UFSC

Federal University of Santa Catarina
Graduate Program in Engineering and Mechanical Sciences

Plasmas and electrical discharges in gases

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Diego Alexandre Duarte
Laboratory of Surface Treatments

SUMMARY
Plasmas and electrical discharge in gases

- Kinetic theory of gases
- Atomic structure
- Ionization
- Deionization
- Electron emission
- Behavior of charged particles in a gas in electric fields of low E/p
- Behavior of charged particles in a gas in electric fields of high E/p
- Glow discharges
- Plasmas

DEIONIZATION

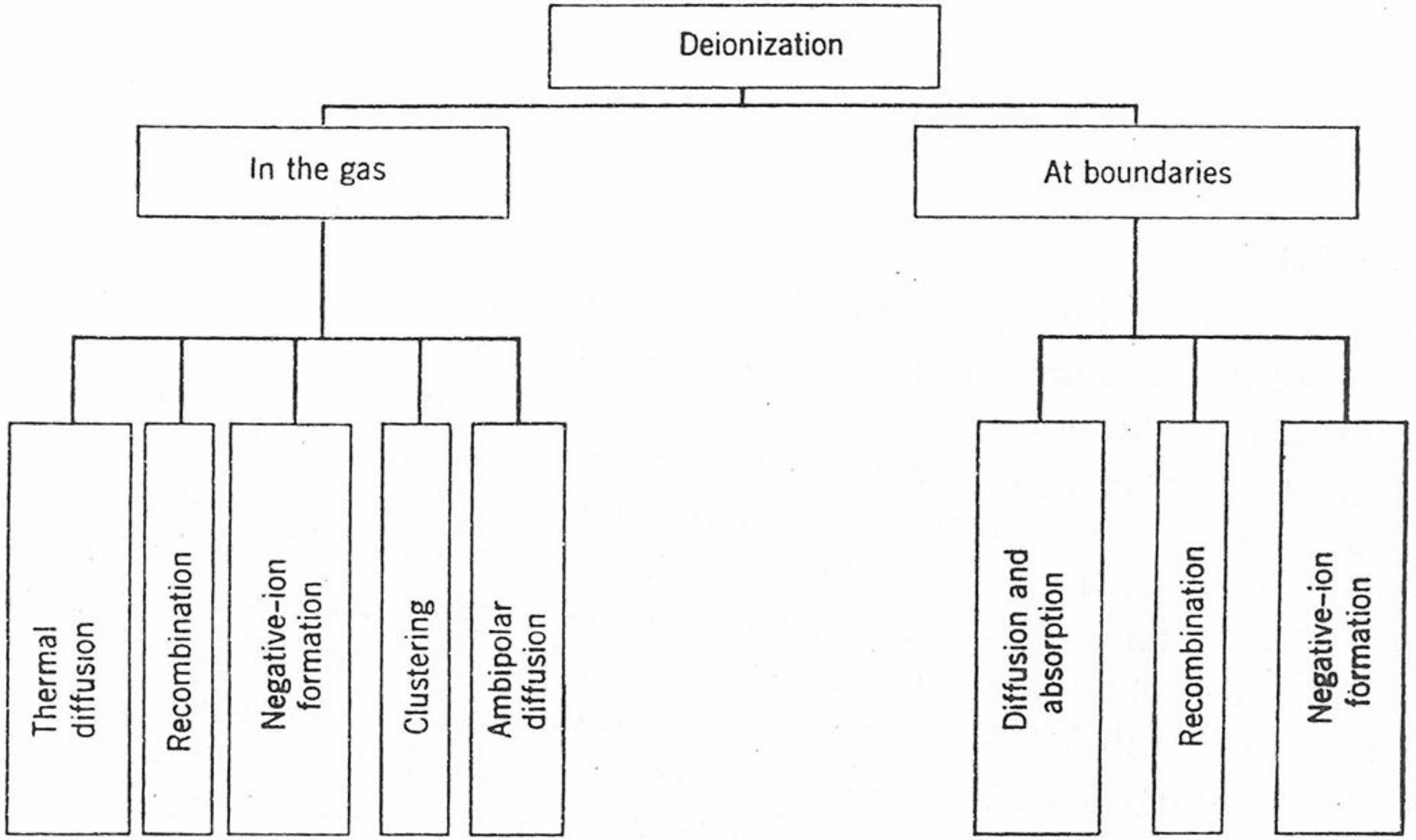


Fig. 4.1 Schematic diagram of possible deionization processes.

