1. INTRODUCTION Plasma Thermal Ioinization

FB242 Gas discharges: physical mechanisms and applications

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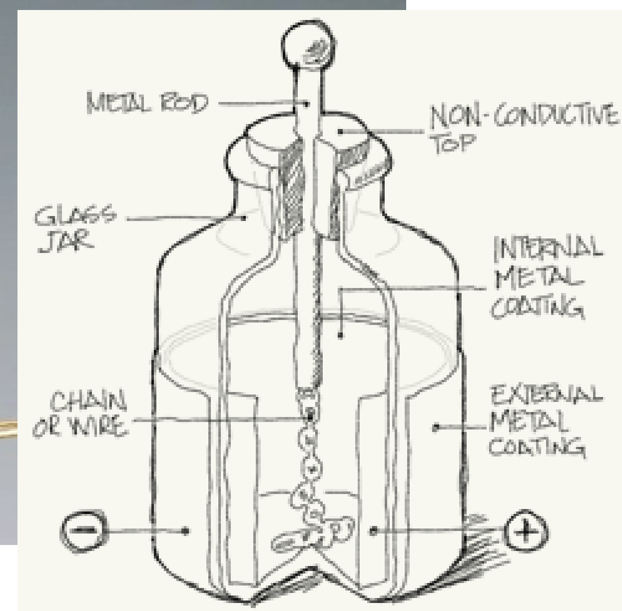
FB 242 Electric Gas Discharges: physical mechanisms and applications

The term „electric gas discharge“ is a historical one, since it refers to <u>the discharge of the voltage stored in a capacitor</u> when the gas between the the capacitor plates become electrically conducting.

The discharging of a Lyeden jar capacitor by a spark el. discharge:



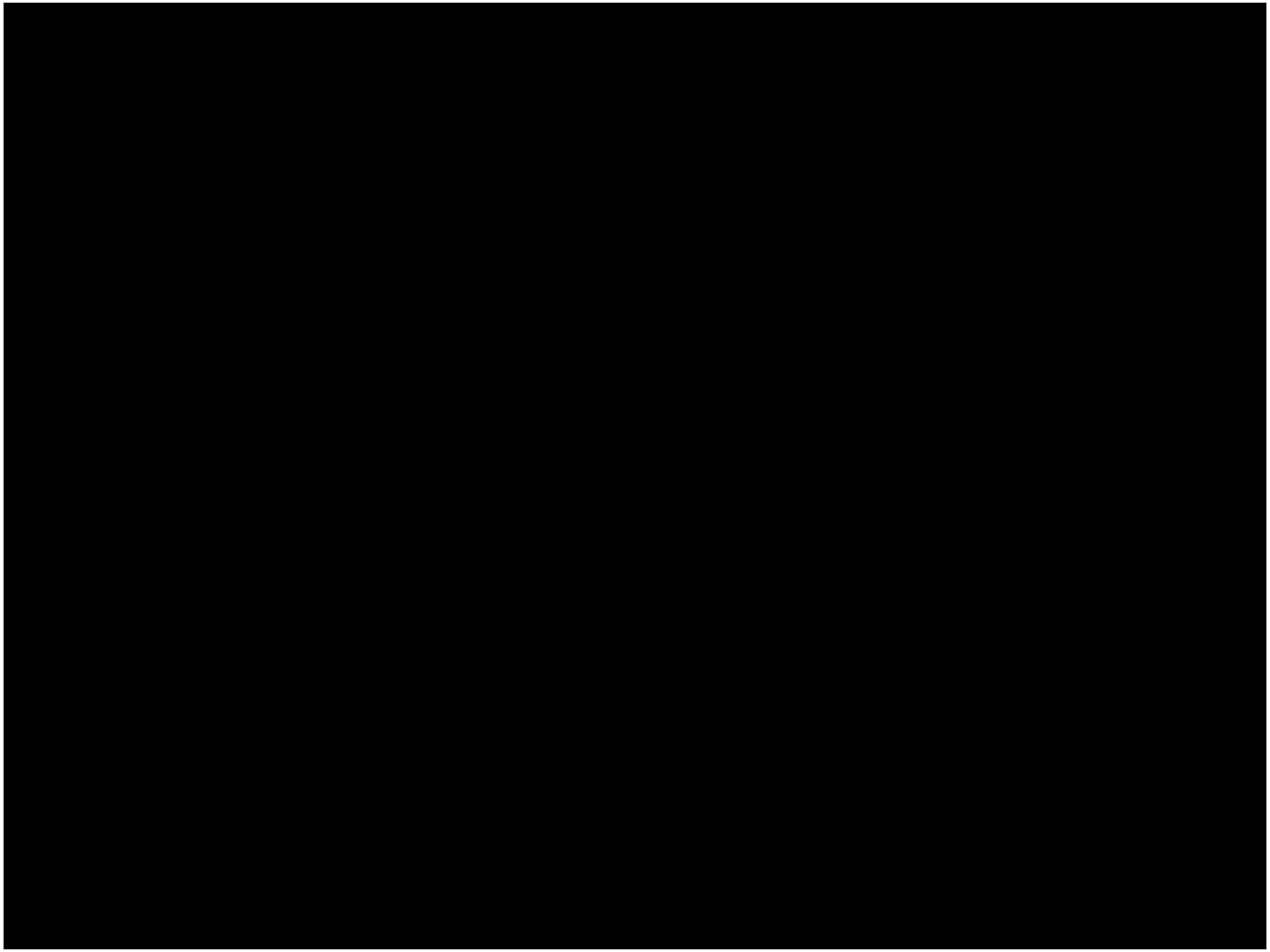
Simple definition of the el. gas discharges:

