Integration of Zeeman decelerator with cryogenic ion trap apparatus

M. Hejduk
Department of Chemistry
University of Oxford

2017 meeting of the Southern Universities Spectroscopy and Dynamics Group

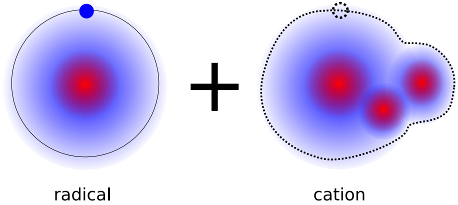
Oxford Chemistry

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

Low temperature ion-radical reactions

Motivation

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY



- very low activation energy → fast reactions;
- difficult to study as isolated system
- almost no studies at low temperatures

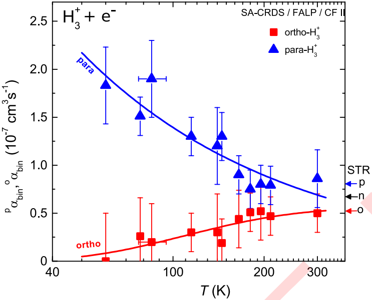
Low temperature studies

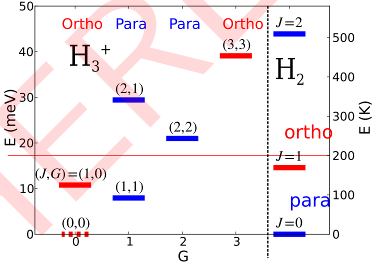
- no thermal averaging → state selectivity

Cold chemistry – trihydrogen cation-electron recombination

Influence of rotational and nuclear spin states – Pathway from chemical kinetics to chemical dynamics

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY





- Long range Coulomb interaction
- Thermal averaging at high temperatures
- ortho-H_3^+: Internal dynamics suppresses the recombination at low temperatures

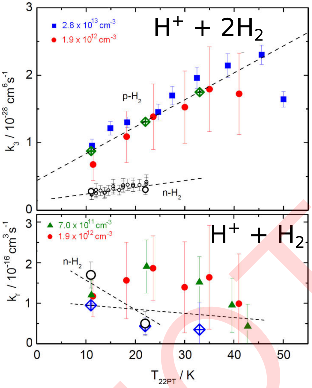
M. Hejduk et al., J. Chem. Phys 143 (4), 2015

Cold chemistry

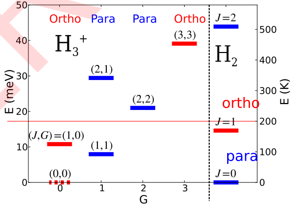
Influence of rotational and nuclear spin states

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

$$H^+ + \text{para/ortho-}H_2 \rightarrow H_3^+$$



D. Gerlich, et al., J. Phys. Chem. A, 117 (39), 2013

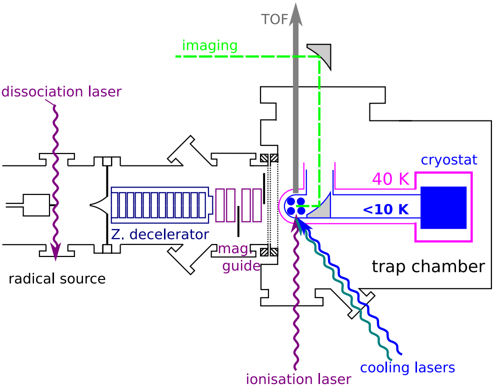


- three body process: para-hydrogen clusters grow faster at higher temperatures?!
- two body process: no significant difference visible

Combination of Zeeman deceleration and ion trapping

Our approach

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY



Zeeman decelerator

- relative velocity of reactants $\approx x \times 10\,\mathrm{m/s}$, $x \in (0, 30\rangle$

Ion trap

- Kinetic temperature down to several K
- Rovibrational temperatures lower than 10 K

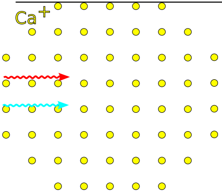
Degeneracy removed only in presence of magnetic field $\rightarrow$ possibility of state selective studies

Sympathetic cooling

How to decrease kinetic temperature of molecular ions

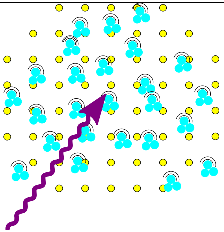
DEPARTMENT OF CHEMISTRY

1.



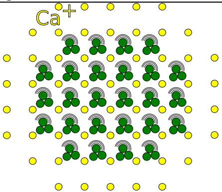
Laser cooling

2.



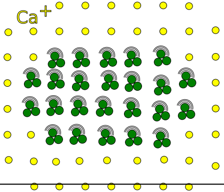
Generation of molecular ions

3.



Coulomb interaction

4.