DEIONIZATION
Diffusion

- Diffusion is caused by the difference in partial pressure or in molecular concentration. Consider a nonuniform distribution of gas A within a uniform gas B of higher concentration. Then, we shall state the following assumptions:

  - Number of atoms A per unit volume is much less than that of B.
  - All the A atoms have the same average speed v and the same mean free path λ.
  - Concentration of the A atoms changes in the x-direction only.

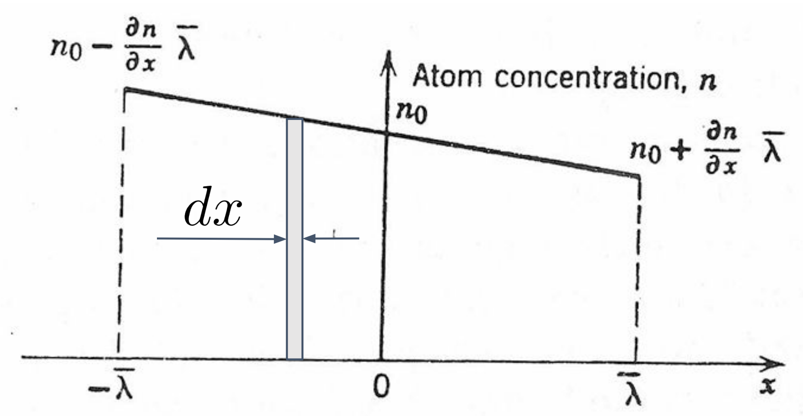


Fig. 4.2 The concentration of A atoms along the x-axis.

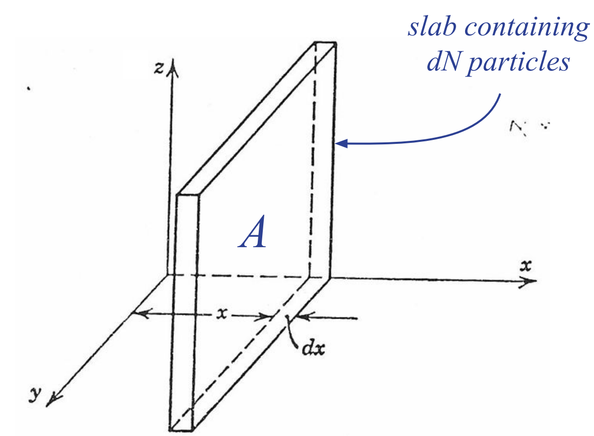


Fig. 4.4 A slab of unit cross section between x and $x + dx$ for the evaluation of the change in particle density due to diffusion.

E. Nasser, Fundamentals of Gaseous Ionization and Plasma Electronics, New York: Wiley, 1971.

DEIONIZATION
Diffusion

- Consider the case when the concentration gradient is linear:

$$n = n_0 + \left(\frac{\partial n}{\partial x}\right) x$$

- To calculate the number of A atoms crossing the plane perpendicular to the x-axis at $x = 0$ from the left to right and then vice-versa, we shall consider all the A atoms to the leftof this plane. Since motion in all directions is equally probable, then only one-sixth of the atoms will be moving in the positive x-direction:

$$n = \frac{dN}{dV} = \frac{dN}{Adx} \quad \therefore \quad \frac{dN}{A} = dj = ndx$$

where dN is the number of particles in dx crossing the plane dA represented by dj. The total amount particles crossing the plane from left to the right j' is:

$$j' = \frac{1}{6}\int_{-\lambda}^{0} \left[n_0 + \left(\frac{\partial n}{\partial x}\right) x\right] dx$$

$$j' = \frac{1}{6}\left[n_0\lambda - \frac{1}{2}\left(\frac{\partial n}{\partial x}\right)\lambda^2\right] = \frac{1}{6}\left[n_0 vt - \frac{1}{2}\left(\frac{\partial n}{\partial x}\right)(vt)^2\right]$$

where t is the time between two successive collisions. The flow of charges is given by:

$$\frac{\partial j'}{\partial t} = \frac{1}{6}\left[n_0 v - \left(\frac{\partial n}{\partial x}\right)\lambda v\right]$$

- Similarly, we can calculate the number of A atoms crossing the plane $x = 0$ from right to left as:

$$j'' = \frac{1}{6}\int_{\lambda}^{0}\left[n_0 + \left(\frac{\partial n}{\partial x}\right)x\right]dx$$

$$\frac{\partial j''}{\partial t} = -\frac{1}{6}\left[n_0 v + \left(\frac{\partial n}{\partial x}\right)\lambda v\right]$$

