Electronic and Atomic Collisions with Hydrogen and Helium Ions

State-Specific Study of Associative, Dissociative and Reactive Processes

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“Atomic and Molecular Data for State-Resolved Modelling of Hydrogen and Helium and Their Isotopes in Fusion Plasma”

IAEA – August 2011
Outline

Three experimental setups ready to use:
- Merged-beams experiment
- Dissociative charge transfer experiment
- Crossed-beams experiment

Scientific scope of the project
- Ion-Ion collisions
- Ion-Atom collisions
- Electron-Molecular-Ion

Work in progress and to be done

X. Urbain, 1st CRP Meeting, Vienna, 11 August 2011
• **Crossed-beams**
  
  – Experimental setup
  
  – Absolute cross sections for electron impact dissociation and/or ionization

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**The people involved ...**

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*X. Urbain, 1st CRP Meeting, Vienna, 11 August 2011*
Crossed-beams experiment

Example: $\text{HeH}^+ + e^- \rightarrow \text{He}^+ + ...$


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Crossed-beams experiment

Similar to the CRP on “Light Element Atom, Molecule and Radical Behaviour in Divertor and Edge Plasma Regions”
Period 2009 – 2014

For example:
Reaction HeH\(^+\) + e\(^-\)
Crossed-beams experiment to measure the absolute cross sections for dissociative excitation and dissociative ionization
Measurement of the energy thresholds and of kinetic energy release distributions for the considered reactions
Deduction of the electronic states contributing in the considered processes
Vibrational population depending on the source conditions and the type of sources

http://www-amdis.iaea.org/CRP/LightElement/

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• **Merged-beams**
  
  – Experimental setup
  
  – Total cross sections for the associative ionisation and mutual neutralisation

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**The people involved ...**

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*Columbia University, USA*

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Merged-beams experiment

Electrostatic Merging

Zoom on the ion sources


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Study of the Mutual Neutralization reaction

\[ \text{H}^- + \text{H}^+ \rightarrow \text{H} + \text{H} \]

(work in progress…)

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Mutual Neutralization (MN)

\[ \text{H}^- + \text{H}^+ \rightarrow \text{H} + \text{H} \]

**Uncertainty of MN cross section**


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Detection efficiency depends on:

- single particle detection efficiency: > 98% for CEM, 57% for MCP
- angular spread of both beams (profiles measured in detection plane)
- deflection accompanying MN: differential cross section

**also visible in TOF spectra**

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TOF spectra and angular scattering

forward/backward

isotropic

X. Urbain, 1st CRP Meeting, Vienna, 11 August 2011
TOF spectra and angular scattering

H\(^{+}\) + H\(^{-}\) : Coulomb scattering

Better approximation:
- scattering up to avoided crossing with MN channel H+H(n=3)
- integration over impact parameter

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$E_r \approx 0$

$$\text{KER} = \text{IP}[\text{H}(n=3)] - \text{EA}[^1\text{H}] = 0.758 \text{ eV}$$
Absolute cross section for MN of $H^+$ and $H^-$

Two independent determinations

**OPTION 1**: measure all relevant quantities
- beam currents
- form factor (beam overlap)

**OPTION 2**: measure ratio of MN and Al signals

Al: 15% systematic uncertainty


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Absolute cross section for MN of $H^+$ and $H^-$

Ratio = 48 ± 2

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Partial cross section for MN to H + H(n=2, 3)

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Other MN studies: $\text{H}_2^+$, $\text{He}^+$ + $\text{H}^-$

• **Dissociative charge transfer**
  
  – Experimental setup
  
  – Total cross sections, vibrational population of molecular ions

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**The people involved ...**

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Study of the HeH$^+$ target (work in progress…)
**XUV photodissociation of HeH⁺**

Experiments performed at the Free Electron Laser (FEL) FLASH in Hamburg (Germany)

\[ \text{HeH}^+(X^1\Sigma^+) + h\nu \rightarrow (\text{HeH}^+)^* \]
\[ \rightarrow \text{He}(1s nl \, ^1L) + \text{H}^+ \]
\[ \rightarrow \text{He}^+(1s) + \text{H}(nl) \]

Experiment


Theory


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(a) He^+ + H(nl) and (b) He(1snl) + H^+, for PD of vibrationally hot (red line) and vibrationally cold (blue line) ions.

