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Ion transport in Nitrogen based mixtures

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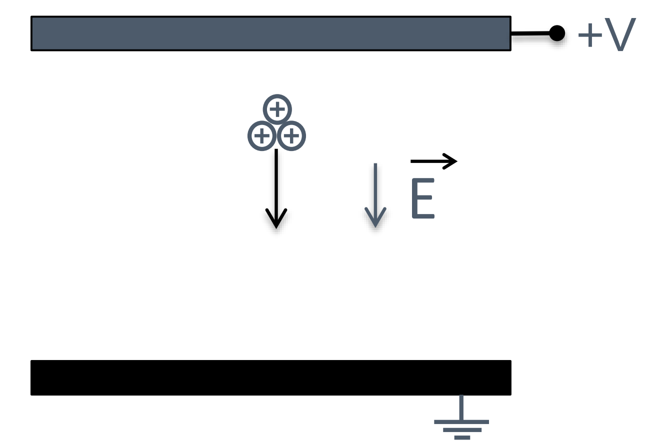
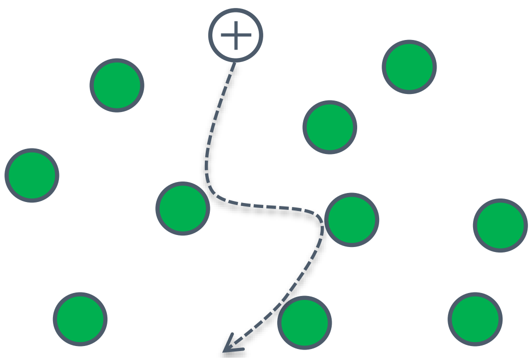
1. Basic Concepts
2. Experimental Setup and Working Principle
3. Ion Identification Process
4. Experimental results in:
   - a. Ne, N_2
   - b. Ne-N_2
5. Reduced Mobility Comparison of mixtures with Nitrogen

Basics

Let us consider a group of ions moving in a gaseous medium under the influence of a uniform electric field…