- Then the resultant number of A atoms crossing the plane from left to the right is:

$$J = \frac{\partial j'}{\partial t} + \frac{\partial j''}{\partial t} = \frac{1}{6}\left[n_0 v - \left(\frac{\partial n}{\partial x}\right)\lambda v\right] - \frac{1}{6}\left[n_0 v + \left(\frac{\partial n}{\partial x}\right)\lambda v\right]$$

DEIONIZATION
Diffusion

where J is the flow of charges (current density):

$$J = -\frac{1}{3}\lambda v \frac{\partial n}{\partial x}$$

- In three coordinates, the above equation is given by:

$$\vec{J} = -D\vec{\nabla}n$$

where $D = \lambda v/3$ is the diffusion coefficient. The above equation states the following assumptions:

- The negative sign indicates that the flow of atoms is opposite to the concentration gradient;
- The flow stops when the gradient is zero.

DEIONIZATION
Recombination: loss equation

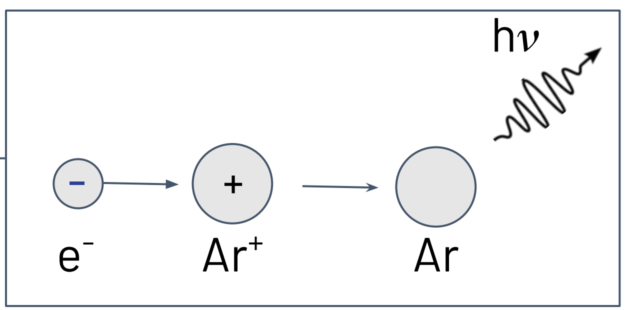
- Considering the densities n^+ and n^- of the positive and negative particles, respectively. The number of recombinations per unit time must be proportional to n^+ and n^-. If the constant of proportionality is ρ then:

$$dn = \boxed{-\rho n^+ n^- dt}$$

Radiative recombination

$e^- + Ar^+ \longrightarrow Ar + h\nu$

where here we assume the so-called quasi-neutrality condition ($n^+ = n^- = n$). Then,

