A Millimeter-Wave Measurement of the Rydberg frequency

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We are carrying out a new determination of the Rydberg frequency, cR_∞, by measuring the frequencies of millimeter-wave transitions between circular states ($|m| = n - 1$) of hydrogen in the range $n = 27$ to $n = 30$. Previous measurements employed laser spectroscopy and the determination of optical frequencies of transitions involving S and D states of hydrogen [1, 2]. Because our technique is fundamentally different, our result will provide an independent value of cR_∞, thus adding to the reliability of this fundamental constant. The contribution of the Lamb shift to the transition frequency is so small that it introduces negligible uncertainty, and the measurement is also free of any nuclear corrections. A single run (one night) yields a statistical uncertainty of 1 part in 10^{11}. We are currently evaluating sources of systematic error.

We carry the experiment out on an atomic beam of hydrogen, using Ramsey's Separated Oscillatory Field method. The beam is cooled by collisions with a cryogenic thermalizing channel in order to slow the atoms and thereby increase the interaction time. After the beam is collimated, the atoms pass through two layers of magnetic shielding and an 80 Kelvin cryogenic shield before entering the interaction region, which is cooled to 4 Kelvin. The interaction region, shown schematically in Figure 1, is logically divided into three sections: the circular state production region, the separated fields region, and the detection region. These are described briefly below.

In the circular state production region, the hydrogen atoms are excited from the $1s$ ground state, through the $2p_{3/2}$ state, to the n=27 or 29, m=0 state by two-photon stepwise excitation. The optical excitation is performed in an electric field to provide selective population of a particular m=0 level. The atoms then pass through the center of a circle of four electrodes which are fed by a 1.8 GHz RF source with a 90° phase delay between adjacent pairs. This creates a circularly polarized field which drives the atoms into the n=27, $|m|$=26 or n=29, $|m|$=28 circular state through a multiphoton absorption process [3]. A pulsed EFI detector in the circular state production region monitors the efficiency of the optical excitation and angular momentum transfer processes.

After the atoms are prepared in the circular Rydberg state, the beam enters the millimeter-wave separated fields region. Because Rydberg atoms interact strongly with external fields, accurate measurement of the energy level structure requires careful control of the interaction

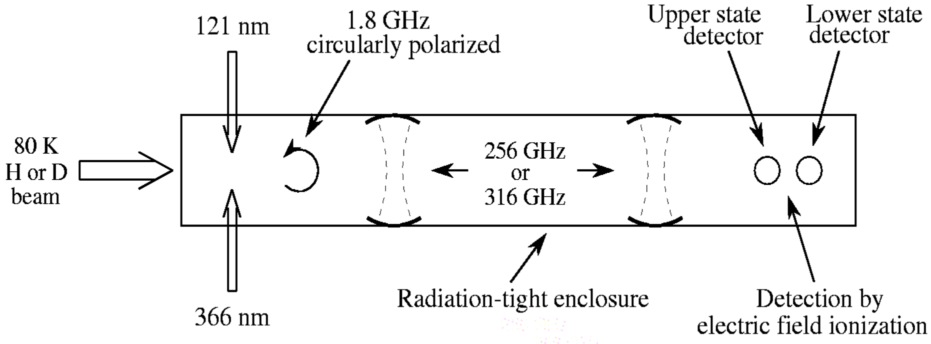

Figure 1: Schematic top view of the interaction region.

environment. Thermal radiation is reduced by cooling the entire interaction region to ≈4 K with a liquid helium flow system. The ambient magnetic field is reduced by the double-wall high-permeablility shields and a uniform magnetic field of ≈150 mG is applied. A small electric field is applied with high uniformity to maintain the atoms in the circular state. The millimeter-waves intersect the atomic beam at two locations separated by 50 cm. The millimeter-wave zones inside the interaction region consist of two Fabry-Perot cavities which determine the spatial mode of the millimeter-wave radiation.

The state distribution of the atoms emerging from the interaction region is analyzed by a state-selective EFI detector. Within the detector, the atoms enter a region of increasing electric field produced by a pair of symmetric ramped plates held at constant potential. Atoms in different states are selectively ionized at different fields and the ions are detected at different positions. The detection electronics record the state and time of detection for each atom. Because the laser system is pulsed, the time resolution of the ionization signal allows contributions to the resonance pattern from each velocity class to be analyzed individually, providing a valuable check on possible systematic errors.

To find the frequency of the circular state to circular state transition, we measure the population inversion as the millimeter-waves are tuned through resonance. In Ramsey spectroscopy, the phase difference between the two oscillatory fields plays an important role in the lineshape, and it must be known in order to extract the center of the fringe. In our experiment, we account for this phase difference by fitting each velocity class of the Ramsey fringe. In this way, we can extract both the phase difference between the fields and the frequency of the transition.

Recent results will be presented.

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