Redistribution

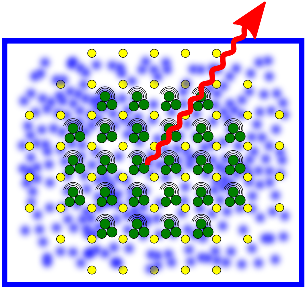
Radiative and buffer gas cooling

Colling of rovibrational motion, stabilisation of reaction intermediates

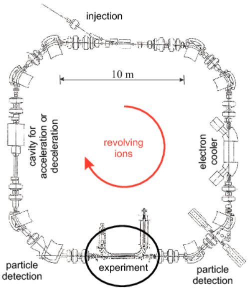
UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

Spontaneous rovibrational cooling can take from ms to ∞ s

- Walls need to be cooled to avoid radiative heating
- Appropriate buffer gas is needed for cooling



Storage ring

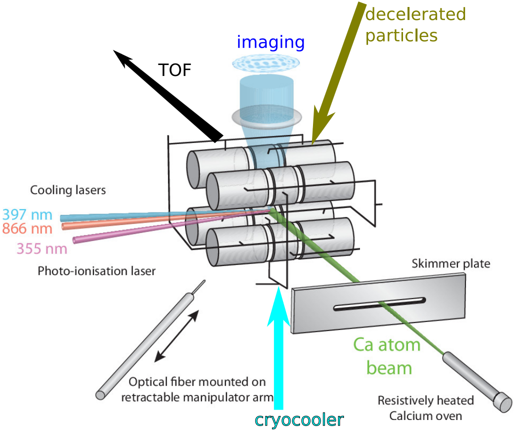


This did not work with H_3^+

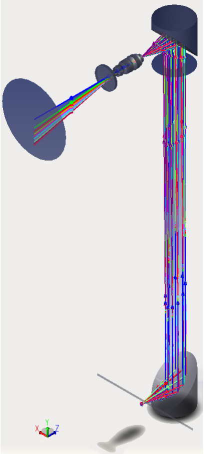
Ion trap

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

Congestion of beams



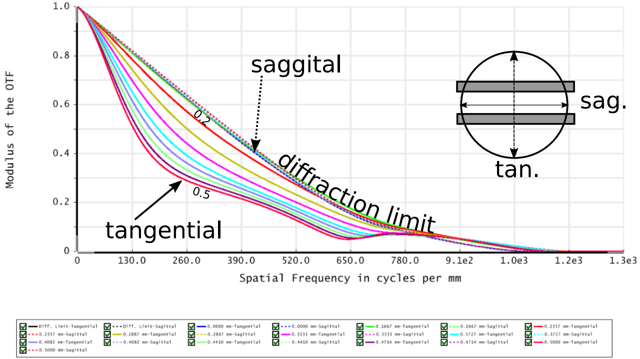
Partial solution:

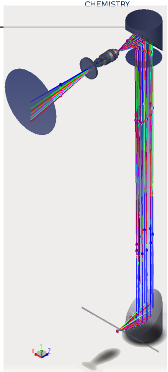


New imaging setup

ZEMAX simulations

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

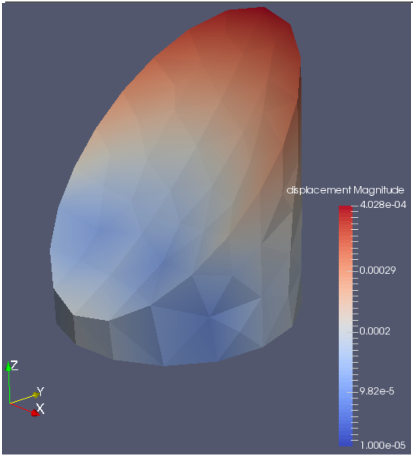




- Bringing the "object" plane out of the chamber allows us to increase the resolution.
- Typical sizes of coulomb crystals tan.$\times$sag.$= 160 \times 400\,\mu$m

Thermal deformation of the parabolic mirror at 10 K

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY



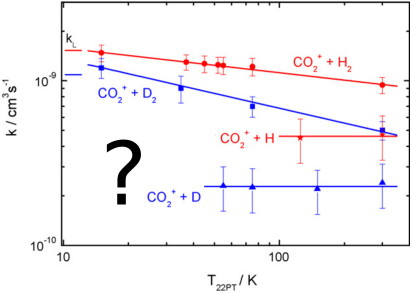
- Made of aluminium (only)
- Magnitude of deformation equal to manufacturing tolerance for the focal length
- Use Invar (low thermal contraction coefficient) for optical mount

Future plans

H atom flow calibration

UNIVERSITY OF OXFORD
DEPARTMENT OF CHEMISTRY

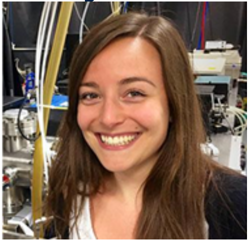
$$CO_2^+ + H \rightarrow HCO^+ + O$$

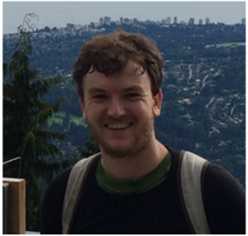


G. Borodi, et al., Int. J. Mass Spec., 280 (1), 2009

Reactants	**H/D**	**O**	**N**	**CN**	**CH_3**
CO_2^+	$HCO^+ + O$ $H^+ + CO_2$	$O_2^+ + CO$ $O^+ + CO_2$	$CO^+ + NO$	Unknown	Unknown
CH^+	$C^+ + H_2$	$CO^+ + H$		Unknown	Unknown
$C_2H_2^+$	C_2HD^+ H (with D)	$HCO^+ + CH$ $HCCO^+ + H$	$HC_2N^+ + H$ $HCNH^+ + C$ $C_2N^+ + H_2$ $CH^+ + HCN$	$HC_3N^+ + H$ $CCCN^+ + H$	Unknown
$C_6H_6^+$	$C_6H_5^+ + H_2$	$C_5H_6^+ + CO$	$C_5H_5^+ + HCN$	Unknown	Unknown

Thank you for your attention





We will welcome:

MARIE CURIE ACTIONS

EPSRC

Pioneering research and skills