Millimeter-wave spectroscopy of Rydberg states in Potassium

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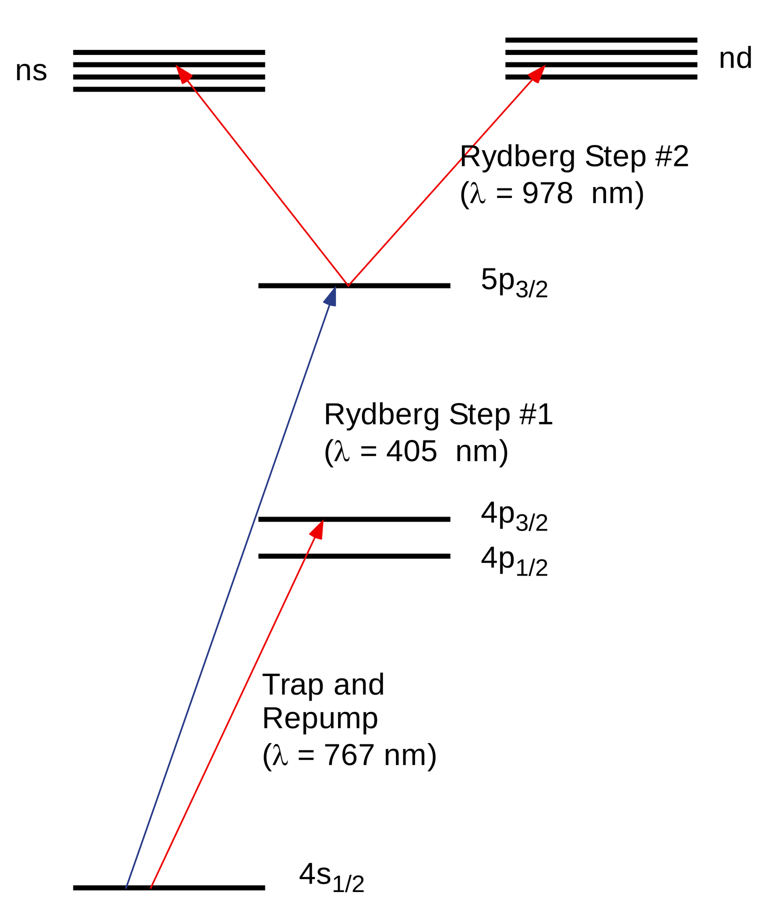
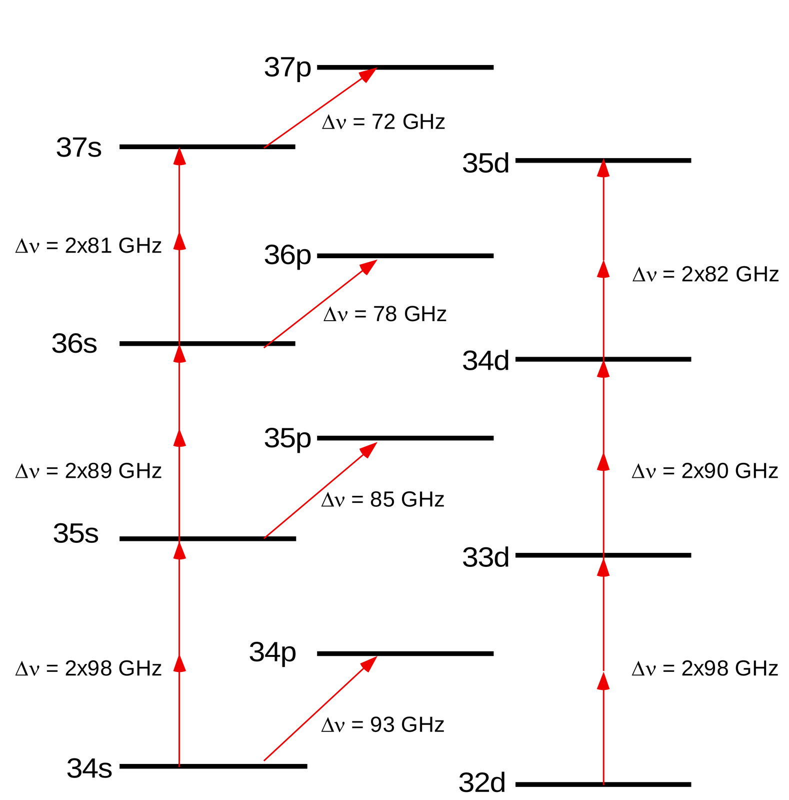
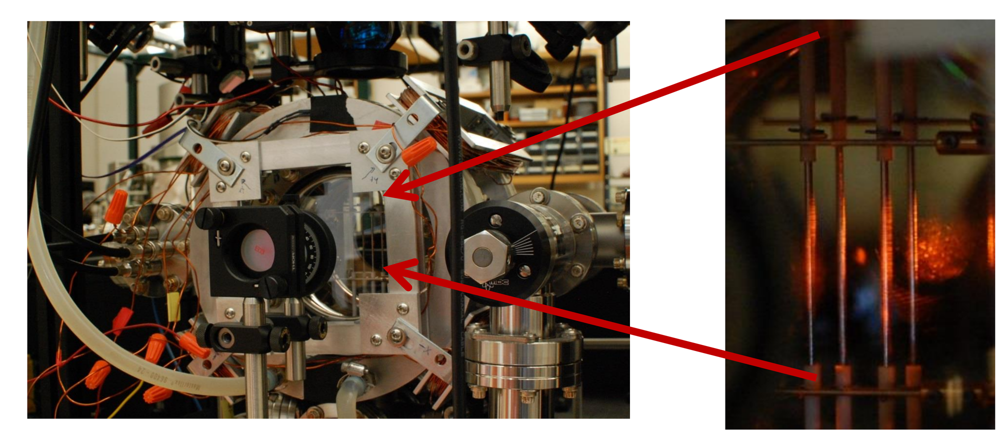
Abstract
We report high-precision measurements of millimeter-wave transitions between Rydberg states in potassium. We make measurements in a magneto-optical trap with a temperature of 1-2 mK and peak atomic density of 10^9 atoms/cm^3. The cold atoms are excited to Rydberg states in steps from $4s_{1/2}$ to $5p_{3/2}$ and from $5p_{3/2}$ to $ns_{1/2}$ states using stabilized external-cavity diode lasers at 405 nm and 980 nm. Millimeter-wave transitions are detected by selective field ionization. We null stray electric fields in three dimensions using potentials applied to a set of mutually perpendicular rods surrounding the MOT cloud. The measured frequency intervals are measured to better than a part in 10^7 and are then used to determine the quantum defects and absolute energies of the Rydberg states.



