ETH zürich

High Voltage Laboratory

Extracting Cross Sections in Alternative Gases for Detector Simulations

Marnik Metting van Rijn
RD51 Collaboration
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Collaboration

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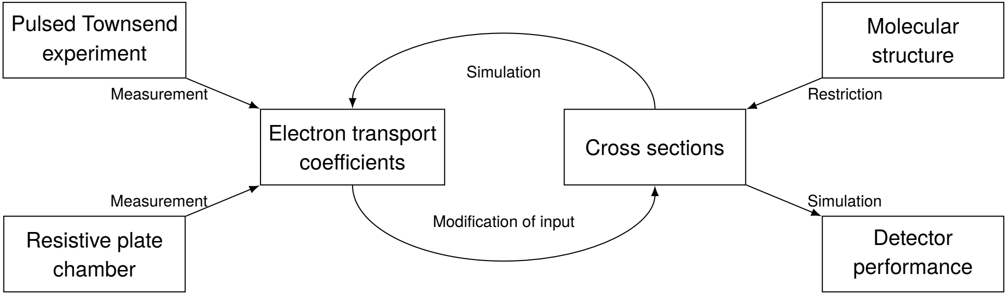
Project Objective

Research question

This project focuses on the cross-section evaluation of promising candidate gases and their application in gaseous tracking and timing detectors at CERN. The resultant cross-sections are expected to cover the low energy regime (~ 100 meV) up to the high energy regime (~ 100 eV) at around atmospheric pressure, as required by the detector geometry.



Electron Cluster Propagating in a Gas

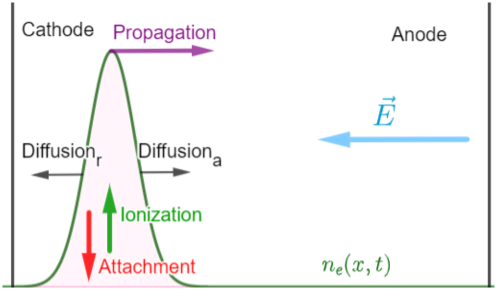


Figure: Spatial electron density in homogeneous electric field. Solution neglecting higher-order terms $\mathcal{O}(\partial_x^3 n)$ and zero initial broadening.

The spatial electron density propagates as

$$n_{\mathrm{e}}(x,t) \sim \underbrace{\exp(\alpha w t)}_{\text{Interaction}} \underbrace{\frac{1}{\sqrt{2\pi D_{\mathrm{L}} t}}}_{\text{Normalization}} \underbrace{\exp\left[\frac{1}{2}\frac{(x-wt)^2}{D_{\mathrm{L}} t}\right]}_{\text{Gaussian enveloppe}},$$

where

α	Townsend coefficient
w	drift velocity.
D_{L}	longitudinal diffusion

are the electron transport coefficients. We refrain from further specifying the measured drift velocity.

Pulsed Townsend Experiment

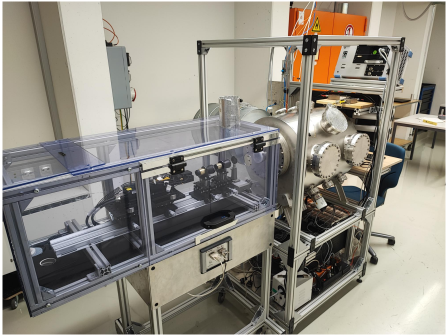


Figure: Pulsed Townsend experiment at the High Voltage Laboratory (ETH Zurich).

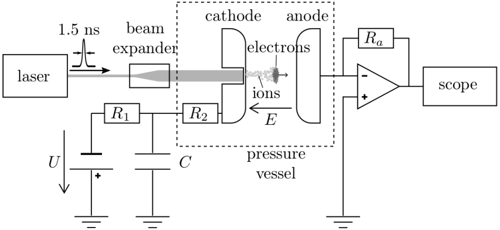


Figure: Schematic

Table: Measurement range

p	1 mbar - 0.8 bar
U	7 V - 60 kV
d	16 mm - 30 mm

Starting with R134a

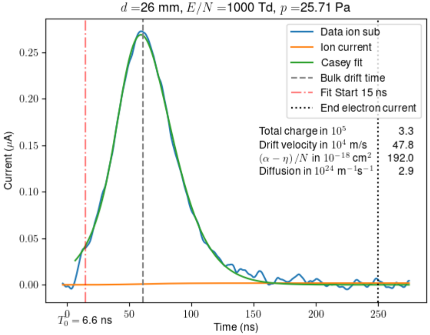


Figure: Pure R134a measurement on the Pulsed Townsend experiment in Zurich.