Electric discharge in gases occurs when electric current flows through a gaseous medium due to ionization of the gas.

Incorrect definition: *(the danger of the Internet as a source of scientific information)*

„A gas discharge is a kind of plasma. It is an ionised gas consisting of equal concentrations of positive and negative charges and a large number of neutral species.“

https://www.uantwerpen.be/en/research-groups/plasmant/research/research-topics/gas-discharge-plasma/

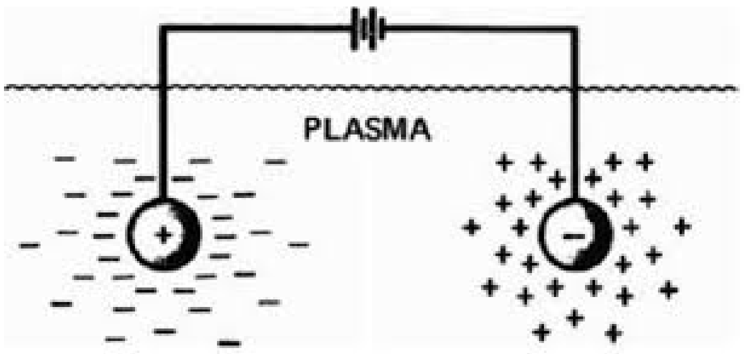


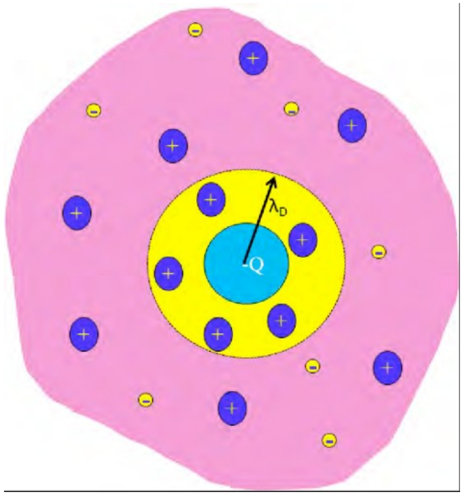
The el.gas discharges are not „a king of el. plasma“ the most common method to generate many types of el. plasmas for a wide range of practical applications:

What is the electric plasma ?

https://www.wtamu.edu/~cbaird/sq/2014/05/28/do-flames-contain-plasma/

A plasma is an ionized gas that is **shields out electric fields**. The distance that an external electric field can reach into a cloud of charged particles is characterized by the so-called **Debye length**.