Microscopically …



Drift velocity

$$v_d = KE$$

E- Electric Field

K-Ion Mobility

Reduced Mobility

$$K_0 = KN/N_0$$

N – Gas number density

N_0–Loschmidt Number

Langevin Limit

$$K_0 = 13.88\left(\frac{1}{\alpha\mu}\right)^{\frac{1}{2}}$$

μ – reduced mass

α – neutral polarizability

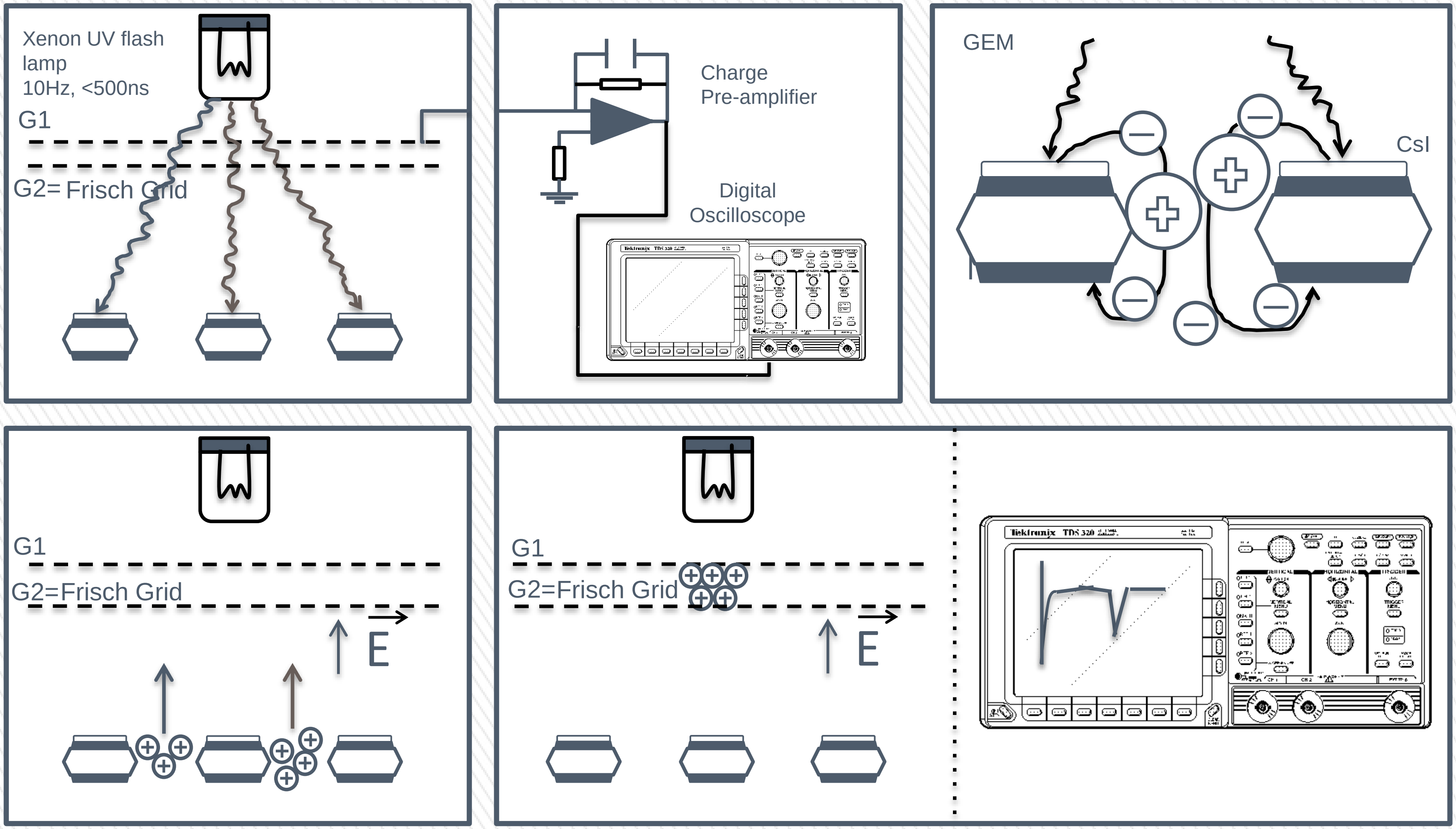
Blanc's Law

$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

f_1,f_2– molar fraction of gas 1, 2

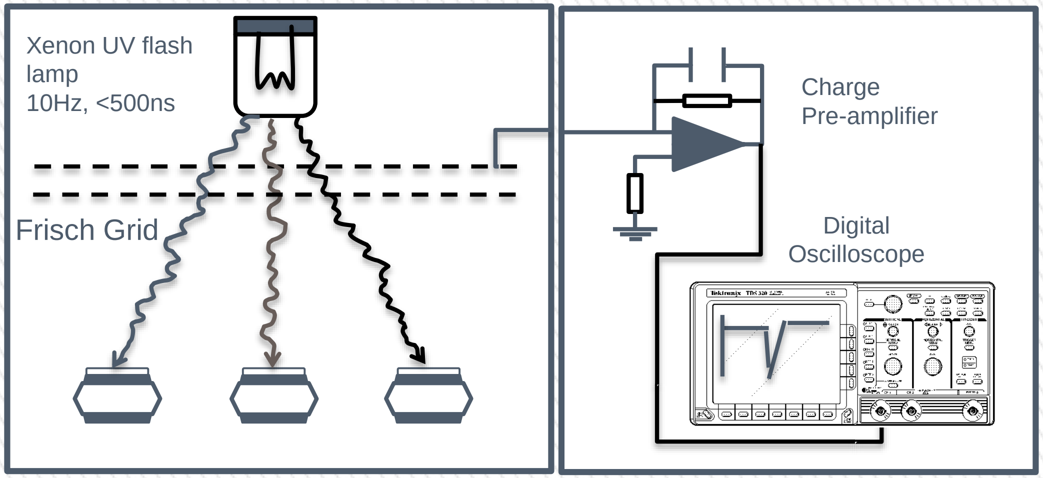
K_{0g1}, K_{0g2} – ion mobility in the gas 1 and 2

Experimental Setup and Working Principle



(Neves, Conde and Távora, 2007)

Experimental Setup and Working Principle

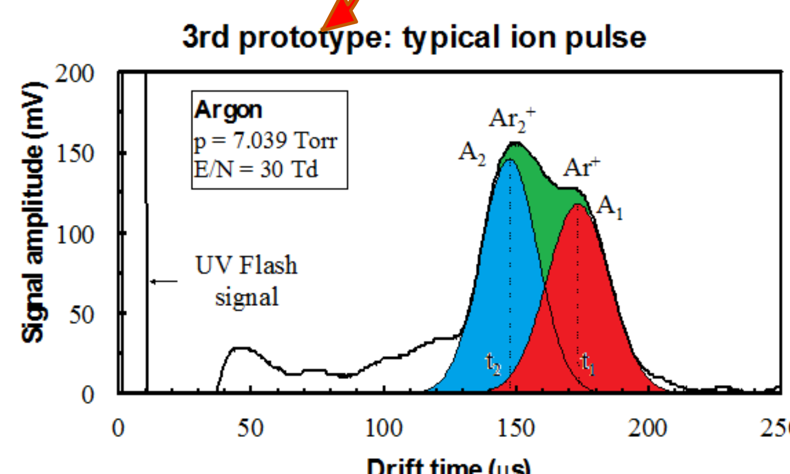


- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the peaks obtained

Peaks centroids

average drift time of the ion's distribution (t_{drift})

$$v_{\mathrm{d}} = \frac{x_{drift}}{t_{drift}} \rightarrow K = \frac{v_{\mathrm{d}}}{E}$$



$K_{01} = 1.57\ cm^2V^{-1}s^{-1}$ (Ar^+)
$K_{02} = 1.92\ cm^2V^{-1}s^{-1}$ (Ar_2^+)

Ion Identification Process

Identification of candidate ions

- GEM Voltage
- Possible Reactions
  - Cross Section
  - Reaction Rates

Selection of Candidate ions

+

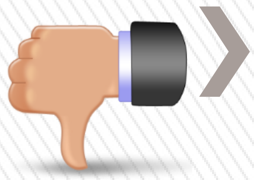
Calculation of expected mobility

- Langevin Limit (formula)
- Blanc's law (mixtures)

Comparison with experimental results

Theoretical Values = Experimental Values

Match?



Experimental Results: N_2

Ionization

$N_2 + e \rightarrow N_2^+ + e$

Above threshold 15,6 eV

Appearance Energies

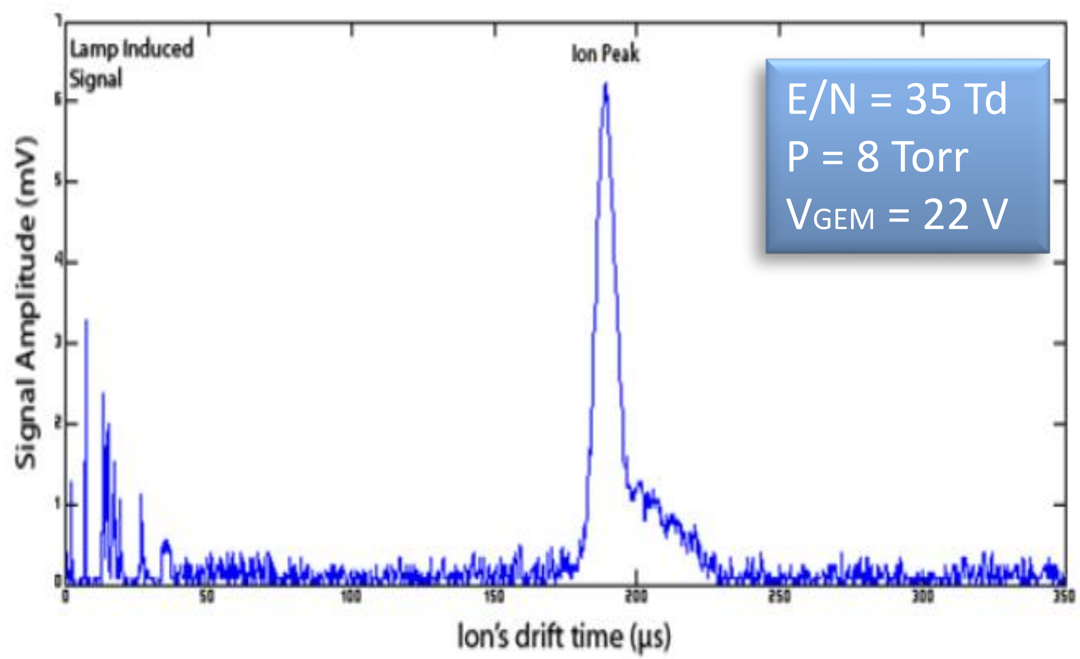
N_2^+	15,6 eV
N_3^+	21,1 eV
N^+	24,2 eV

Secondary Reactions

$N_2^+ + 2N_2 \rightarrow N_4^+ + N_2 + 0{,}87$ eV

Rate constant $\rightarrow 5\text{X}10^{-29} cm^6 s^{-1}$

[1,2,3]