Energy levels and appropriate transitions for the cooling and trapping and two-color excitation of Rydberg states in potassium.



Millimeter-wave transitions and their approximate frequencies



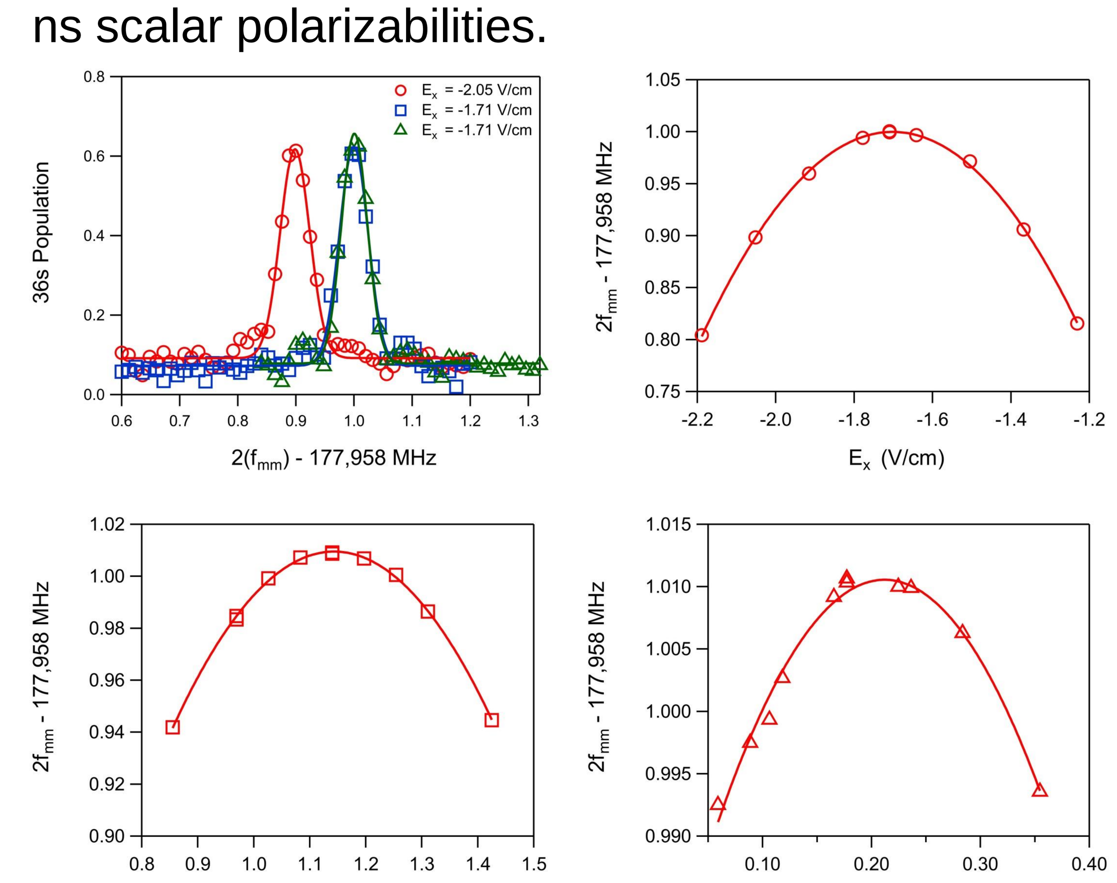
Photograph of the MOT, with the inset photo showing the MOT cloud centered between eight rods that can be used to apply static and ramped electric fields to selectively field ionize the atoms. Millimeter waves are introduced using a horn outside the vacuum chamber.

Effect of Static Electric Fields

Rydberg state energies are very sensitive to the static electric field. The measured ns to (n+1)s transition frequency versus static field is

$$\Delta\nu = \nu_0 - \frac{1}{2}\Delta\alpha\mathcal{E}^2$$

where $\Delta\alpha$ is the difference between the (n+1)s and ns scalar polarizabilities.

