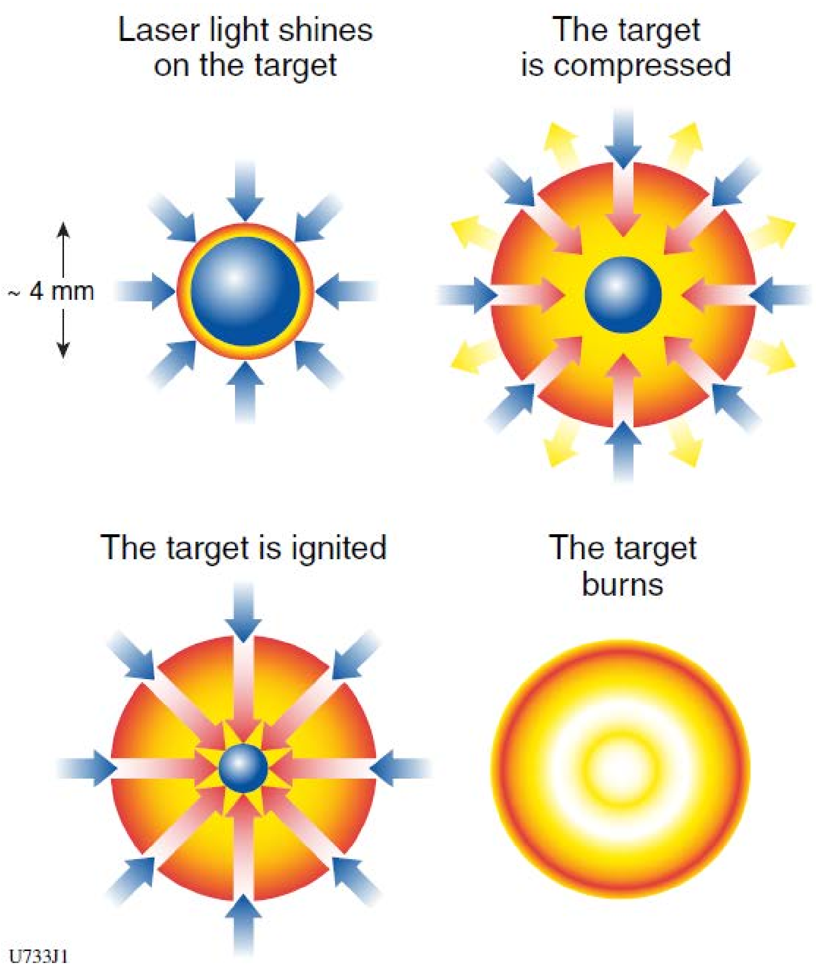


Stellarator

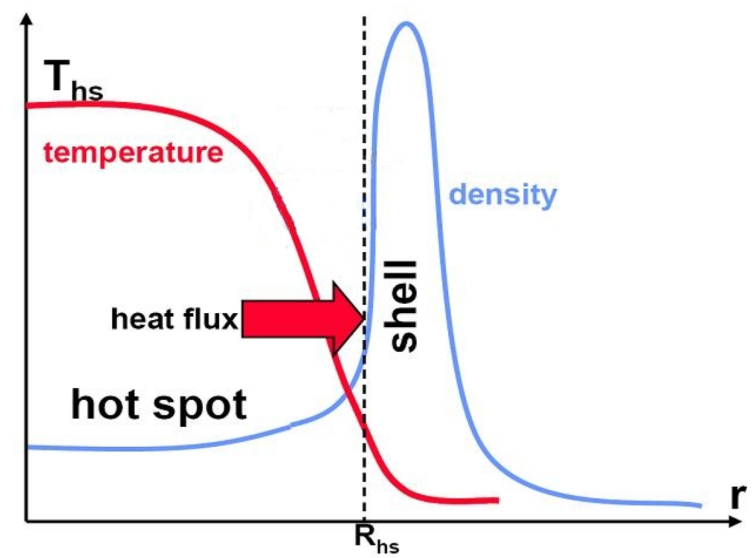


https://www.euro-fusion.org/2011/09/tokamak-principle-2/
https://en.wikipedia.org/wiki/Stellarator