$K_{01} = 2{,}37\ cm^2V^{-1}s^{-1}$ (N_4^+)

[4]A.N.C. Garcia, 2012, JINST

Experimental Results: Ne

Ionization

$Ne + e^- \rightarrow Ne^+ + 2e^-$

Above 21.56 eV

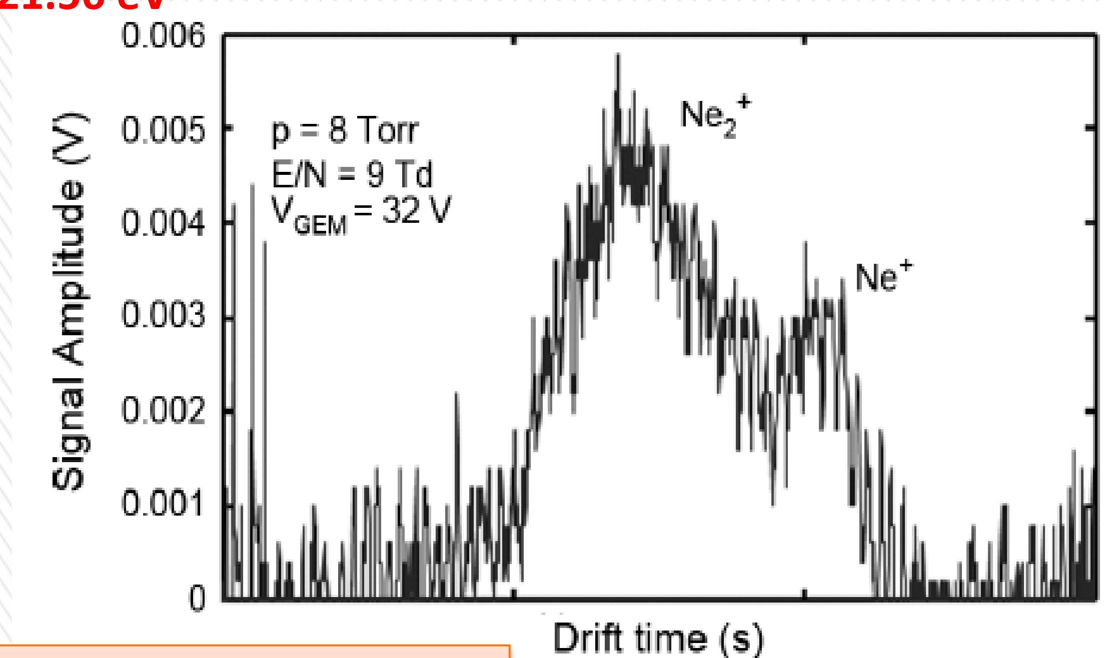
Appearance Energies

Ne^+	21.56 eV

Secondary Reactions

$Ne^+ + 2Ne \rightarrow Ne_2^+ + Ne$

$Ne^+ + Ne \rightarrow Ne + Ne^+$

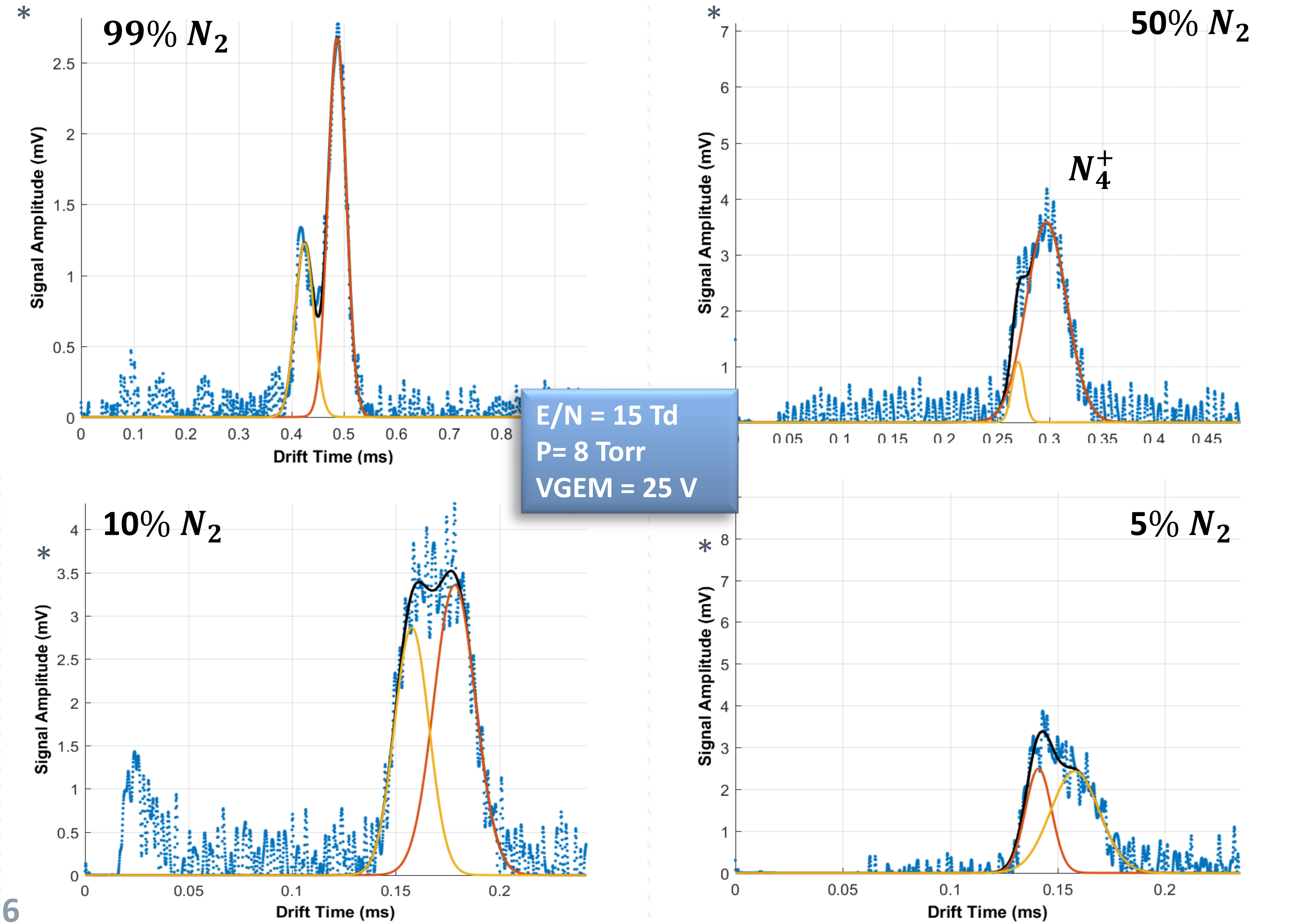


$K_{01} = 4,4\ cm^2V^{-1}s^{-1}$ (Ne^+)
$K_{02} = 6,2\ cm^2V^{-1}s^{-1}$ (Ne_2^+)

[5]P.N.B.Neves, 2011, IEEE

Experimental Results: Ne-N_2

*Not at scale



E/N = 15 Td
P= 8 Torr
VGEM = 25 V

Experimental Results: Ne-N_2

