



Máster Universitario en Ingeniería Aeronáutica

The Space Environment

Plasmas (Introduction)

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*Página web de la Asignatura basada en la web del Prof. Dr. L. Conde
: <https://plasmalab.aero.upm.es/~lcl/EntornoEspacial/>*

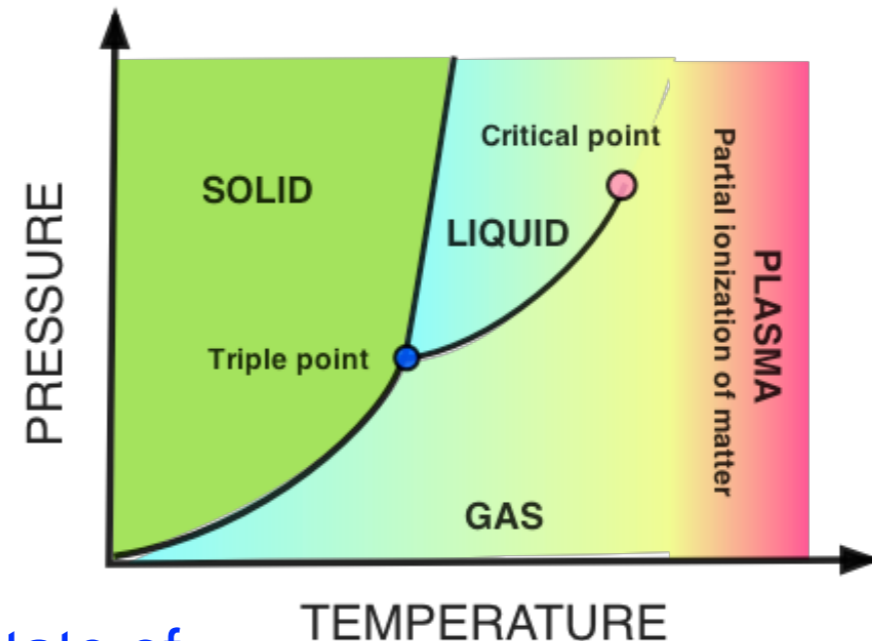
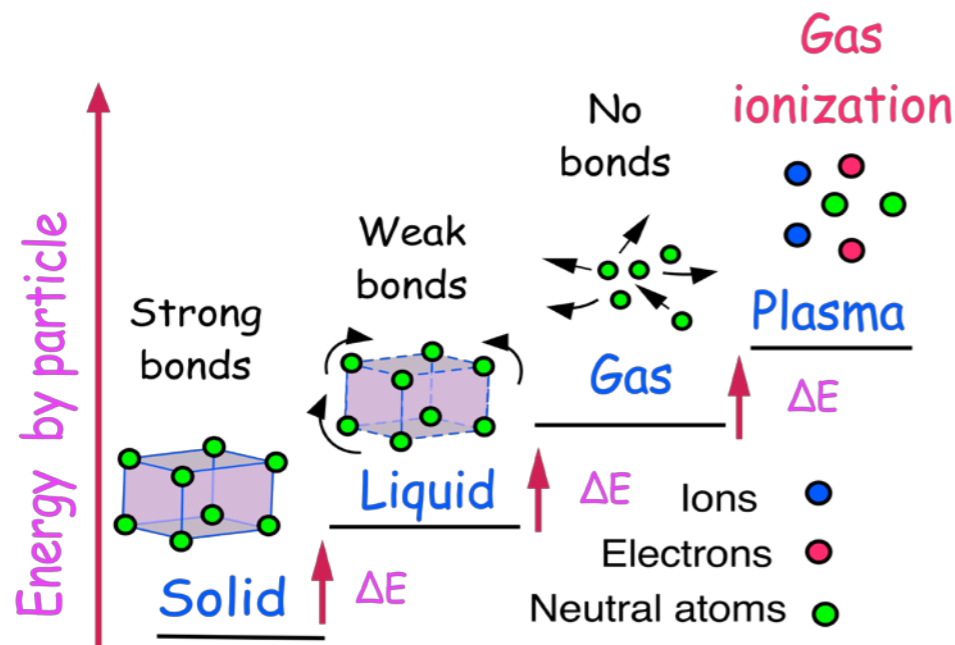
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Equilibrium states of condensed matter

The **equilibrium state of a plasma** is usually associated with high-temperature states of condensed matter.