- R134a is the main component in the standard mixture
- Large amount of R134a measurements is available
- Revision enables verification of the simulations to higher accuracy

R134a Cross Sections

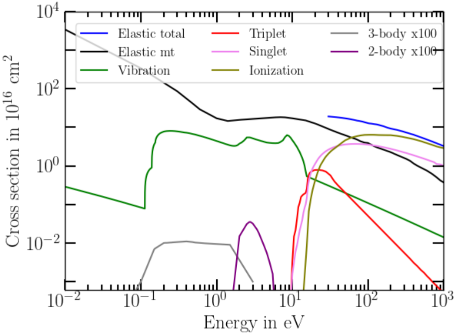


Figure: Cross section of R134a. Ionization accounts for gross ionization.

- Vibrational amplitudes adjusted
- First vibrational resonance reduced in energy
- Ionization threshold updated
- Excitation split into dipole allowed and triplet levels

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Experimental verification

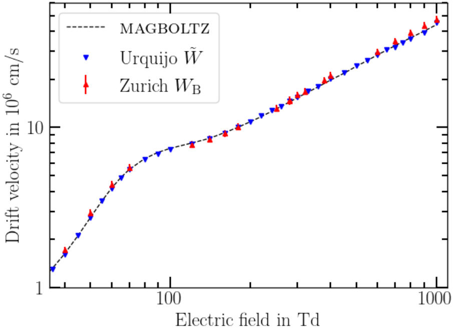


Figure: Drift-velocity simulations and measurements in pure R134a.

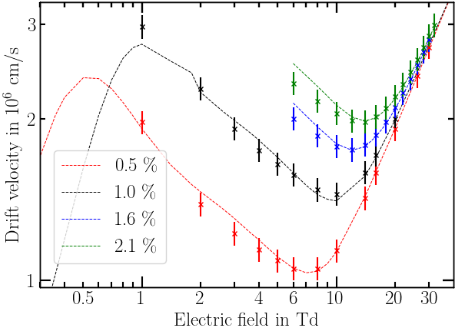


Figure: Drift-velocity simulations and measurements in argon diluted R134a. Percent is R134a concentration.

Detector Relevant Results

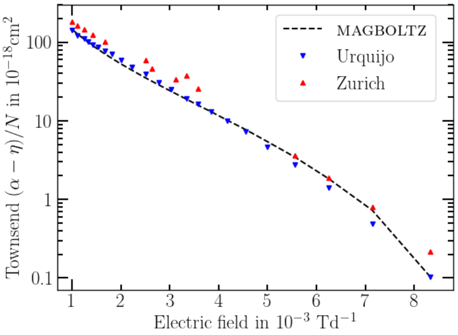


Figure: Townsend coefficient predicted by MAGBOLTZ and experimental verification.

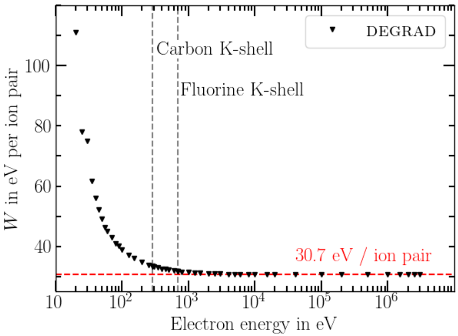
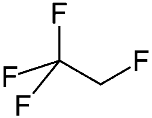


Figure: W value in R134a simulated by DEGRAD.

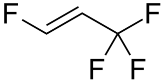
Concluding on R134a

- A revised R134a cross section was found.
- Limitations in high-electric-field measurements were found, while interpretation of the data remains ambiguous .
- Verification within experimental uncertainties provided.
- Publication expected beginning of 2024.

HFO1234ze



(a) R134a



(b) HFO1234ze(E)

R134a amounts to $95.2\ \%$ of the standard gas mixture. HFO1234ze(E) is a promising alternative.

