Rydberg atoms in surface-electrode traps

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Rydberg states

- Lifetimes $\propto n^3 - n^5$
- Maximum induced electric dipole moment $\propto n^2$

$$E_{n\ell} = E_{IP} - \frac{Ry\cdot\hbar c}{(n-\delta\ell)^2}$$
Motivation

• Interactions of Rydberg atoms and molecules with surface
  

• Hybrid cavity-QED
  

• Preparation of cold molecules

• Experiments with positronium and antihydrogen
Chip-based traps

Ions

J. Jost (NIST)

Ground state atoms

P. Treutlein (Basel)

Polar molecules

G. Meijer (FHI)
Stark effect in the H atom

Stark Energy:

\[ W_{\text{Stark}} = -\mu_{\text{elec}} \cdot \vec{F} \]
\[ = \frac{3}{2} nk e a_0 F_z \]

Force:

\[ \vec{f} = -\nabla W_{\text{Stark}} \]

Stark effect in the H atom

\[ |\vec{\mu}_{\text{elec}}| = 213 \text{ D} \]

Rydberg-Stark deceleration

- Surface-electrode decelerator

Surface-electrode traps

![Diagram showing surface-electrode traps with voltage levels and positions in y and z dimensions.](image-url)
Surface-electrode traps

[Diagram showing electric field lines with labels for positions in y and z dimensions, and voltage fields marked as -30 V and +30 V.]
Surface-electrode traps
Surface-electrode decelerator
Surface-electrode decelerator
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Surface-electrode decelerator

- Decelerator operation

\[ V_i = (-1)^i V_0 \left[ 1 + \cos(\omega t + \varphi_i) \right] \]

\[ v_z = \frac{3d_z \omega}{2\pi} \]

Initial velocity: 760 m/s
Final velocity: 300 m/s

Meek et al., *Science* 324, 1699 (2009)
Surface-electrode decelerator

Decelerator structure

- Potentials: $V_{pp} \sim 30$ V
- Trap depth: $T \sim 2$ K ($n = 30$)
H atom production: \[ \text{NH}_3 + h\nu \rightarrow \text{NH}_2 + \text{H} \]

Photoexcitation: \[ 1^2S \rightarrow 2^2P \rightarrow ns/nd \]
Acceleration/deceleration

• Acceleration/deceleration of H atoms ($a_z \sim \pm 10^8 \text{ m/s}^2$)
Acceleration/deceleration

- Acceleration/deceleration of H atoms \( (a_z \sim \pm 10^8 \text{ m/s}^2) \)

Experiment

- \( n = 31 \)
- \( v_f = 600 \text{ m/s} \)
- Undecelerated \( v = 760 \text{ m/s} \)
Acceleration/deceleration

- Acceleration/deceleration of H atoms \((a_z \sim \pm 10^8 \text{ m/s}^2)\)

![Graph showing normalized integrated H\(^+\) ion signal with different final velocities: \(v_f = 200\) m/s, \(v_f = 300\) m/s, \(v_f = 450\) m/s, and \(v_f = 600\) m/s. The graph also includes a label indicating an undeaccelerated condition with \(v = 760\) m/s.]
• Acceleration/deceleration of H atoms \( (a_z \sim \pm 10^8 \text{ m/s}^2) \)
Acceleration/deceleration

- Acceleration/deceleration of H atoms \((a_z \sim \pm 10^8 \text{ m/s}^2)\)
Rydberg-state acceptance

- Deceleration in low fields with large gradients
  - wide range of Rydberg states accepted

Electrostatic trapping

• Trap atoms for time $\tau_{\text{trap}}$ above electrode array
  - after trapping re-accelerate toward detection region
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- Trap atoms for time $\tau_{\text{trap}}$ above electrode array
  - after trapping re-accelerate toward detection region

Decay time $\sim 30 \, \mu s$
- dominated by collisional losses

Coupling to microwave circuits

Surface-based electrostatic guides

- Based on geometry of co-planar waveguide
Surface-based electrostatic guides

- Based on geometry of co-planar waveguide
Surface-based electrostatic guides

- Metastable helium beam
Surface-based electrostatic guides

- Metastable helium beam
Summary

• Surface-based decelerators and traps for atoms in Rydberg states
  H. Sassmannshausen, P. Allmendinger, H. Schmutz, J. Agner and F. Merkt (ETH Zurich)

• Surface-based electrostatic guides
  P. Lancuba (UCL)