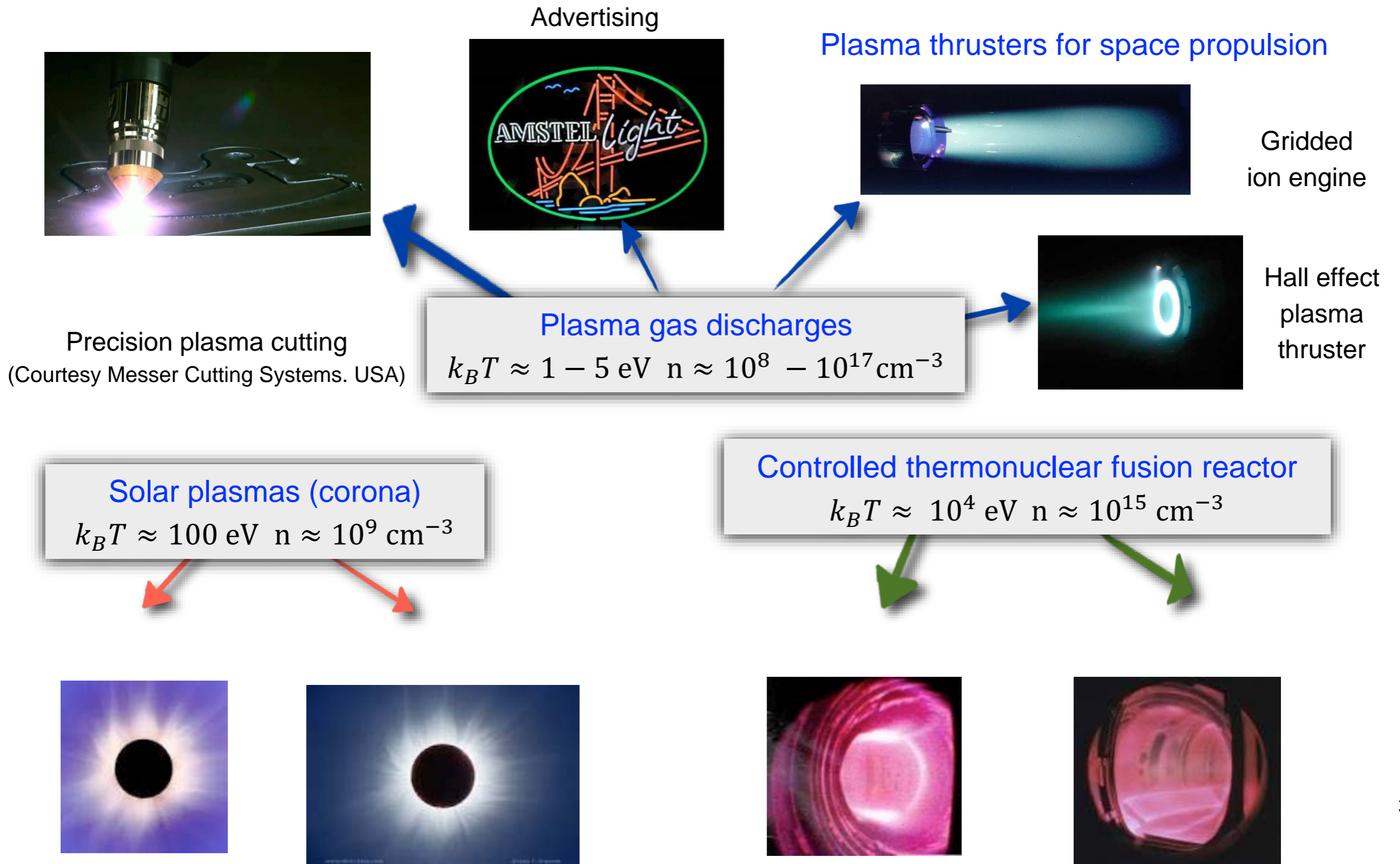
- The plasma state is usually a non equilibrium state of condensed matter: An external energy source is required to sustain the ionization of particles.
- Temperatures are usually expressed in energy units (electron-volts).

- Laboratory plasma production:*
- Neutral gas heating
 - Ionizing radiation
 - Collisional ionization

$$\langle E \rangle = e\phi = k_B T$$

$$T[1 \text{ eV}] = \frac{e \times 1 \text{ volt}}{k_B} = \frac{1.6 \cdot 10^{-19} \times 1 \text{ volt}}{1.38 \cdot 10^{-23}} = 1.1594 \cdot 10^4 \approx 11600 \text{ K}$$