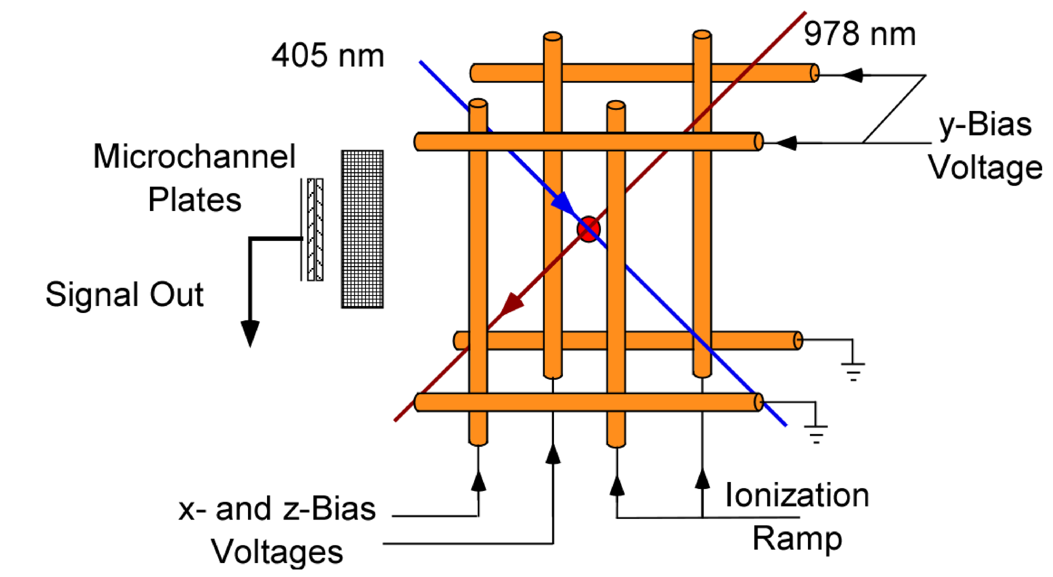


Observed spectra, and peak location versus the static field in three orthogonal directions. The maximum frequency is measured when the component of the field is nulled to zero.

For the 35s to 36s transition shown we calculate

$$\alpha_{36s} = 9.19\ \text{MHz/(V/cm)}^2$$
$$\alpha_{35s} = 7.53\ \text{MHz/(V/cm)}^2$$
$$\Delta\alpha = 1.66\ \text{MHz/(V/cm)}^2$$

in good agreement with the experimental measurements.



Schematic diagram of the Rydberg setup showing the paths of the Rydberg excitation lasers, the arrangement of the rods used to apply fields, and the charged particle detector.