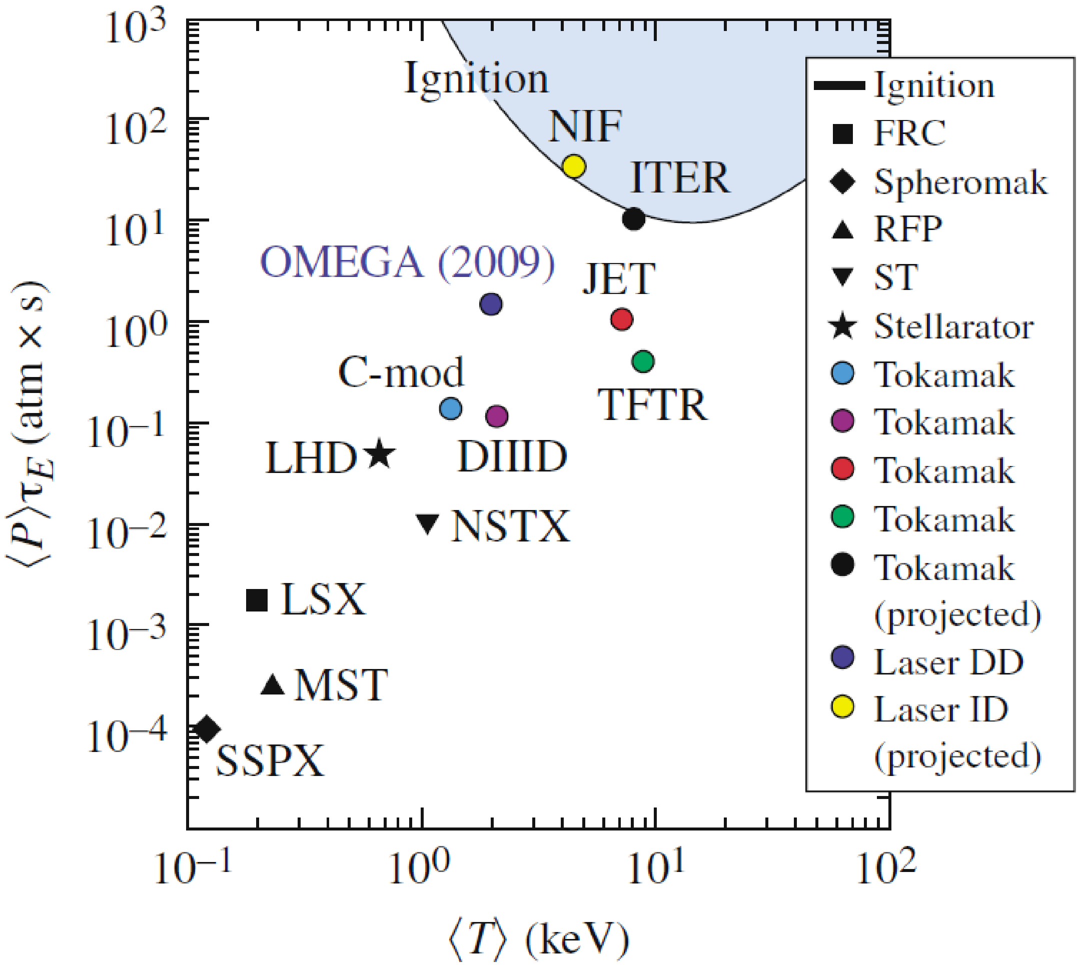
Plasma is confined by its own inertia in inertial confinement fusion (ICF)



Spatial profile at stagnation



We are really closed!



Phys. Plasma 17, 058102 (2010)

Course Outline

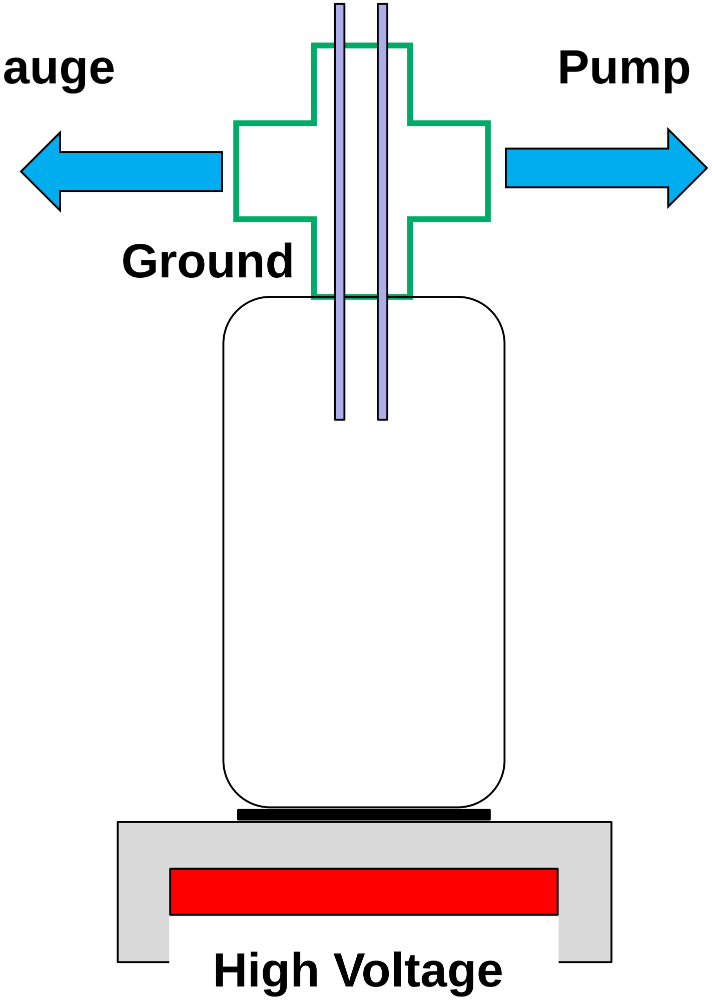
1. Introduction to plasma
   a. What is Plasma?
   b. How to generate plasma
   c. Applications of plasma
2. **Theory of Langmuir probe**
   a. **Sheath**
   b. **Single Langmuir probe**
   c. **Double Langmuir probe**
   d. **Triple Langmuir probe**
3. **Demonstration of Langmuir probe**
   a. **Building vacuum systems**
   b. Building Langmuir probes
   c. Measuring temperatures and densities of plasma