Direct Ionization	Cross Section (25V) (10^{-16} cm^2)	Final Ion
Ne + e → Ne^+ + e	0,20	Ne^+
N_2 + e → N_2^+ + e	0,64	N_2^+

E/N = 15 Td
P= 8 Torr (95% N_2 5% Ne)
VGEM = 25 V

Secondary Reactions	Rate Constant $cm^3.s^{-1}$ or $cm^6.s^{-1}$	Final Ion
N_2^+ + $2N_2$ → N_4^+ + N_2 +0,87eV	$5X10^{-29}$ [1,2,3]	N_4^+ ¥
N_2^+ + N_2 → N + N_3^+	$1,5X10^{-15}$ [6]	N_3^+ *
Ne^+ + 2Ne → Ne^{2+} + Ne	$5,6X10^{-32}$ [7]	Ne_2^+
Ne^+ + N_2 → N_2^+ + Ne	$1,1X10^{-13}$ [6]	N_2^+

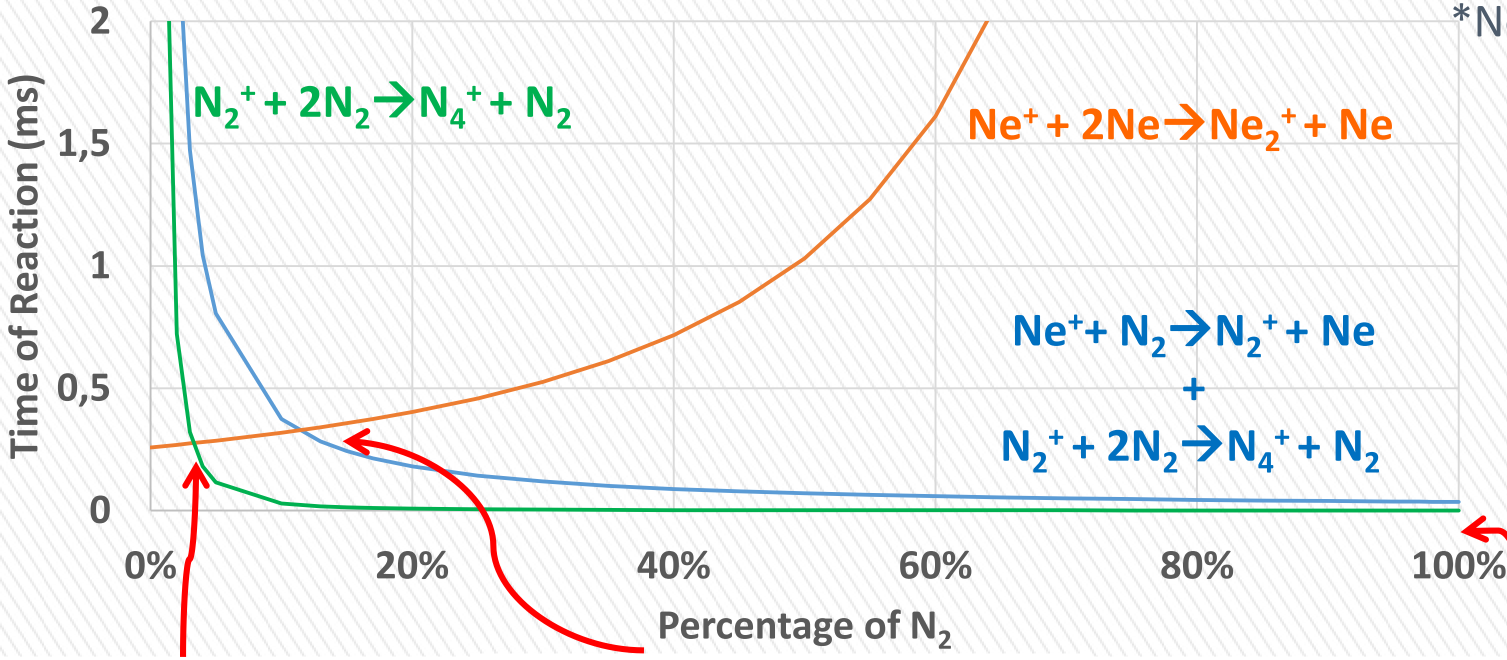
K_{01} ~ 2,62 $cm^2V^{-1}s^{-1}$
K_{02} ~ 2,32 $cm^2V^{-1}s^{-1}$