Determination of s-state quantum defects

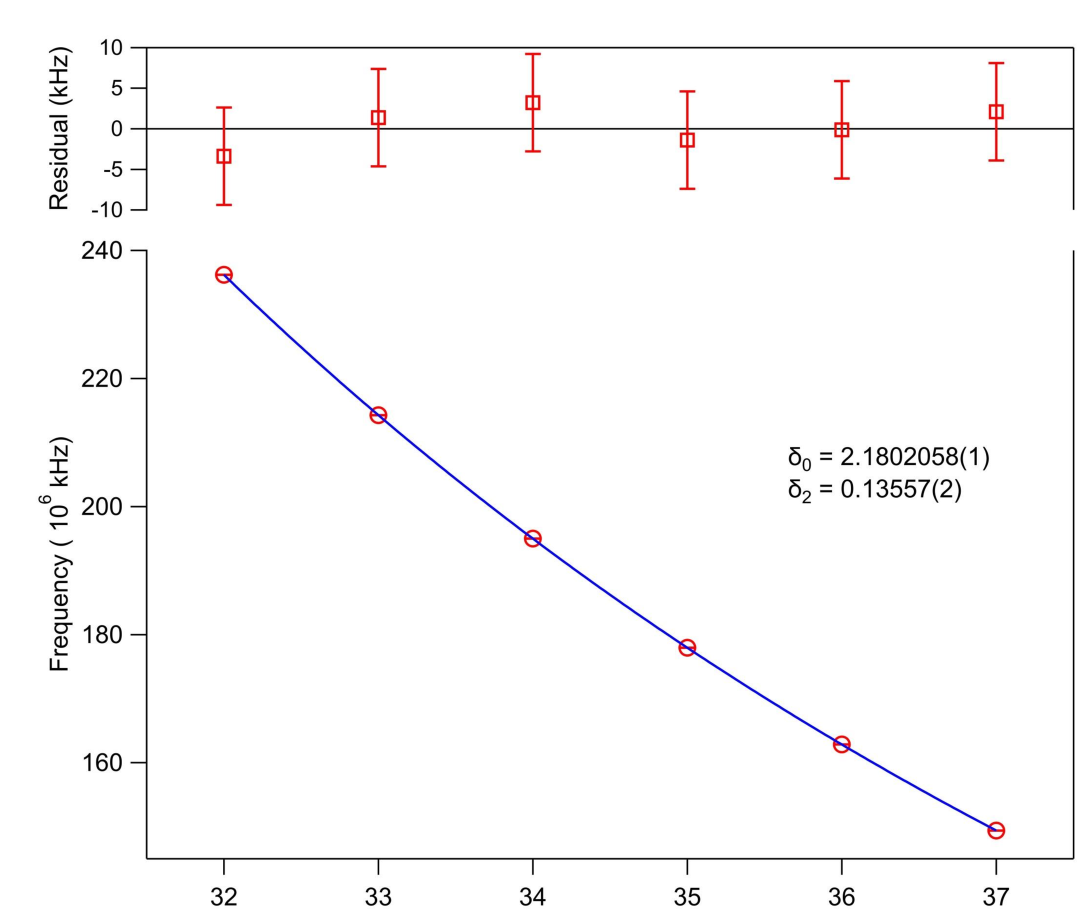
With the Rydberg state energies

$$E_n = -\frac{hcR_K}{(n-\delta(n))^2}$$