Day 1~3

Day 4~5: Experiments

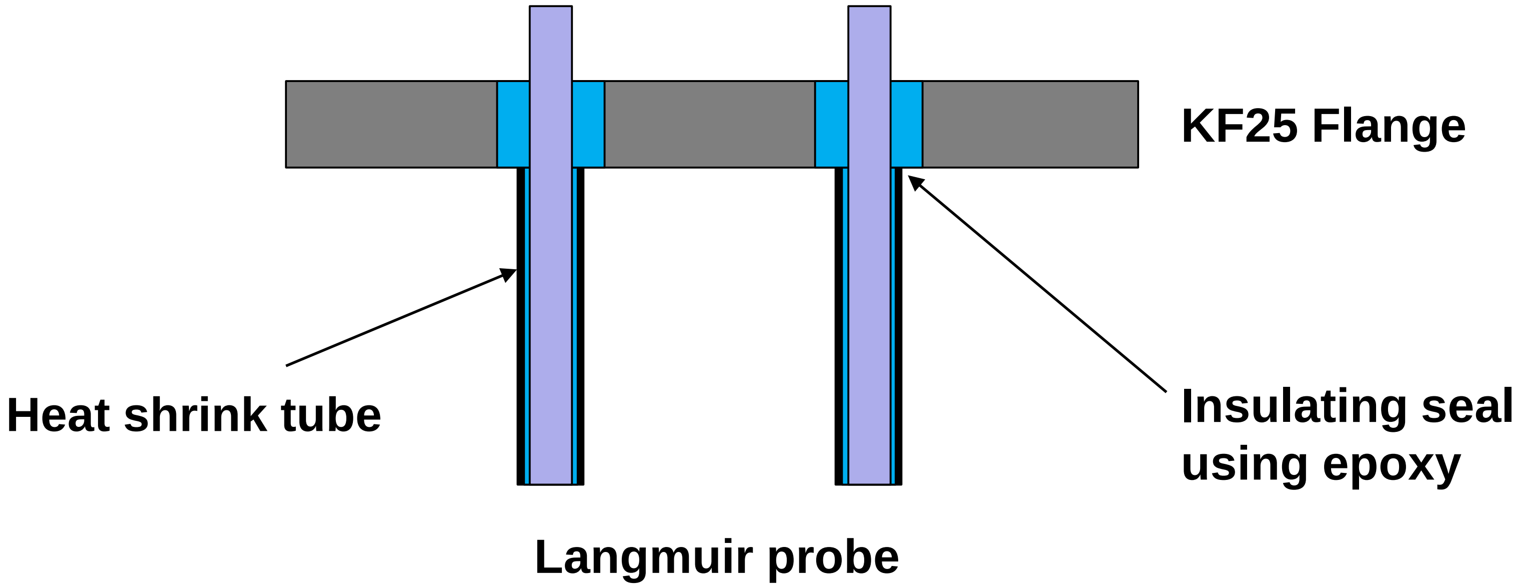
- **Wear shoes!**

T_e and N_0 measurements of a glow discharge in a glass jar

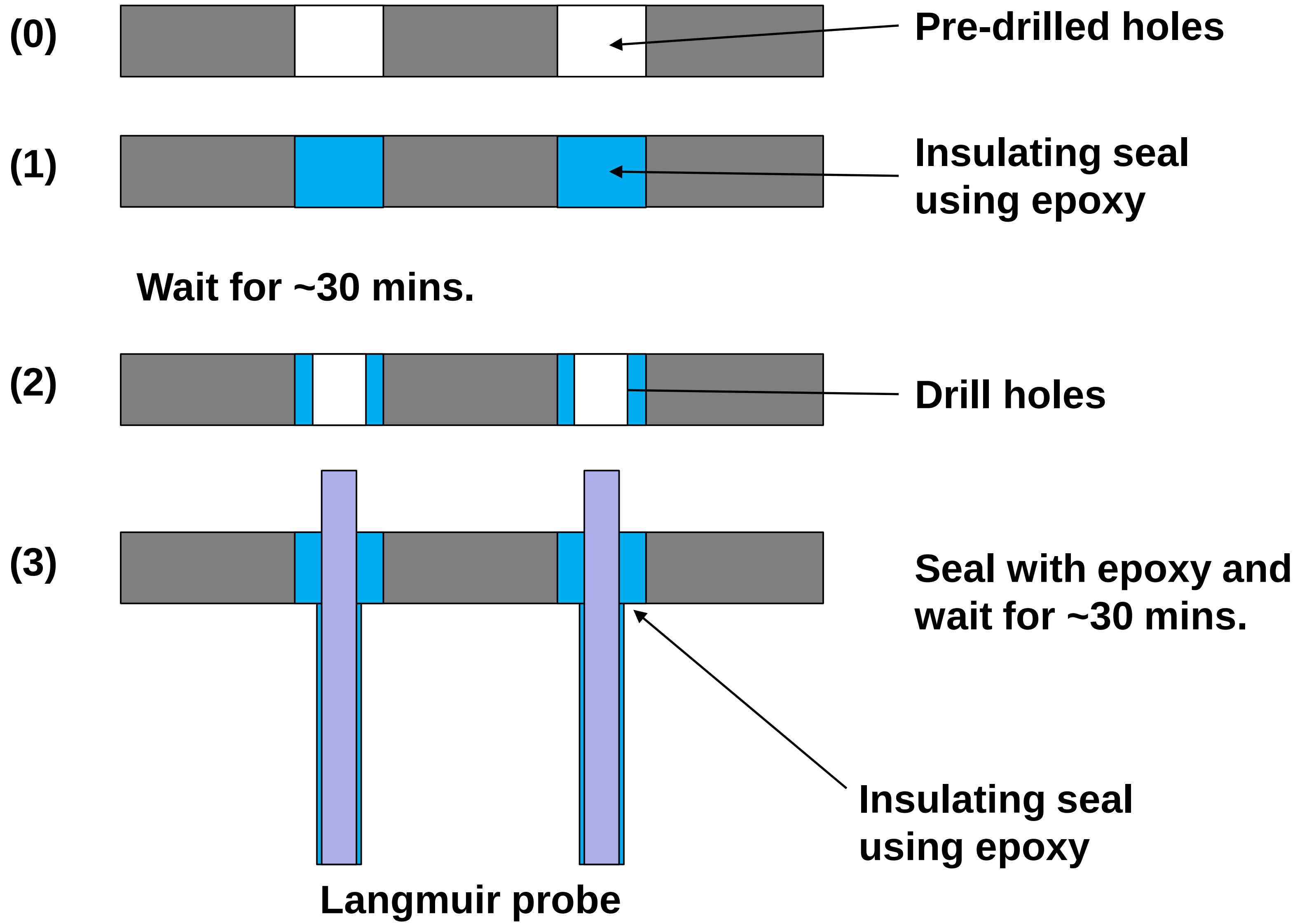


Vacuum chamber

- Watch up the vacuum interface.
- Use high voltage tape to cover the bottom plate.
- Clean all O-ring and center ring.
- Cut the rubber ring.
- Build the feedthrough for Langmuir probe.