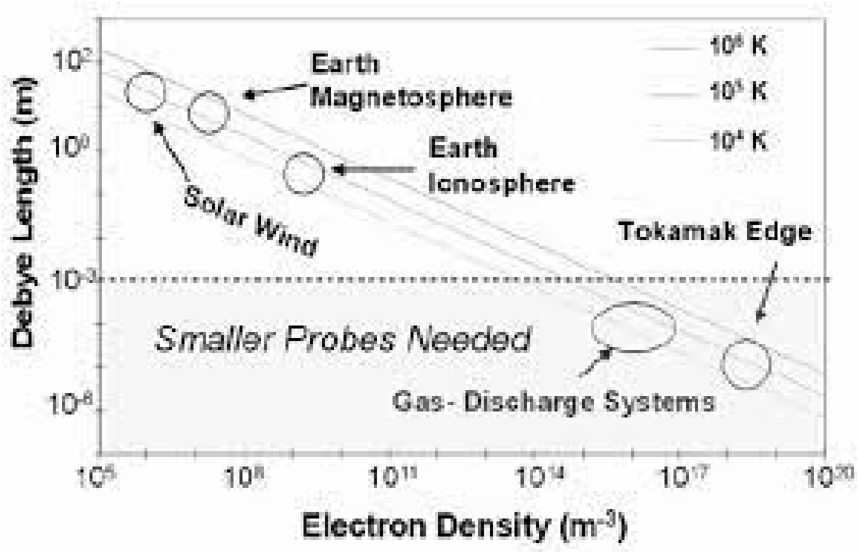
A plasma is able to do this because enough negatively-charged electrons and positively-charged ions are locally free and are able **bind to each other in a long-range, collective way.** The collective behavior of ions and electrons means that they are able to respond strongly to incident electric fields and move to cancel out these fields. Therefore, a stricter definition of a plasma is **an electrically quasi-neutral gas where there are enough freed electrons and ions that they act collectively**. ". The more atoms that are ionized, the stronger the collective oscillations of the charges, and the smaller the Debye length. ***The strictest definition of a plasma is therefore an ionized gas with enough ionization that the Debye length is significantly smaller than the width of the gas cloud.***

Debye length and plasma sheaths

The electrical neutrality of plasma is true only in the macroscopic sense. The electric field of each particle interacts with the electric charges of surrounding particles. Neutrality of the majority of the systems is achieved when the field of each particle is negligible outside the zone where shielding occurs. The Debye length λD defines the volume (Debye sphere) within which the neutrality rule can be violated. This parameter can be approximated by the following equation

$$\lambda_{\mathrm{D}} = \sqrt{\frac{T_{\mathrm{e}}}{m_{\mathrm{e}}}}\,\omega_{\mathrm{p}}^{-1} = \sqrt{\frac{\varepsilon_0\, T_{\mathrm{e}}}{n_{\mathrm{e}}\, e^2}}$$

where ε_o is the permittivity of free space; e is the charge of the electron; Te is the temperature of electrons, and ne is the electron density (number of electrons per unit volume). An ionized gas is considered plasma only if the Debye length is much smaller than the physical dimensions of the plasma region and if the number of the particles within the Debye sphere is much larger than unity. (the number of electrons in the Debye sphere of cold plasma is in the range of 104 –107)

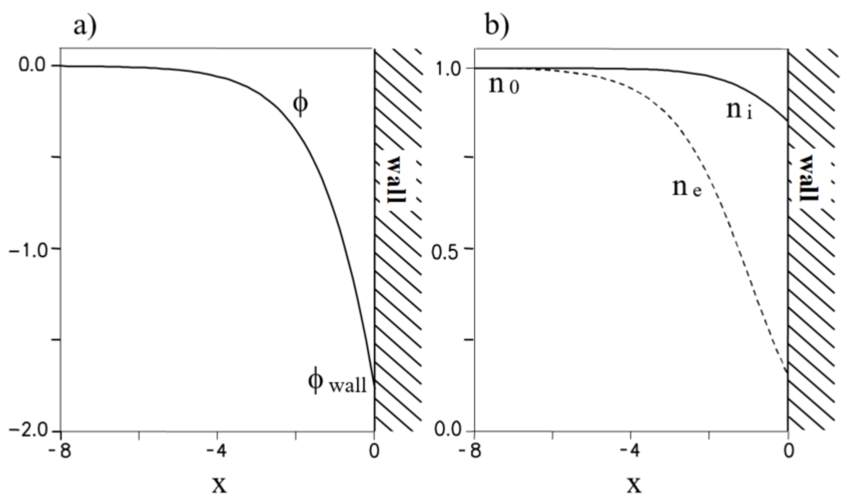


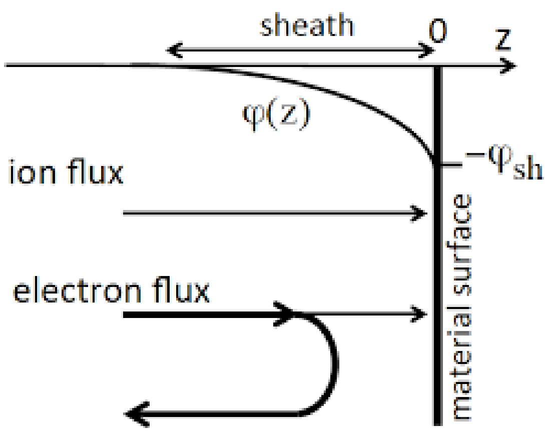
Loschmidt number : The number of molecules **in one cubic centimeter** of an ideal gas at standard temperature and pressure equal to ***2.69×10^{19} molecules***