* Slow reaction

¥ See A. N. C. Garcia work regarding the experimental measurement of the N_4^+ ion mobility [1]

Reactions Paths

*Not at scale



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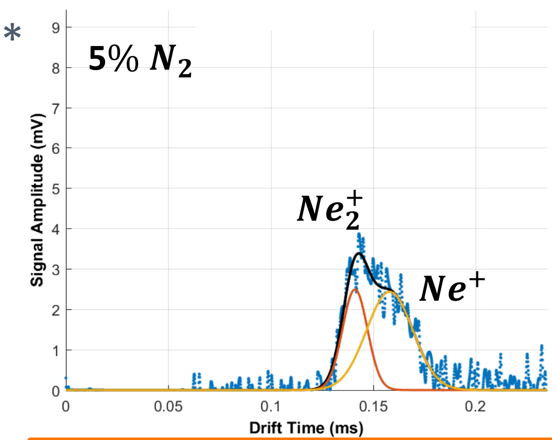
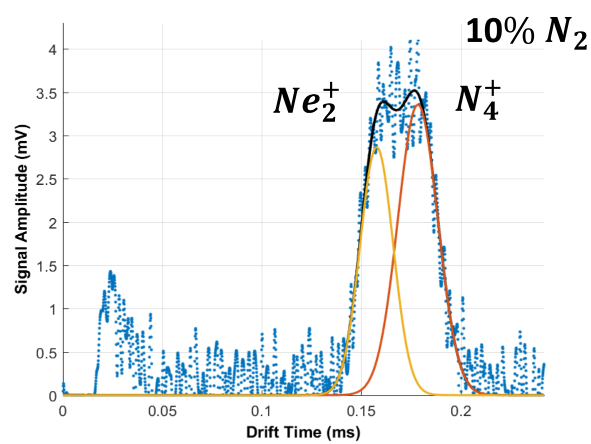
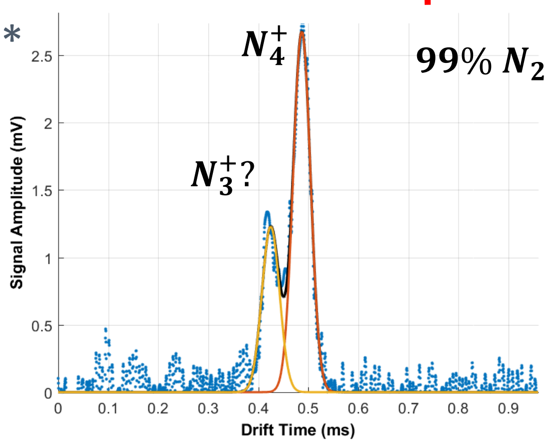