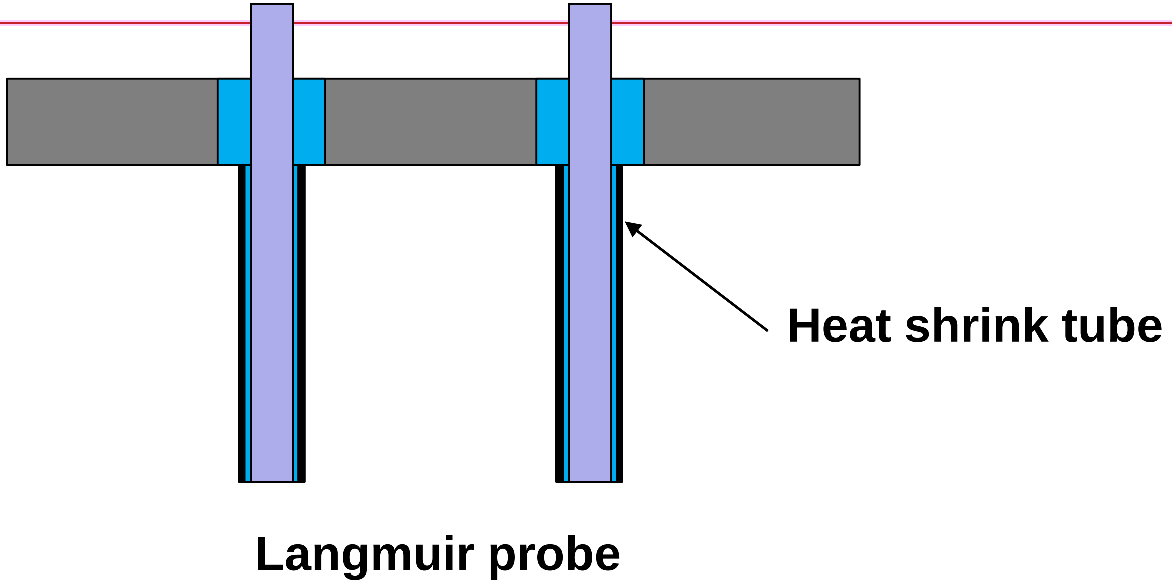


feedthrough



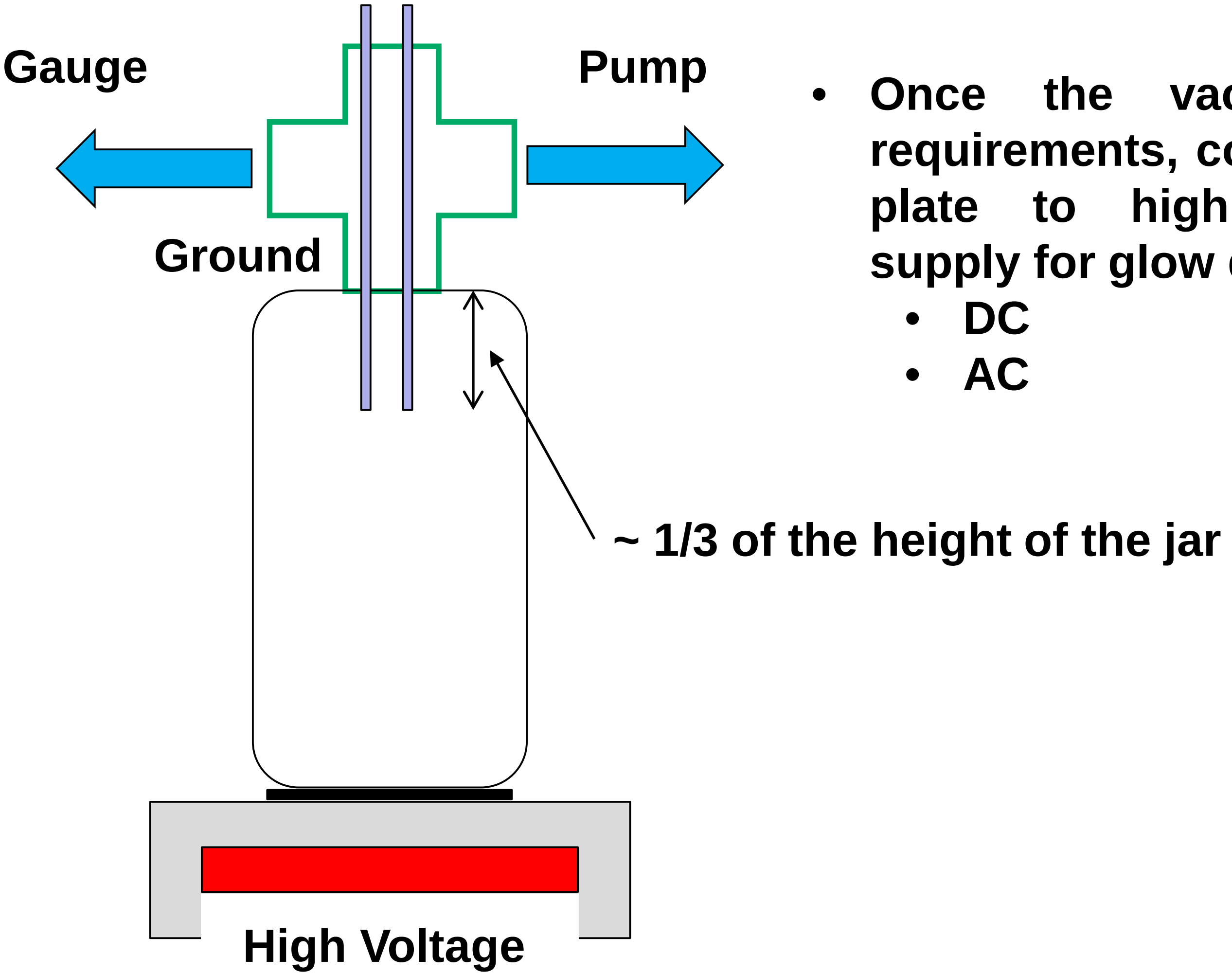
feedthrough

(4)



