First Stark deceleration of SO$_2$

– a source of cold atoms and molecules

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Applications of cold molecules

- High resolution spectroscopy
  \( \text{ND}_3 \) HFS: EPJD 31, 337 (2004)

- Evolution of fundamental constants
  fine structure constant: arXiv:physics/0601054

- Route to ultra-cold molecules
  sympathetic cooling

- Scattering experiments

- Quantum controlled reactions
  formaldehyde, hydroxyl: arXiv:physics/0508120
Controlled coupling

- Coherent coupling in thermal clouds

- Coherent coupling in BECs
  $\text{Rb}_2$: PRL 95, 063202 (2005)  $\text{Na}_2$: PRA 72, 041801 (2005)

- $\text{Cs}_4$ formation
Applications of cold SO$_2$

- Photodissociation: new way to cold particles
- Trapping of SO$_2$ and fragments SO + O
- Control of pathways and energies
- Cold chemistry?
- Study of cold molecule – particle collisions
Overview

- Control: Photodissociation in electric fields
- Stark decelerator setup
- Stark decelerator principle
- Time of flight spectra
- Outlook
Predissociation

Bound states embedded in continuum:

Coupling between both excited states:

Predissociation

Excess energy and initial quantum state determined by predissociating level
Stark effect measurement

\[ E = 0 \text{ kV/cm} \]
\[ E = 40 \text{ kV/cm} \]

Intensity [a.u.]

Energy [cm^{-1}]

SO_2 to PM

GND

lens

beam

+ HV
Stark effect measurement

\[ v = (510) \tilde{C} \]
Stark effect measurement

parameters (field free):
- rot. constants
- rot. temperature

free parameters:
- dipole moment
- geometry factor

\[ \mu_b = 1.99(6) \text{ D} \]
Tuneable kinetic energy

Energy levels relative to $v = 0, J = 0$ of $SO_2$ ground state (field free)

Only the $M = 0$ components of $SO_2$ are shown

Energy levels for $SO_2$ (510) $J(K_-,K_+)$ and $SO \nu = 2 (N,J) + O$

Term energy ($cm^{-1}$) vs. electric field (kV/cm)
Experimental setup

1. beam generation by a pulsed valve
2. geometrical cooling by a skimmer
3. hexapole to achieve phase matching of beam and decelerator
4. Stark decelerator for low-field seeking states
5. time of flight measurements
Decelerator principle

switching sequence for one molecule
Field of two electrodes

- minimum electric field on the molecular beam axis
- low-field seeking states experience a focusing force (guiding)
- no focusing in direction of the electrodes (y-axis)
- alternate horizontally and vertically positioned pairs
Definition of phase:
relative position of a molecule to electrodes (periodicity of 2L) when switching the field

\[ \phi = \frac{x}{2L} \cdot 360^\circ + 90^\circ \]

Deceleration requirements:
- switching intervals \( T \) must be gradually increased
- the bunch of molecules must be kept together
Switching times and phase stability

Molecules will oscillate with phase and velocity around the equilibrium values.

example:

$$\phi > \phi_0, v = v_0$$

Switching intervals are calculated for one selected molecule ($\phi_0, v_0$).

molecule loses more energy

phase gets smaller
Phase space inside decelerator

330 stages with 12.5 kV

$\Phi = 55^\circ$

330 stages with 12.5 kV

$\Phi = 55^\circ$
Our realized decelerator

- 140 stages
- Total length: 77 cm
- Potential difference: 25.0 kV, 125 kV/cm
  0.85 cm\(^{-1}\) per stage ≈ 1.22 K
Phase space inside decelerator

Decelerator with 140 stages
12.5 kV
Deceleration from 285 m/s to 217 m/s

\[ \Phi = 55^\circ \]

\[ U = 12.5 \text{ kV} \]

\[ l_{11} |M| = 0 \]

Guiding 317 m/s

Monte Carlo simulation
Outlook

- Building a Stark decelerator with 330 stages
- Photodissociation in electric fields and observation of kinetic energies
- Electrostatic trap for the SO$_2$ molecules
- Magnetic trap for SO and O
Summary

- Photodissociaiton: new way to cold particles
  - Cold radicals SO and O
  - Quantum state selective
  - Oriented

- Control of dissociation pathways
  - Stark effect tunes excess energy

- First decelerator for SO$_2$
  - Agreement with simulations allows to design the long decelerator
  - New decelerator can load a trap for SO$_2$