K_{01} ~ 7,13 cm^{2}V^{-1}s^{-1}
K_{02} ~ 6,40 cm^{2}V^{-1}s^{-1}

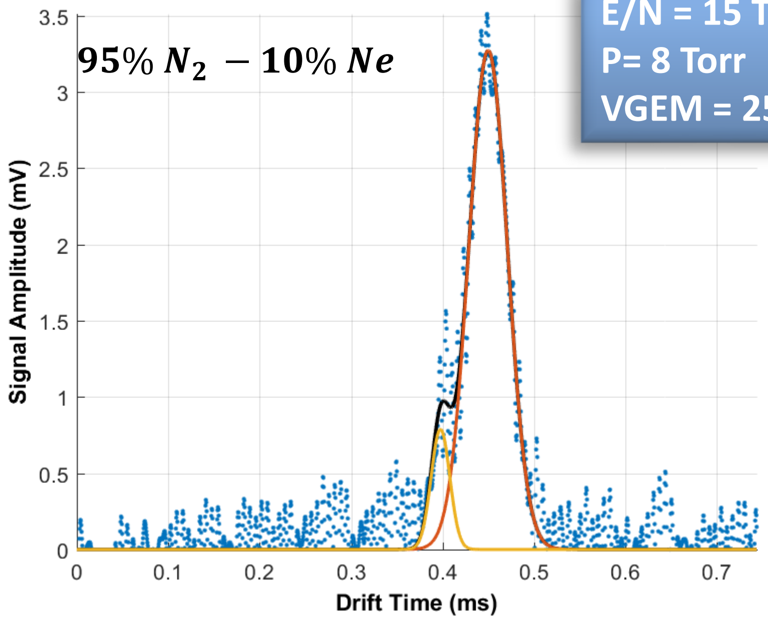
*


K_{01} ~ 6,60 cm^{2}V^{-1}s^{-1}
K_{02} ~ 5,84 cm^{2}V^{-1}s^{-1}

*


K_{01} ~ 2,47 cm^{2}V^{-1}s^{-1}
K_{02} ~ 2,16 cm^{2}V^{-1}s^{-1}

Degradation Signal: Ne-N_2



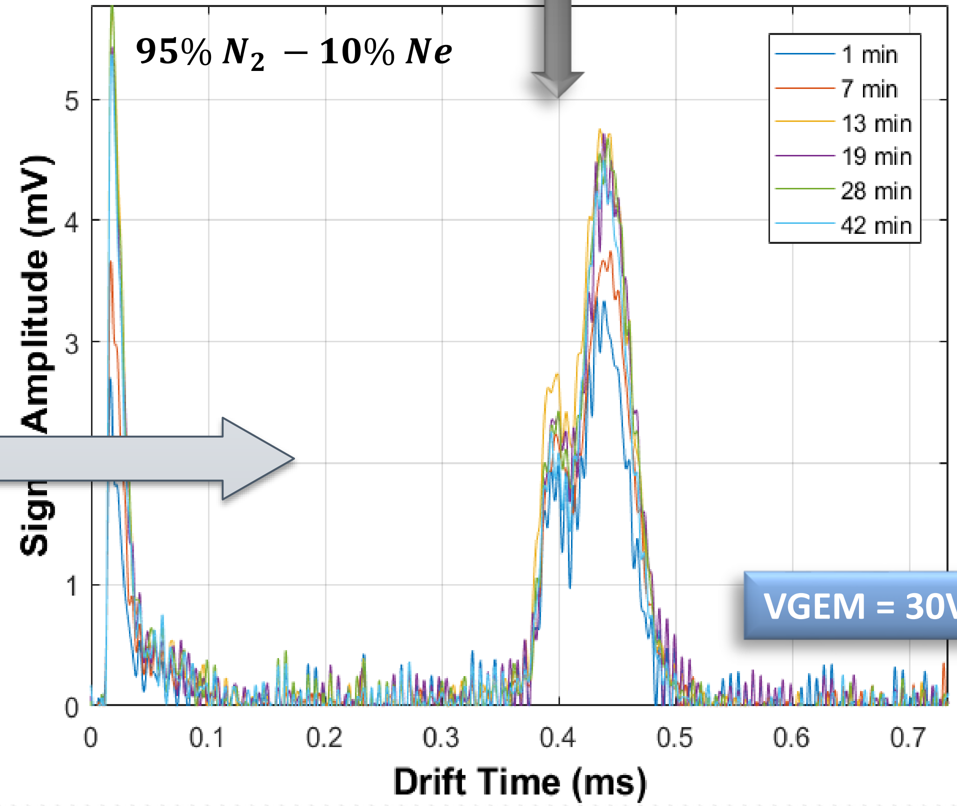
E/N = 15 Td
P= 8 Torr
VGEM = 25 V

Both peaks rise with time

The impurities have influence on peak's amplitude

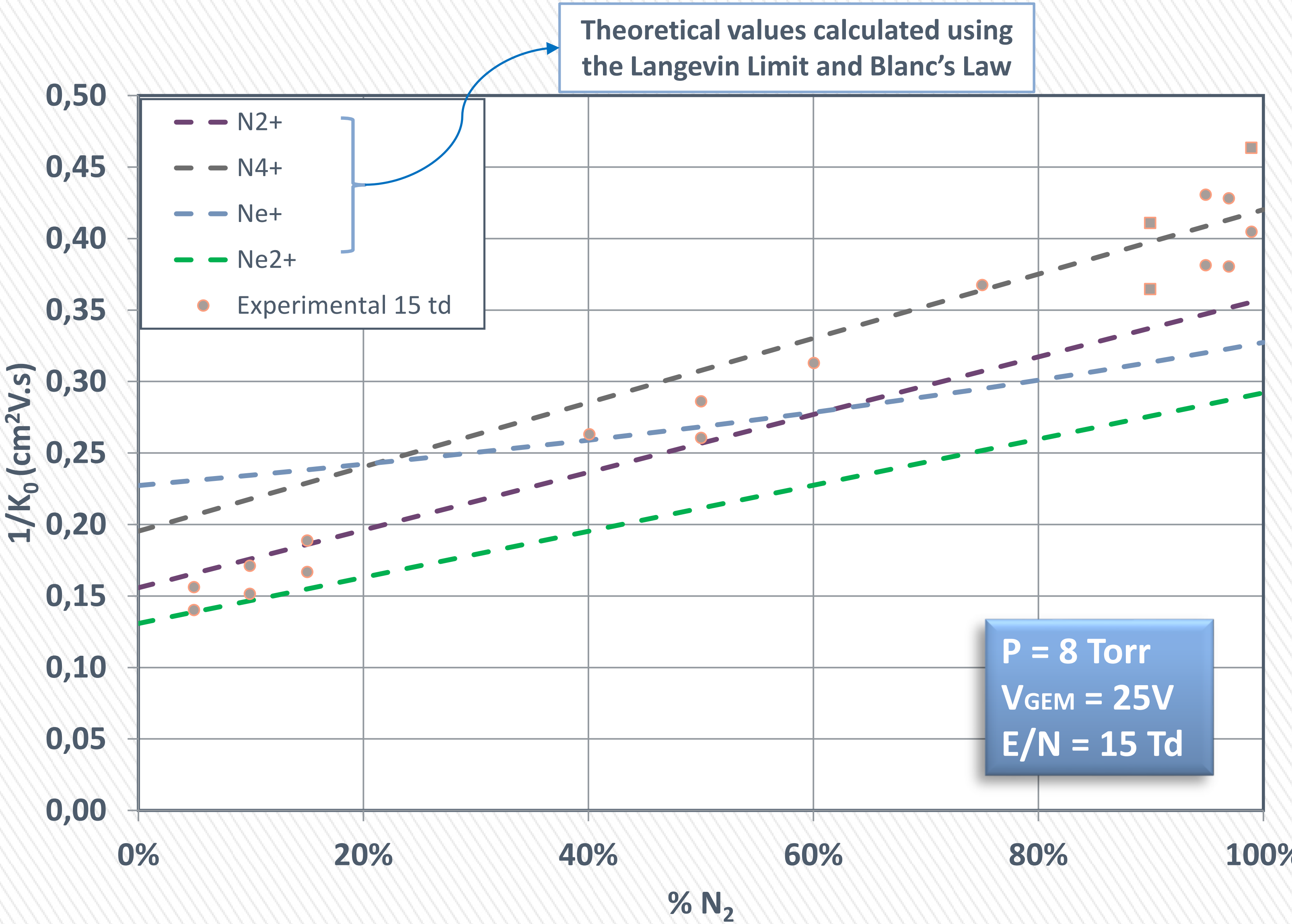
Causes:

- Gas purity (99,99997%) (HP)
- Outgassing process (LP)
- Contribution of the GEM