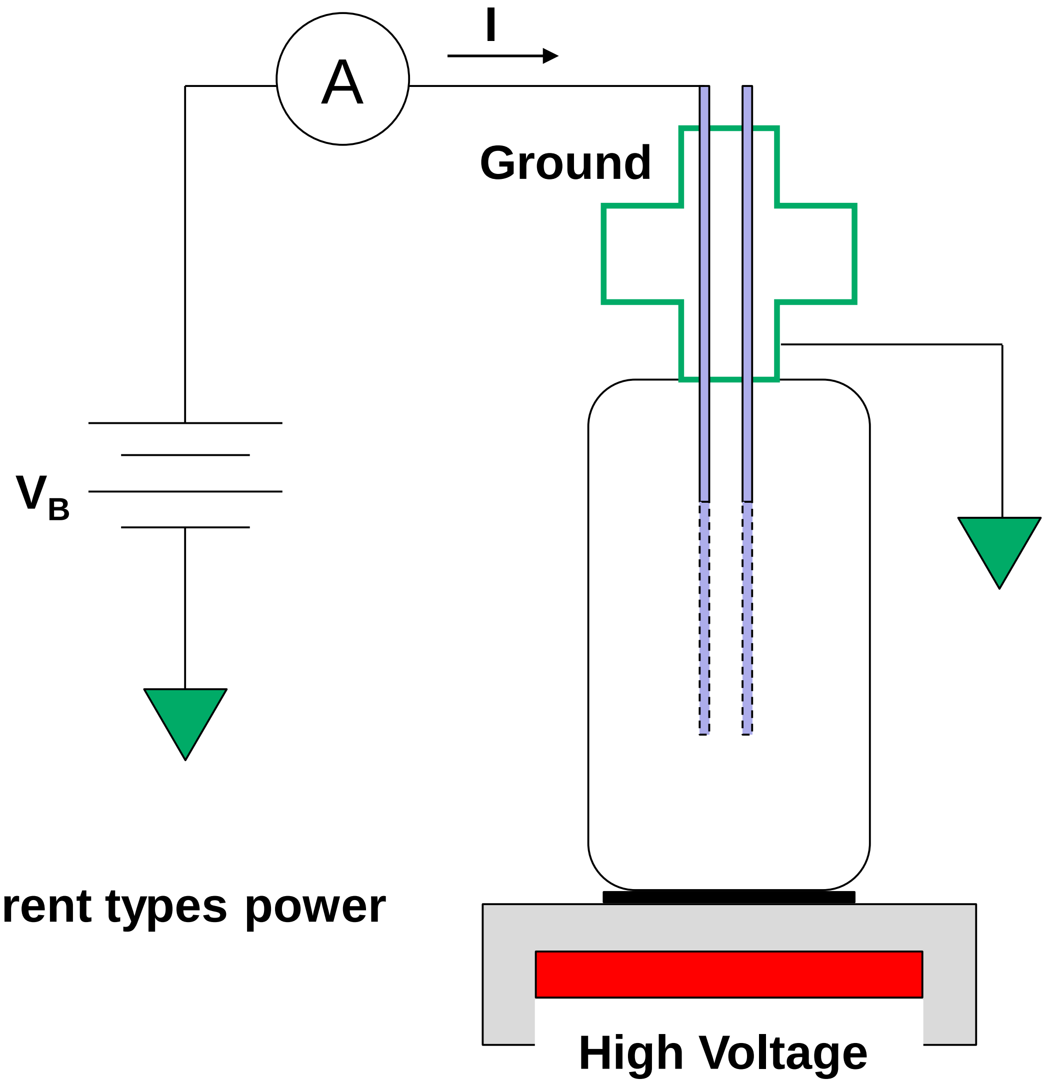
- Each group need to finish two probes on a single flange. Need to pass the vacuum test where P ≤ $9x10^{-2}$ Torr (12 Pa).
- Length of Langmuir probe:

Glow discharge test



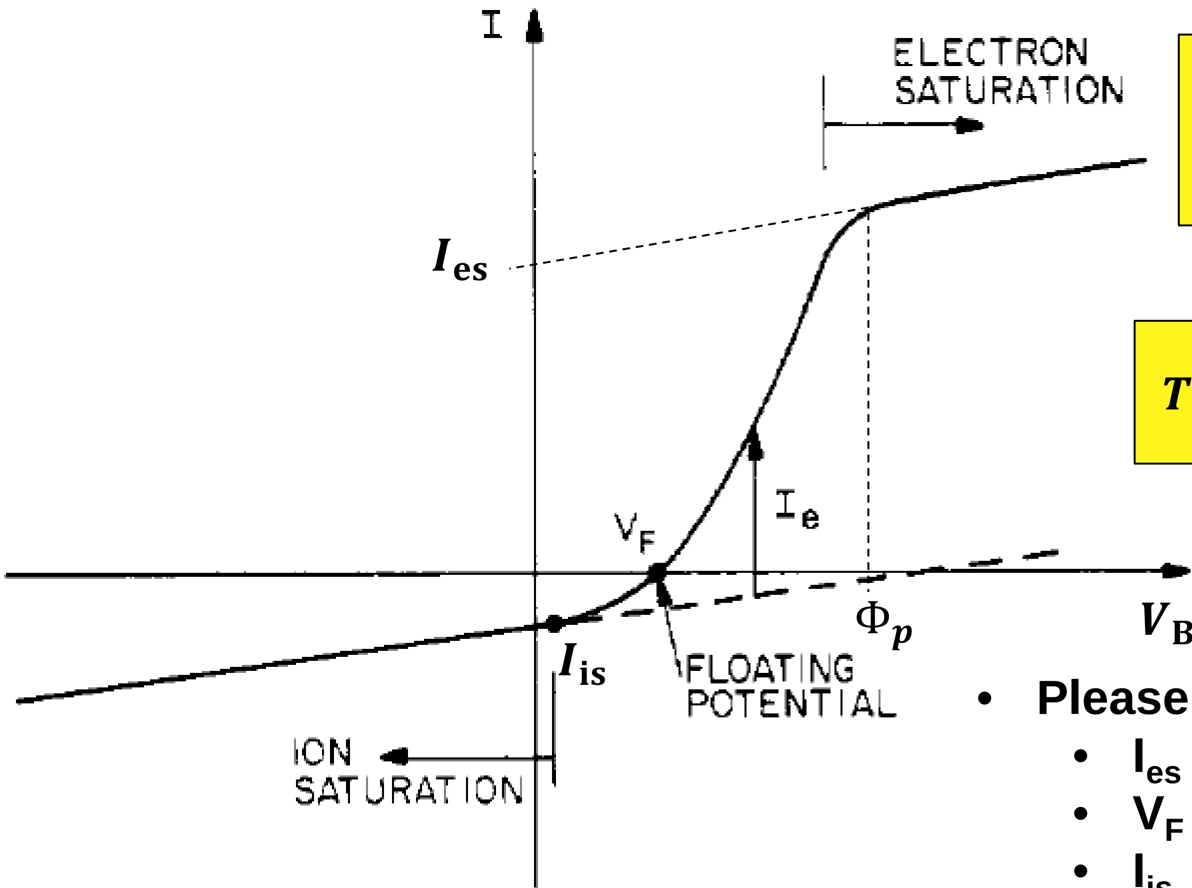
- Once the vacuum meet the requirements, connect the bottom plate to high voltage power supply for glow discharge test.
  - DC
  - AC