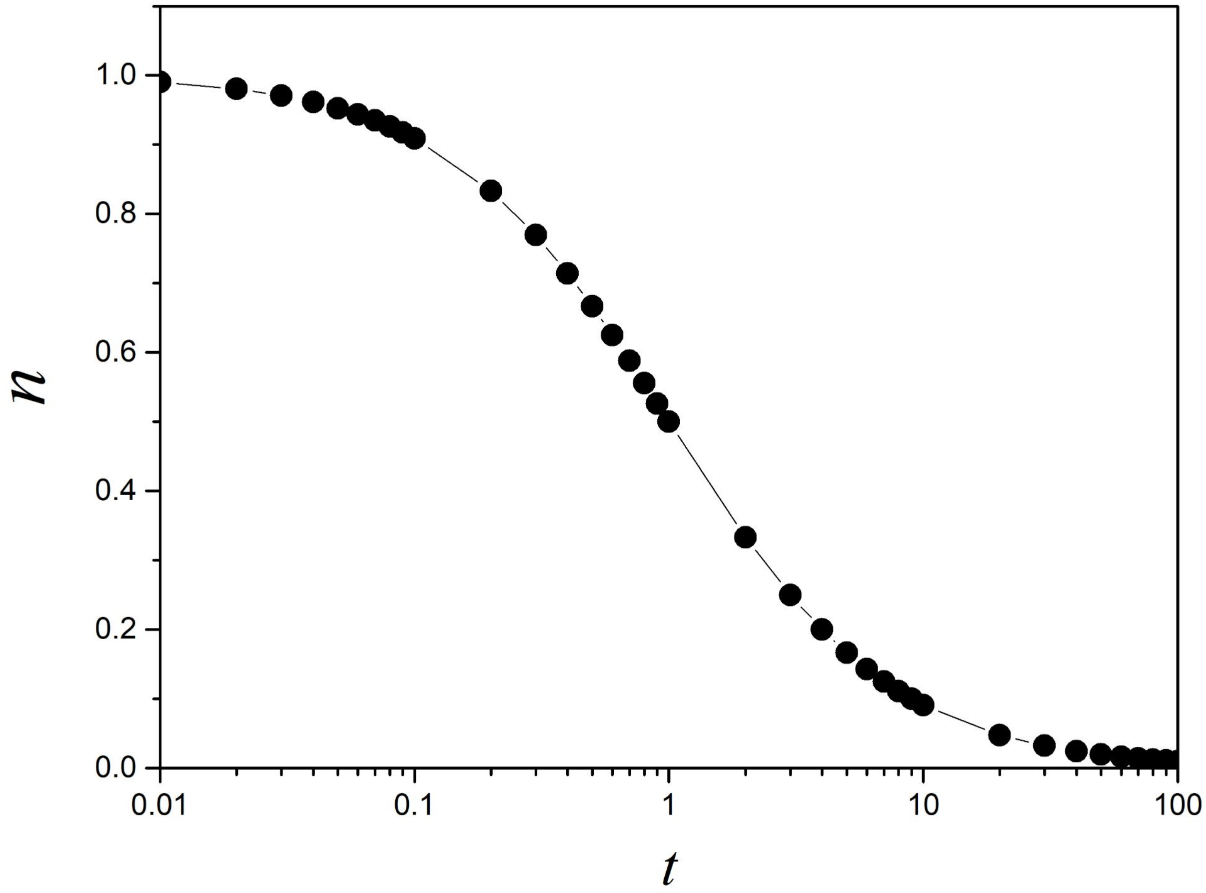


$$dn = -\rho n^2 dt$$

$$\int_{n_0}^{n} \frac{dn}{n^2} = -\rho t \quad \therefore \quad \boxed{n = \frac{n_0}{1 + n_0 \rho t}}$$

that is defined as "ion-loss equation" where ρ is defined by plotting $1/n$ versus t.

DEIONIZATION
Recombination: loss equation



$$n = \frac{n_0}{1 + n_0 \rho t}$$

where $\rho = 1$ and $n_0 = 1$ (dimensionless). Then,

$$n = \frac{1}{1 + t}$$

DEIONIZATION
Recombination: ionization-growth method

- If, however, the gas is subject to an external ionizer that continuously ionizes some neutral particles, an increase in the charge-particle density n will take place. If the density of newly ionized particles per second is n_i we get:

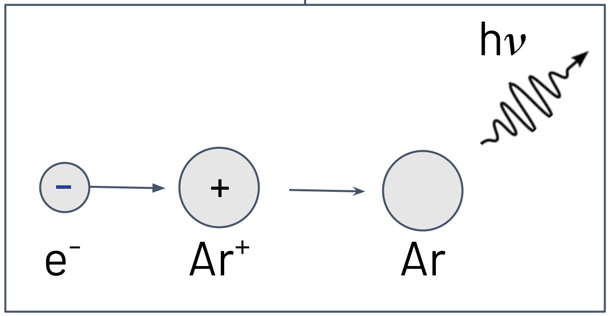
$$dn = \boxed{n_i dt} - \boxed{\rho n^2 dt}$$