and using the parameterization

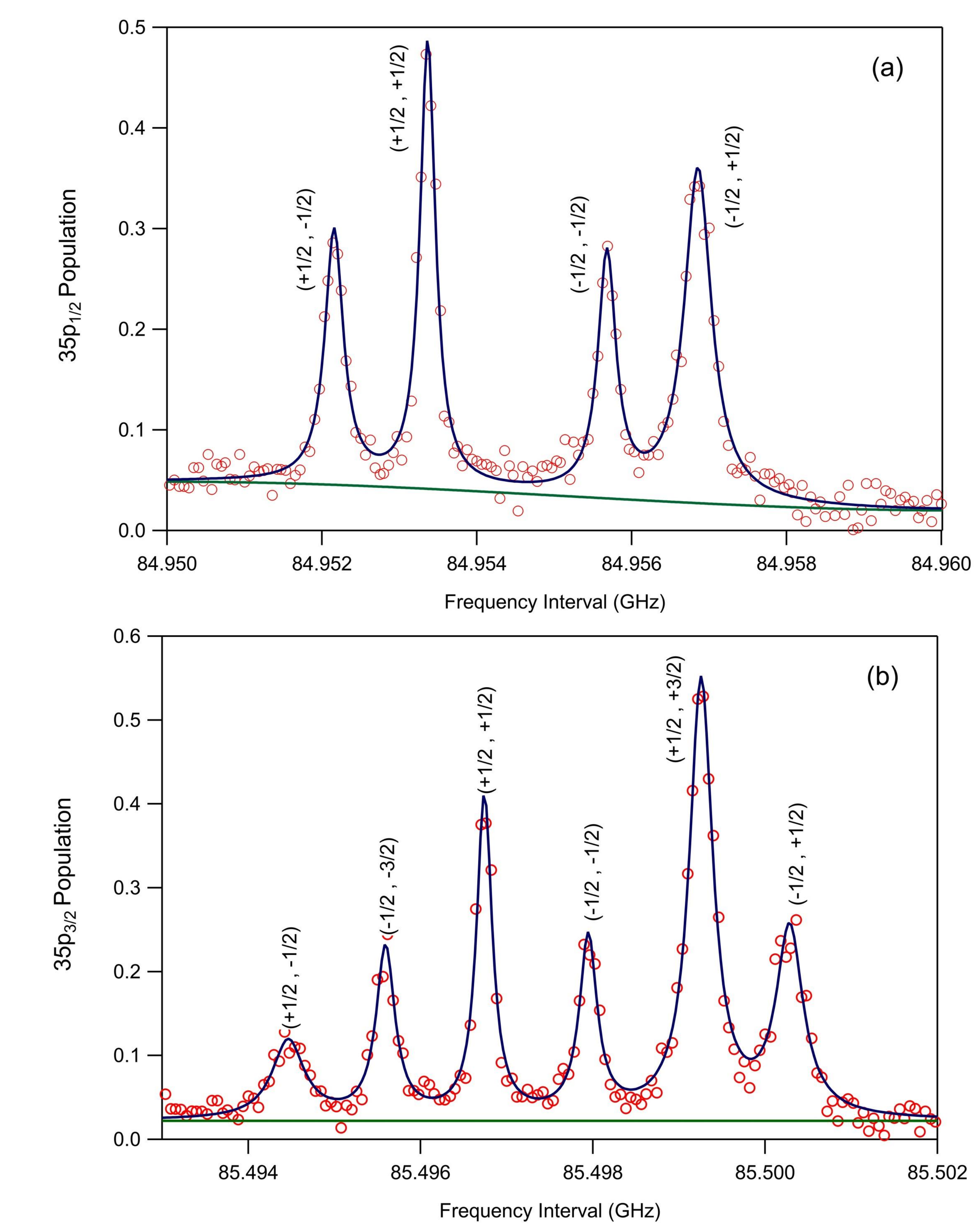
$$\delta(n) = \delta_0 + \frac{\delta_2}{(n-\delta_0)^2}$$