Single Langmuir probe measurements - Vary V and measure I



- **Two different types power supply**

Expected I-V curve of single Langmuir probe



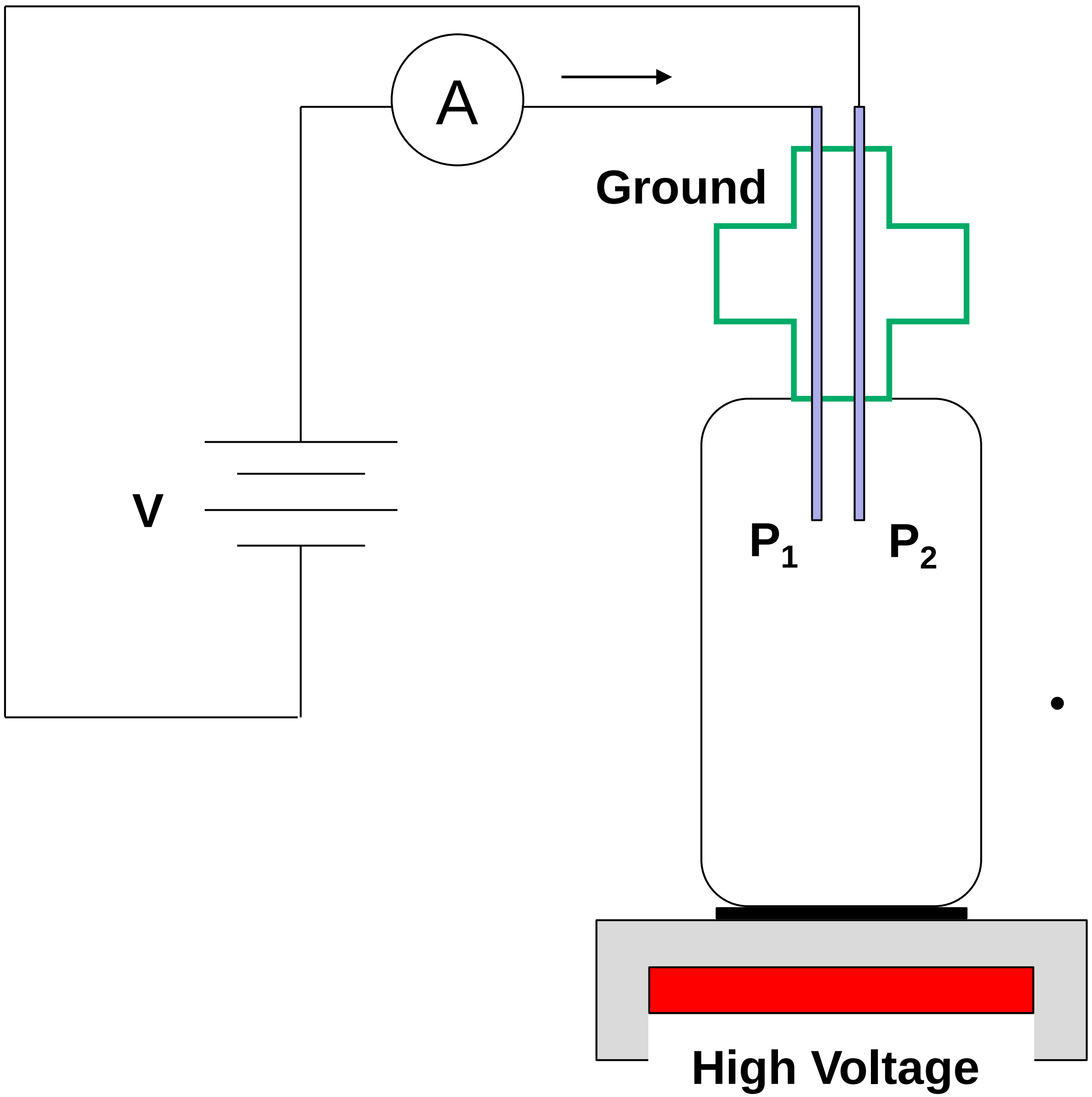
$$n_0 = \frac{I_{es}}{eA}\sqrt{\frac{2\pi m}{kT_e}}$$

$$T_e = \frac{e(V_B - \Phi_p)}{k(\ln I_e - \ln I_{es})}$$

$$n_0 = \frac{1}{0.61}\frac{I_{is}}{eA}\sqrt{\frac{M}{kT_e}}$$

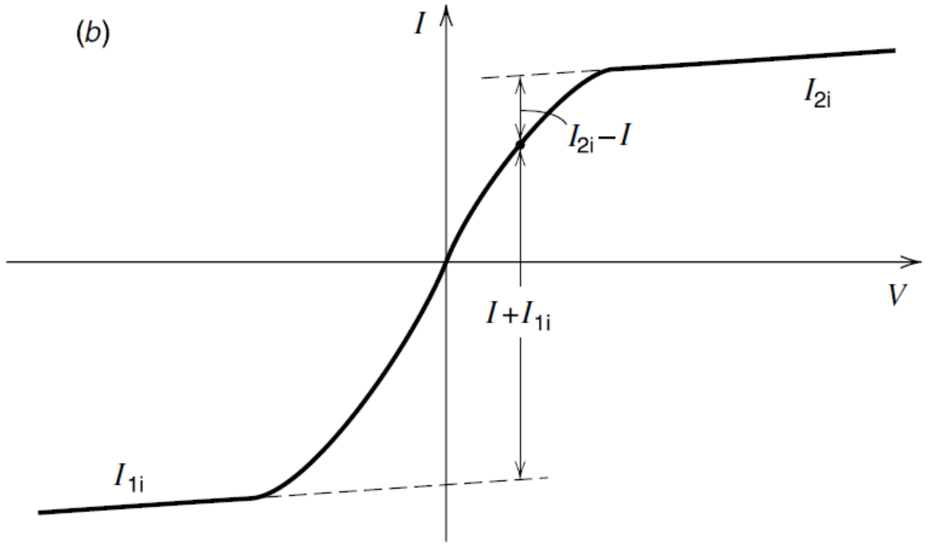
- **Please measure if possible:**
  - I_{es}
  - V_F
  - I_{is}
- **Please calculate if possible:**
  - T_e
  - n_0
  - **Ionization fraction**

Double Langmuir probe measurements
- Vary V and measure I



- DC HV power supply

Expected I-V curve of double Langmuir probe



$$I = I_{is}\,\mathrm{Tanh}\left(\frac{eV}{2kT_e}\right)$$

$$\left.\frac{dI}{dV}\right|_{V=0} = \frac{e}{2kT_e} I_{is}$$

- **Please calculate if possible:**
  - **T_e**
  - **n_0**
  - **Ionization fraction**

$$n_0 = \frac{1}{0.61}\frac{I_{is}}{eA}\sqrt{\frac{M}{kT_e}}$$