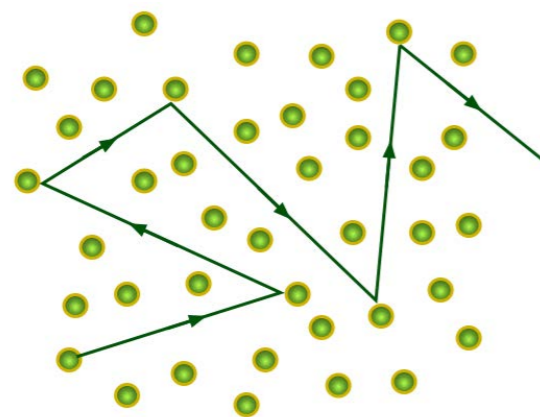
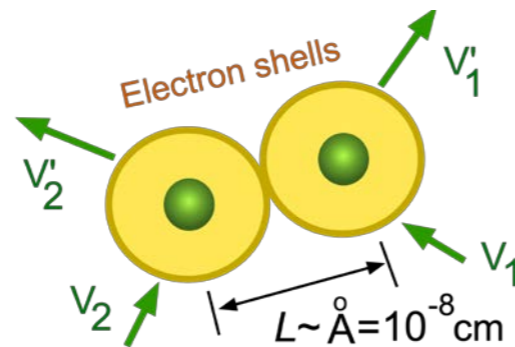
Electric gas discharges



Neutral gases: All atoms and molecules are electrically neutral

- No inter-particle field.
- Move randomly along straight paths
- Interact by short-range collisions

The motions of all atoms and molecules are independent.

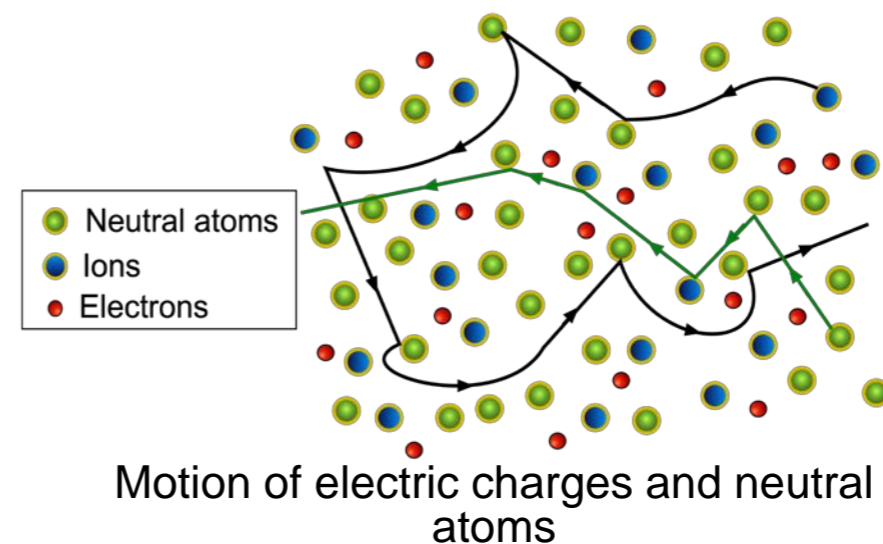
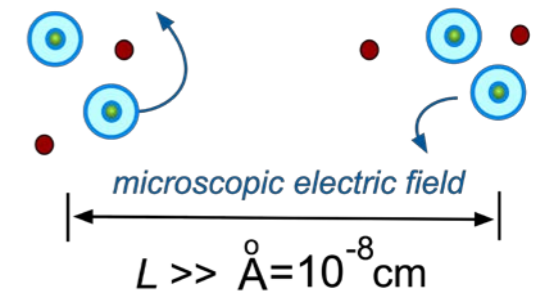


Motion of a neutral gas atom

Partially ionized gases: Are a mixture of neutral atoms, ions and electrons

- Self-consistent microscopic electric field
- Charged particles make complex motions
- Short-range and long-range collisions coexist

Charged particles move into a self-consistent microscopic electric field but atoms remain unaffected



Motion of electric charges and neutral atoms

A definition of the plasma state of condensed matter

The plasma state of matter can be defined as a mixture of positively charged ions, electrons and neutral atoms which constitutes a *macroscopic electrically neutral medium which responds to the electric and magnetic fields in a collective mode*