Electron impact ionization

$e^- + Ar \longrightarrow 2e^- + Ar^+$

Radiative recombination

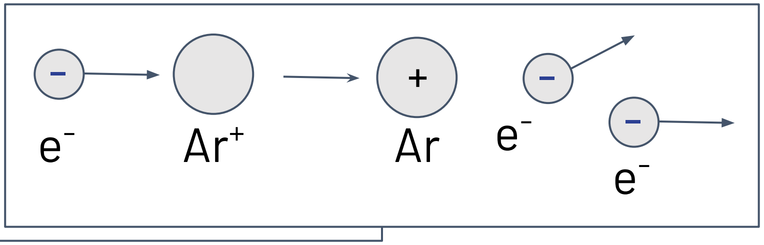
$e^- + Ar^+ \longrightarrow Ar + h\nu$



where n is the amount of recombined charged particles. Then,

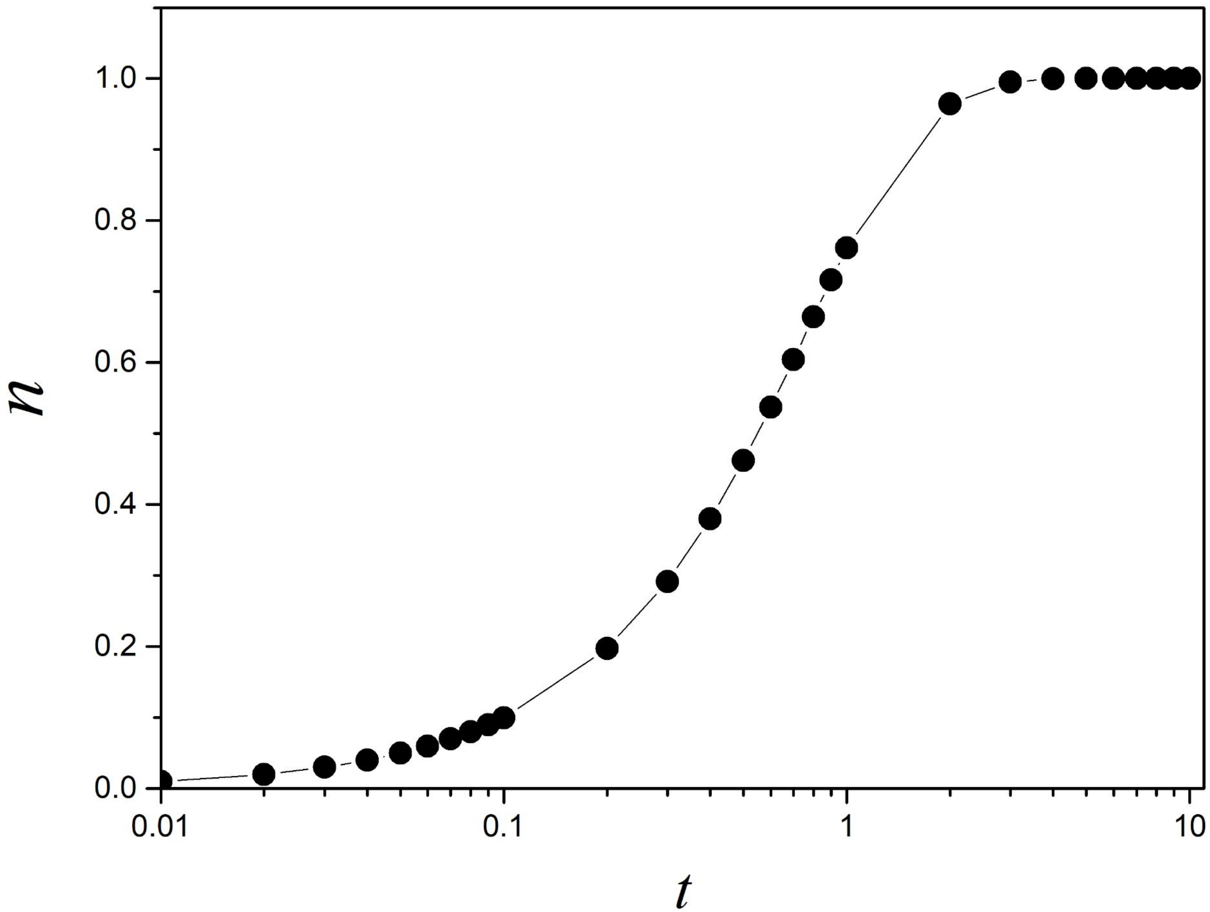
$$\int_0^n \frac{dn}{n_i - \rho n^2} = -\int_0^t dt \quad \therefore \quad \boxed{n = \left(\frac{n_i}{\rho}\right)^{1/2} \frac{e^{2t\sqrt{\rho n_i}} - 1}{e^{2t\sqrt{\rho n_i}} + 1}}$$

that is defined as "ionization-growth method".



DEIONIZATION

Recombination: ionization-growth method



$$n = \left(\frac{n_i}{\rho}\right)^{1/2} \frac{e^{2t\sqrt{\rho n_i}} - 1}{e^{2t\sqrt{\rho n_i}} + 1}$$

where $\rho = 1$ and $n_i = 1$ (dimensionless). Then,

$$n = \frac{e^{2t} - 1}{e^{2t} + 1}$$

DEIONIZATION

Recombination processes: electron attachment (examples)

- Radiative recombination:

$$e^{-} + Ar^{+} \longrightarrow Ar + h\nu$$

- Dissociative recombination:

$$e^{-} + O_2^{+} \longrightarrow O + O$$

- Dielectronic recombination:

$$e^{-} + Ar^{*} \longrightarrow Ar^{**} \, (Ar^{**} \longrightarrow Ar^{+} + e^{-} \text{ (autoionization)}$$

- Three-body-recombination;

$$A^{+} + B + e^{-} \longrightarrow A^{*} + B$$
$$A^{+} + 2e^{-} \longrightarrow A^{*} + e^{-}$$

DEIONIZATION

Recombination processes: negative ions (examples)

- Radiative attachment (the reverse case is called photodetachment):

$$e^- + O \longrightarrow O^- + h\nu$$

- Three-body attachment:

$$e^- + A + B \longrightarrow A^- + (B + W_K)$$

- Dissociative attachment (the reverse case is called associative detachment):

$$e^- + AB \longrightarrow A^- + B$$

- Charge transfer between heavy particles:

$$A + B \longrightarrow A^+ + B^-$$

IONIZATION
Reading

- Chapter 4 - E. Nasser, Fundamentals of Gaseous Ionization and Plasma Electronics (pages 102-107; 114-118).

See you next topic!

Diego A. Duarte
diego.duarte@ufsc.br
https://lats.ufsc.br