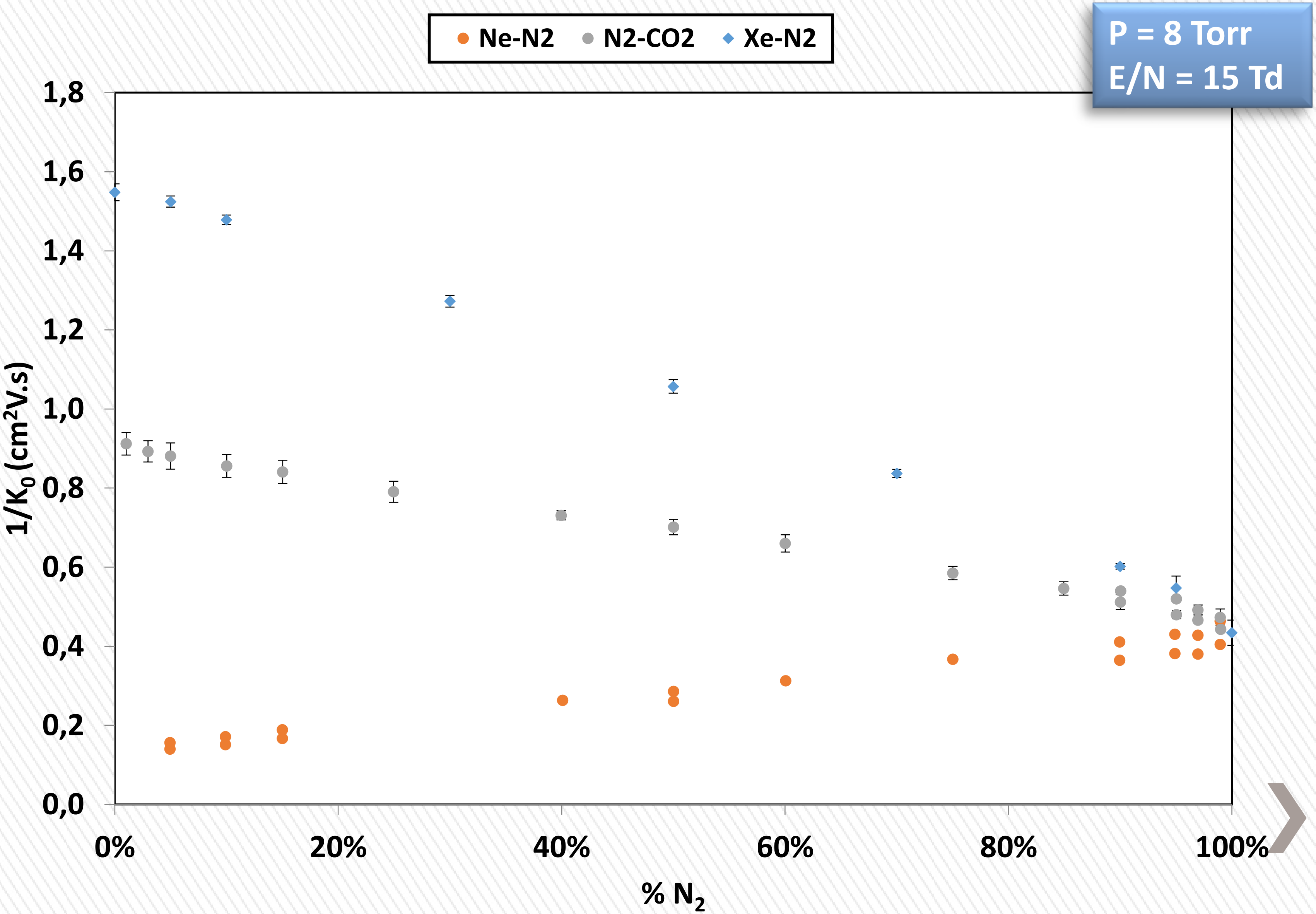


VGEM = 30V

Experimental Results: Ne-N_2



Comparison of mixtures with Nitrogen



Present Status and Future Work

- Pursuit the investigation of the mobility of ions in different gas mixtures of practical use (if you have any suggestions feel free to contact us).
  - In the scope of the RD51 common project submitted with GSI (Germany), Uludag Univ. (Turkey) and VECC (India).

Ne-N_2 (started)
Ne-CO_2-N_2 (only prelimary results)
Ar-CO_2-N_2 and Xe-CO_2-N_2
Ar-CF_4 and Ne-CF_4

- Optimization of the detector:
  - *Variable Drift Distance*
  (Already started -redesigning)
  - *Higher Pressure*
  - *Measurement of the mobility of negative ions*

  - Rate constant influence
  - Study lighter ions (H_2)
  - Water influence on the ion's mobility
  - (...)

- Study of improved ion-neutral interaction models

- A special thank to FCT-Fundação para a Ciência e Tecnologia for supporting this work through the National funds in the frame of the Project QREN n.4825, Rad for Life

and to

- CERN/RD51 Collaboration – Common Projects - 'Measurement and calculation of ion mobility of some gas mixtures of interest'. Participating institutions:

GSI

LIP

ULUDAĞ ÜNİVERSİTESİ 1975

Variable Energy Cyclotron Centre

Thank you!

Universidade de Coimbra

References

[1] A. Bekstein, Donnees de base des ions polyatomiques dans les gaz d'echappment: modelisation et validation experimentale, these de doctorat, universite de toulouse, Jan. 2009, http://thesesups.ups-tlse.fr/596/1/Bekstein

[2] W. Lindinger et al., Reactions of N+4 with O2, CO2,H2, and D2 and mobilities of N+4 in nitrogen, J.Chem. Phys. 68 (1978) 2607.

[3] P.A.M. van Koppen et al., Ion-molecule association reactions: A study of the temperature dependence of the reaction N2+ +N2 + M→N4+ +M =N2, Ne, and He: Experiment and theory, J. Chem. Phys.81 (1984) 288

[4] Garcia, A N. C., et al., A new contribution to the experimental measurement of the N4+ ion mobility in N2 at 298K. *Journal of Instrumentation*, *7*, P02012–P02012. http://doi.org/10.1088/1748-0221/7/02/P02012

[5] Neves, P. N. B., Garcia, A. N. C., Trindade, A. M. F., Barata, J. A. S., & Távora, L. M. N. (2011). Experimental Measurement of the Ne + and Ne +, *58*(4), 2060–2063.

[6] V.G. Anicich, Evaluated Bimolecular Gas Phase Kinetics of Positive Ions for Use in Modeling Planetary Atmospheres, Cometary Comae, and Insterstellar Clouds, J. Phys. Chem. Ref. Data 22 (1993)

[7] A. P. Vitols and H. J. Oskam, "Reaction rate constant for Ne^++2Ne-> Ne_2^++Ne in Phys. Rev. A, Gen. Phys., 1972, vol. 5, pp. 2618–2622.