a fit of the measured transition frequencies can be used to determine the quantum defect parameters δ_0 and δ_2.



Measured ns to (n+1)s transition frequencies versus principal quantum number. The fit has residuals that are smaller than 5 x 10^{-8} of the transition frequency.

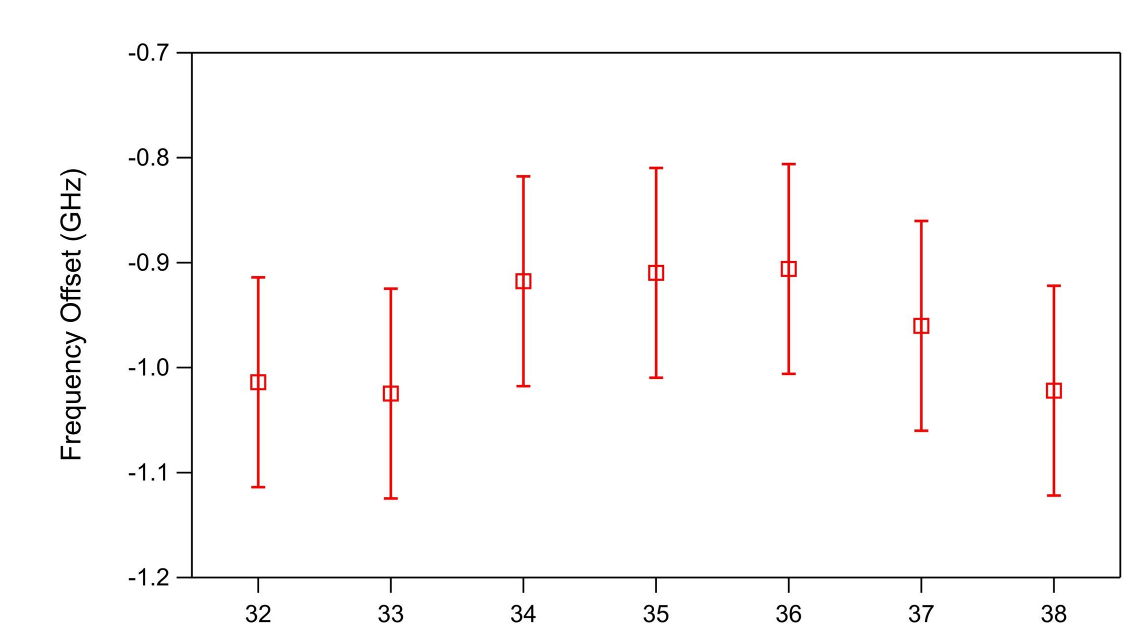
Observed 35s to 35p transitions



Spectra of the (a) 35s to $35p_{1/2}$ and (b) 35s to $35p_{3/2}$ transitions measured in the MOT. The mm-wave pulse width was 4 μs; the lines are close to transform limited. Hyperfine structure is not resolved and the spacings between the transitions are due to a 1.25 G magnetic field.

Re-evaluation of the $5p_{3/2}$ energy

We find a systematic offset between the measured $5p_{3/2}$ to $ns_{1/2}$ transition frequencies and those calculated based on the determined energies of the $ns_{1/2}$ states and the NIST tabulated $5p_{3/2}$ energy.



The measured offset is roughly six times the uncertainty reported in the NIST tables.

Acknowledgements
The research was supported by Colby College and the National Science Foundation.