Electron Swarm Parameters and Electron Collision Cross Sections

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1. Introduction

• Reliable data on electron collision cross sections and electron swarm parameters: the key to quantitative modeling of low-temperature plasmas
• Collection and evaluation for reliable sets of cross sections are needed.
• Electron swarm data and their analysis can evaluate and even provide cross section data.
• Electron swarm study, known to be complementary to beam experiment
2. Electron swarm parameters

- Every possible scattering process of electrons is reflected in their collective behaviors.
  - Elastic momentum transfer and vibrational excitation
- A trace amount of molecular impurities in a Ramsauer gas (Ar, for example) can alter swarm parameters drastically.
  - Manifestation of vibrational excitation processes in the mixture
  - Diminished elastic momentum transfer to the molecule because of its low density

⇒ Chance to separate determination of elastic momentum and vibrational cross sections

This swarm-derived resonance peak was confirmed by electron beam experiment. (H. Tanaka e al., 1990).
Then we established a procedure;

- **Step 1: Swarm parameters in mixtures**
  Vibrational excitation cross sections
- **Step 2: Swarm parameters in pure gas**
  Elastic momentum transfer cross section

These two steps are repeated alternately until the set of cross sections of the molecule converges and is consistent with all known experimental swarm parameters in pure gas and also in the mixtures.

**Tool:** Visually-interactive Boltzmann equation analysis
3. An example: $\text{C}_2\text{H}_4$

Ethylene($\text{C}_2\text{H}_4$) is one of the simple hydrocarbon molecules with two double-bonded carbon atoms. Experimental swarm data in ethene, however, are rather scarce.

We have already studied ethane (single-bonded) and acetylene (triple-bonded), and the present study will complete a systematic investigation on the molecular bond.
Preparation of an initial cross section set
(1) Elastic momentum transfer, $Q_m$

![Graph showing elastic momentum transfer cross section](image)

- **Theory:**
  - Winstead et al (2005)

- **Beam:**

- **Swarm derived:**
  - Duncan and Walker (1972)
  - Gee and Freeman (1984)
  - Hayashi (1990)
(2) Vibrational excitation, $Q_v$

![Graph showing cross sections for vibrational excitation](image)
(3) Electronic excitation, $Q_{ex1}$

Calculated from DCS of Asmis and Allan(1997)
(4) Electronic excitation, $Q_{ex2}$
(5) Total ionization, $Q_i$
Initial Set of Cross Sections for C$_2$H$_4$
Measurement of swarm parameters

Collector current (10^-12 A)

Delay time (μs)

L=2cm  4cm  6cm  8cm  10cm

Drift length (0-100mm, 5mm step)

Contacts to Photocathode

UV light from D2 lamp

Photocathode

Shutter 1

Shutter 2

Collector

Linear motion drive
(1) Pure C$_2$H$_4$

Estimated uncertainty of swarm parameters:
- Drift velocity: ±0.5%
- ND$_L$: ±3%
(2) 0.5% $\text{C}_2\text{H}_4$-Ar mixture

Estimated uncertainty of swarm parameters
drift velocity: $\pm 2\%$, $\text{ND}_L$: $\pm 6\%$
Amendment begins with $Q_m$ using swarms in pure $C_2H_4$. 

![Graph showing $W$ and $ND_L$ as functions of $E/N$ (Td)]
Then move to vibrational cross sections using swarms in C₂H₄-Ar mixtures.

These two steps are repeated alternately until the set converges.
Final set of cross sections

Cross sections ($10^{-16}$ cm$^2$)

Energy (eV)
Our final cross section set was compiled so that it was consistent with …

… swarm parameters in pure C\textsubscript{2}H\textsubscript{4} (above) and also in C\textsubscript{2}H\textsubscript{4}-Ar mixture (right).
Our final set is consistent also with...

Duncan and Walker (1972), ±5%

Heylen (1963), ±3%
Features of the final cross section set

Two structures

No threshold peak for Qv3
Conclusions

• In order to evaluate cross section data for a molecule electron swarm parameters in dilute mixtures of the molecule and argon can be very useful.

• Alternate use of experimental swarm data in the mixture and in pure molecular gas can give a more reliable set of cross sections for the molecule.