Mixing Langevin Limit with Blanc's Law

Langevin Limit

To determine the mobility of an ion within a gas (not the parent).

$$K_p = 13.88\left(\frac{1}{\alpha\mu}\right)^{\frac{1}{2}}$$

μ – reduced mass
α – neutral polarizability

↓

Theoretical Mobility Values

Experimental Ion Mobility Values

Mobility of an ion within his parent gas (if known).

↓

Blanc's Law

Used to calculate the mobility of an ion in a gas mixture.

$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

f_1 , f_2 – molar fraction of gas 1 and 2

↓

Mobility of an ion in a mixture

Candidate ions identification

GEM Voltage

- Maximum energy gained by electrons.
- Primary ions possible to be formed.

Rg (pure)

$Rg + e \rightarrow Rg^+ + 2e$

Possible Reactions

Ions formed through reactions of the primary ions with neutral atoms or molecules from the medium.

Reaction Time

Used to calculate the mobility of an ion in a gas mixture.

$$\tau = \frac{1}{kN}$$

- Identification the possible ions present.

Universal decay law

Used to calculate the variation of the concentration of a specific ion in a mixture.

$Rg + Rg^+ \xrightarrow{k} X^+ + Y$

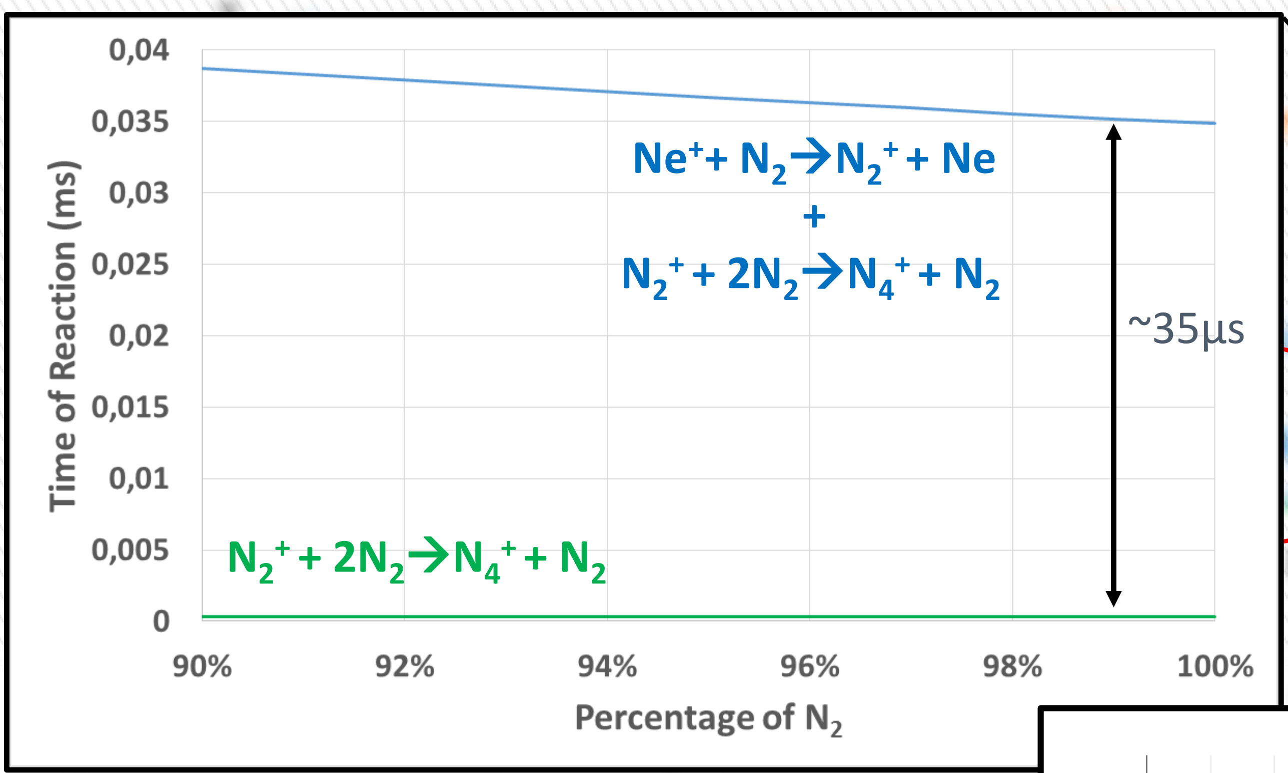
$$\frac{[Rg^+]}{[Rg^+]_0} = e^{-\frac{t}{\tau}}$$

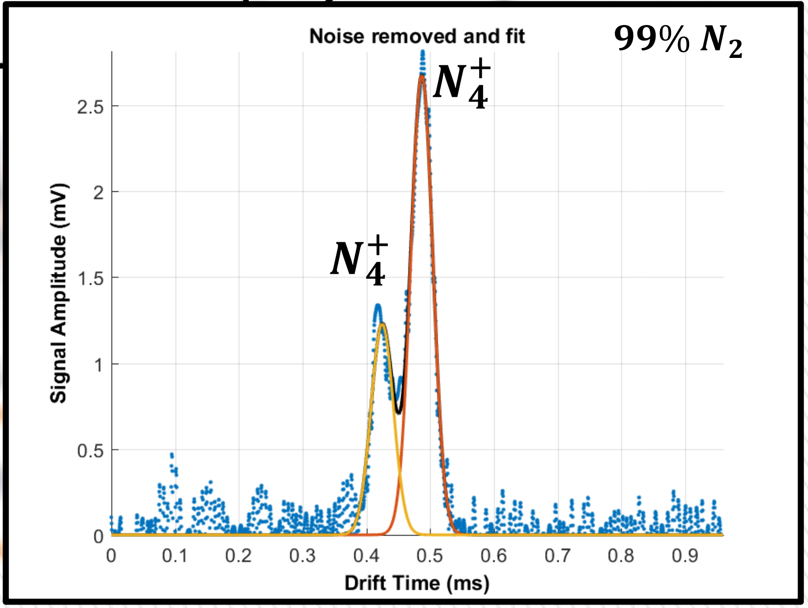
$$\frac{[X^+]}{[X^+]_0} = 1 - \frac{[Rg^+]}{[Rg^+]_0}$$

- Identification the possible ions present.

Select Most Probable Ions

Reactions Paths





Ion mobility results comparison