R134a	$C_2H_2F_4$	1430 GWP
HFO1234ze(E)	$C_3H_2F_4$	< 1 GWP

- Zero ozone depletion potential
- Low flammability
- Low toxicity

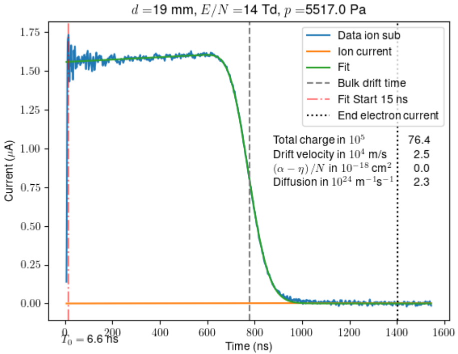


Figure: $1\ \%$ HFO1234ze(E) in argon at 5.5 kPa.

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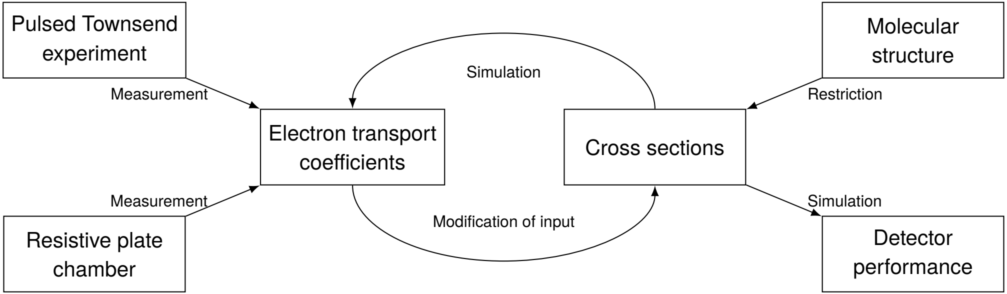

Electron Scattering Collaboration for HFO1234ze(E)

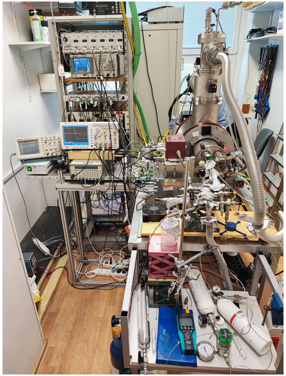

Figure: Dissociative attachment cross section measuring apparatus situated at the Heyrovsky Institute. Built by Michael Allan (Université de Fribourg).

HFO1234ze(E)

Collaboration established with the Heyrovsky Institute of Physical Chemistry in Prague to acquire electron-scattering data. With limitations, serves as an outstanding basis for finding cross sections.

- Dissociative attachment measured with fragment identification on time-of-flight and mass spectrometer
- Vibrational and elastic cross sections acquired including resonances
- Electronic excitation cross section obtained
- Novel excitation effect observed

145 meV vibrational excitation in HFO1234ze(E)

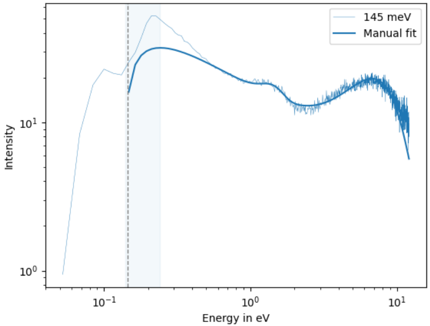

Figure: Vibrational cross section with energy threshold of 145 meV.

- With limitations, the cross section can be measured directly using electron scattering.
- Resonances can be observed, which are not visible in infrared spectra.
- Fitting of Born-dipole scattering formula performed manually.
- Absolute values not attainable, but relative to other measured cross sections.
- Detector response function not available, thus blue shaded region not reliable data.
- Unphysical non-zero intensities are due to detector resolution.

Conclusion and Outlook

- Electron scattering data in HFO1234ze(E) was acquired in collaboration with the Heyrovsky Institute.
- Code for HFO1234ze(E) cross section fitting implemented and first approaches were undertaken.
- MAGBOLTZ was adapted to include the novel excitation.
- Publication expected summer 2024.

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