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**Present work**: Ro-vibrational analysis of the XUV photodissociation of HeH$^+$ ions

Dissociative charge transfer:

$$\text{HeH}^+ + K \rightarrow (\text{HeH})^* + K^+ \rightarrow \text{He} + \text{H} + K^+$$

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Ro-vibrational excitation

Vibrational population extracted from measurements performed with a duoplasmatron source operating under conditions similar to FLASH experiment

- **Direct Beam**
  - $v=0$: 55%
  - $v=1$: 23%
  - $v=2$: 11%
  - $v=3$: 7%
  - $v=4$: 4%
  - $T_{rot} = 3400 \, K$

- **10 ms Trapping**
  - $v=0$: 99%
  - $v=1$: 1%
  - $T_{rot} = 3100 \, K$

$T_{rot} = 3100 \, K$ obtained by optical spectroscopy!

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Total cross section

Total cross section for the photodissociation into $\text{He}(1s n l \ ^1L) + \text{H}^+$ starting from the initial state $v = 0, J = 0$

The cross section for the photodissociation into $\text{He} + \text{H}^+$ weighted by the experimental vibrational distribution

BUT: branching towards $n>3$ states ($\text{H}^*$ and $\text{He}^*$ alike) not explained


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State-to-state problem to be addressed

\[ H^+ + H_2 \text{ (HD, D}_2\text{)} \rightarrow H + H_2^+ (v) \]
H^+ + H_2 (HD, D_2, ...) collisions at low impact energies

Total cross sections for vibrational excitation and electron capture processes.

Theory:
L.F. Errea et al, JCP 133, 244307 (2010)

Experiments:

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H^+ + H_2 (HD, D_2, ...) collisions at low impact energies

Measurement of the vibrational distributions of H_2^+ by DCT

Partial cross sections for population of individual vibrational states of H_2^+ and H_2.

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Merged Beams Setup for H+H⁻ AD studies

- Interaction region
  - H₂ molecule formation
  - H⁻ + ν_{IR} → H₂
  - H⁻ + H → H₂ + e⁻

- Photodetachment region
  - Partial neutralization of the H⁻ beam inside a drift tube at variable voltages -U_f
  - H⁻ + ν_{IR} → H + e⁻

- Detection region
  - H₂ stripping in helium
  - H₂⁺ detection by energy analyzers
  - H₂ + He → H₂⁺ + [He, e⁻]


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$H^- \rightarrow H$ photodetachment scheme

Neutralized fraction of the $H^-$ beam

$$f_{PD} = C \frac{P_{\text{laser}}}{v_{HH} \sin(\alpha)}$$

To reach a photodetachment efficiency of $\sim 10\%$ at 10keV, we need a laser with $\sim 2$ kW of cw power @ 1000 nm

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Laser system: interleaved stacks @ 975 nm

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Measured AD rate coefficient 3.7 meV – 1eV


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- Three experimental setups ready to use:
  - Merged-beams experiment
  - Dissociative charge transfer experiment
  - Crossed-beams experiment

- Study of Ion-Ion, Ion-Molecule and Electron-Molecular-Ion collisions

- Fundamental data for collisional processes involving H, H⁺, H⁻, He, He⁺, He²⁺, He⁻, H₂, H₂⁺, H₃⁺, HeH⁺, He₂⁺ (and isotopes).

- Cross-sections for collisions with electrons and collisions among themselves, photon-induced processes, lifetimes of excited states…

- Comparison and critical evaluation of existing data.

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Thank you for your attention

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