For the derivation of the Debye length, see Ref.1 pp. 21-22

The Debye sheath (also **electrostatic sheath**) The Debye sheath is **the transition from a plasma to a solid surface**. It is a layer which has a greater density of positive ions, and hence an overall excess positive charge, that balances an opposite negative charge on the surface of a material with which it is in contact. **The thickness of such a layer is several Debye lengths thick**, a value whose size depends on various characteristics of plasma (e.g. temperature, density, etc.).

Journal: Le Vide (ISSN : 1266-0167) 306 - 4/4 – 2002 pp. 810-835





AMBIPOLAR DIFFUSION

https://www.youtube.com/watch?v=wo7XDN2A8KEA

Debye sheath arises in a plasma because the electrons usually have a temperature on the order of magnitude or greater than that of the ions and are much lighter. Consequently, they are faster than the ions by at least a factor of m_i/m_e. At the interface to a material surface, therefore, the electrons will fly out of the plasma, charging the surface negative relative to the bulk plasma. **Due to Debye shielding, the scale length of the transition region will be the Debye length.**

https://en.wikipedia.org/wiki/Debye_sheath

https.://is.muni.cz/el/sci/jaro2017/FC250/um/talk-FC250-part03c-sheath.pdf

Plasma can be artificially generated by heating a neutral gas or subjecting it to a strong elmg. field (el. discharges), or both

The **Saha ionization equation** is an expression that relates the ionization state of a gas in thermal equilibrium to the temperature and pressure.[

Ionization energies:

O_2 (12.7 eV),

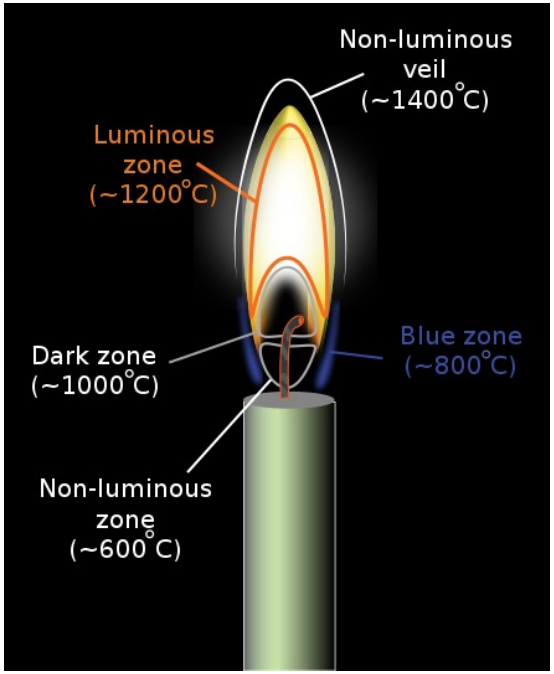
N_2 (15.58 eV),

Ar (15.4 eV),

He (24.59 eV – the highest one)

$$\frac{n_i}{n_n} \approx 2.4 \times 10^{21} \frac{T^{\frac{3}{2}}}{n_i} e^{\frac{-u_i}{K_B T}}$$

n_i: Number density of ions
n_n: Number density of neutral atoms
T: Temperature
u_i: Ionisation energy
K_B: Boltzmann constant



For example, a **wax candle** has a flame that burns at a maximum temperature of **1,500°C**, which is too low to create very many ions. A candle flame is therefore not a plasma. Note that the red-orange-yellow colors that we see in a flame are not created from the flame being a plasma. Rather, these colors are emitted by hot incompletely-burnt particles of fuel ("soot"). With this in mind, it should be clear that a candle flame gives off light even though it is not a plasma. In contrast to candle flames, certain burning **mixtures of acetylene** can reach **3,100 °C**, with an associated Debye length of 0.01 millimeters. Such flames are therefore plasmas (as long as the flame is much larger than 0.01 millimetere).