Cold molecules from deceleration and photodissociation

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Overview

- Motivation
- Reactive collisions, Feshbach resonances, and photodissociation
- Photodissociation \( \text{SO}_2 \)
- Deceleration experiment with \( \text{SO}_2 \) molecules
  - Stark effect
  - Molecular beam source
  - Hexapole lens
  - Design of the decelerator
- Summary
Applications of cold molecules

- Trapping of molecules
- High resolution spectroscopy
- Study of cold molecule – particle collisions
- Control of dissociation near the threshold
- Quantum chemistry
Cold collisions and photodissociation

Control of both reactant AB and photon, observation of products

»Cold« means close to the threshold
Photodissociation

- Complementary aspects to reactive and cold collisions
- Control of one particle only
- Steering by laser light
- Suitable system required
Photodissociation

Excitation of repulsive state

or

Excitation above threshold

Excess energy determined by photon energy
Predissociation

Bound states embedded in continuum:

Coupling between both exited states:

Predissociation

Excess energy and initial quantum state determined by predissociating level
Observed fragments

SO \left( v = 0 \right) + O

continuum

SO_{2} bound

N = 0
N = 1
N = 2

studied in our group

spectroscopic knowledge is highly important
Kinetic energy of $\text{SO} + \text{O}$

**Kinetic energy of fragments** is given by the relative position of levels $\text{SO}_2$ and $\text{SO} + \text{O}$.

Dissociation of $\text{SO}_2$

Cold $\text{SO}$ and $\text{O}$, kinetic energy gained can be **below 200 mK**.

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**SO**

- **A**
  - $N = 0$
  - $N = 1$
  - $N = 2$

- **B**
  - $6_{25}$
  - $6_{34}$
Tunable kinetic energy

SO and O in triplet states:
Magnetic trapping? Accumulation in phase space?

in external fields

bound

continuum

in external fields

SO₂

SO (v = 0) + O

N = 2

B
Experimental part

- Cold SO$_2$ is required for long observation time and cold fragments
- SO$_2$ comes in bottles
- Supersonic beam for high population in the lowest levels
- Deceleration of the molecules (Stark decelerator)
Ground state Stark effect

Graph showing the energy levels in the ground state as a function of electric field strength.

- Energy levels labeled: $|M|=0$, $|M|=1$, $|M|=2$.
- Electric field range: 0 to 200 kV/cm.
- Energy range: -3.0 to 6.0 cm$^{-1}$.

The graph illustrates how the energy levels change with increasing electric field strength.
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
5. time of flight measurements
Pulsed valve

supersonic expansion is used to produce internally cold molecules with narrow velocity distribution

Principle:
• cooled gas
• gas expansion with high pressure into vacuum
• multiple collisions
• high average velocity
• narrow velocity distribution
Pulsed valve

Supersonic expansion is used to produce internally cold molecules with narrow velocity distribution.

![Diagram of a pulsed valve](image)
Pulsed valve

Supersonic expansion is used to produce internally cold molecules with narrow velocity distribution.

![Image of pulsatile valve](image)

![Graph showing mean velocity vs. nozzle temperature](graph)

- Ar carrier gas
- Xe carrier gas
Electric field of a hexapole constructed of cylindrical rods with radius $r = 0.5 r_0$
Simulation of hexapole

Simulated trajectories of the $|J M> = |1110>\text{ state}$
Hexapole measurements

$U_{\text{hexapole}} = \pm 11.0kV$

with and without voltage at the hexapole

Stark selection: focussing + defocussing
Hexapole measurements
Hexapole measurements

![Graph showing energy levels vs. electric field for |M| = 0, 1, 2. The x-axis represents the electric field in kV/cm, and the y-axis represents energy in cm⁻¹.](image-url)
Hexapole measurements

![Graph showing hexapole measurements with voltage [V] on the x-axis and relative amplitude on the y-axis. Two curves are present, one for 290 m/s and the other for 330 m/s, representing simulated data.](image-url)
Field of two electrodes

- minimum electric field on the molecular beam axis
- low-field seeking states experience a focusing force (guiding)
- no focussing in the plane parallel to the electrodes
- alternate horizontally and vertically positioned pairs
Decelerator principle

switching sequence for one molecule
Molecules will oscillate with phase and velocity around the equilibrium values.

$v > v_0$

molecule loses more energy

velocity and phase get smaller
Simulations of decelerator

\[ v_{\text{start}} = 282 \text{ m/s}, \text{ distance of stages } 5.5 \text{ mm} \]
Simulations of decelerator with 300 stages

Guiding

hexapole

decelerator with 300 stages

displacement [mm]
distance [m]
The first decelerator will have 100 stages and should reduce the velocity from 285 m/s to 240 m/s.

This corresponds to 30% of the kinetic energy!
Summary

• Dissociation of cold SO\(_2\)
• Source of cold particles SO + O
• Trapping of radicals SO and O, accumulation in phase space
• Feshbach resonances: Tuning of velocities, switching of channels

• Successful focussing of SO\(_2\)
• Feasibility of a Stark decelerator