Properties

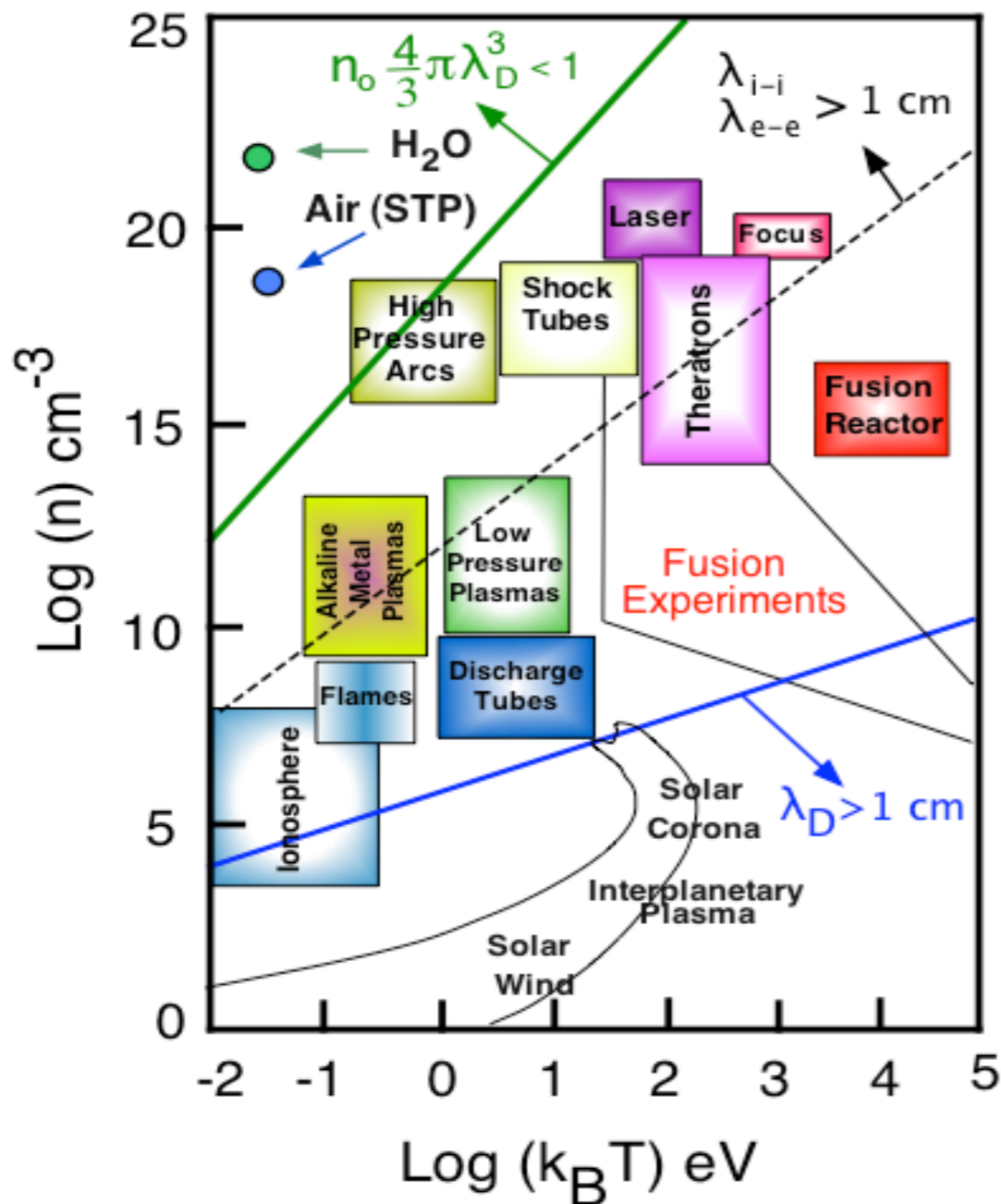
- Charged particles interact thanks to *large-distance electromagnetic forces* in addition to short-range molecular collisions.
- The (number) densities of negative n_e and positive n_i charged particles are equal, *on the average the medium is electrically neutral* (quasineutrality).
- The *response to external perturbations is collective* since large number of charges are involved due to electromagnetic field providing force interactions.
- There are *multicomponent plasmas*, ions with negative charge, dusty plasmas (complex plasmas), ...etc.

In the following:

- For simplicity, we will only consider plasmas composed of **one atom or molecule** species,
- The particle densities will be n_α where $\alpha = a, e, i$ denotes be electrons e , ions i and eventually a neutral atoms.
- Ions can be multiple charged $Q_i = eZ$ but except in few cases we will consider only single charged ions ($Z=1$).
- We will use MKSC unit system.

Plasmas in nature and in the laboratory

Plasmas can be roughly classified according to the **number densities** ($n_e \simeq n_i$) of charged particles and their **average kinetic energies** $\langle E \rangle \sim k_B T$



Both magnitudes, density and kinetic temperature characterize two fundamental plasma parameters, the Debye Length and the plasma frequency. One can find in laboratory and in Nature plasma regimes with similar parameters.

Room temperature: $\langle E \rangle = 0.025 \text{ eV}$

- Water: $n \sim 10^{22} \text{ cm}^{-3}$
- SPT Air: $n \sim 10^{19} \text{ cm}^{-3}$

- Fusion reactor: $\langle E \rangle \sim 10^4 \text{ eV}$ $n \sim 10^{15} \text{ cm}^{-3}$
- Laser plasmas: $\langle E \rangle \sim 10^2 \text{ eV}$ $n \sim 10^{20} \text{ cm}^{-3}$
- Glow discharge: $\langle E \rangle \sim 1 - 3 \text{ eV}$ $n \sim 10^8 \text{ cm}^{-3}$
- Ionosphere: $\langle E \rangle \sim 0.05 \text{ eV}$ $n \sim 10^6 \text{ cm}^{-3}$

Plasma models: from particle motions to fluid description:

