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Observation of molecular resonance during the excitation of a cold Rydberg atom pairs

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Synopsis We present experimental results that show a significant yield of nP atoms after excitation of nS Rb Rydberg atoms from a MOT using a pulsed dye laser, where 29 < n < 37. The observed nP population is quadratically dependent on the nS atomic density. Such results are naturally attributed to binary collisions. However, this cannot be the case here, because the interaction between Rb nS atoms is repulsive. In this experiment, the AC Stark effect and multipole interactions work together to create a nonvanishing final population of nP + (n − 1)P pairs.

Samples of cold Rydberg atoms have been proposed as ideal prototypes for quantum computation [1]. Such proposals are based on long range potentials, which can be modified in the presence of a small background DC electric field [2]. However, no work has considered the combination of the AC Stark effect of the excitation laser and multi-pole interactions on the preparation of excited Rydberg atoms through Rydberg atom pair production.

In this experiment, we report the observation of atomic population in the nP state after the excitation of nS Rydberg atoms in a Rb magneto-optical trap (MOT). The observed nP population is quadratically dependent on the nS atomic density for 29 ≤ n ≤ 37. Such a result would naturally be attributed to binary collisions; however, the interaction between Rb nS atoms is repulsive. In order to explain our results, we need to consider the influence of the AC Stark effect and multi-pole interactions on a two-photon Rydberg molecular excitation. Briefly, the multi-pole interactions cause an admixture of nS + nS character into the nP + (n − 1)P pairs. The Autler-Townes effect from the laser pulse shifts the intermediate state, 5P + nS, into resonance with nP + (n − 1)P leading to excitation.

In fig. 1, we show the time resolved electron signal for 32S, 32P and 31P after the 32S excitation. The population transfer from 32S to 32P is about 2.8%. We compare our results to calculations done by numerically solving the density matrix equations for a two-photon excitation of the nP + (n − 1)P pair state at 0.55 < R < 1.8 µm. This leads to an estimated 32P to 32S signal ratio of 3.9%, which is in excellent agreement with the experimental value. The principal quantum number dependence of nP/(nS)² population was also measured, and it was shown to be consistent with our model.

Our findings may have important implications for the excitation of high n Rydberg states for quantum computation, since this effect leads to the excitation of undesirable Rydberg states that can cause decoherence and the reduction of the collective Rabi frequency. We also believe that the control of electric field effects with regard to Rydberg atom interactions is important in order to use these novel and interesting systems for dipole blockade and quantum computation.

Fig. 1. Time resolved electron signal for 32S, 32P and 31P after the 32S excitation.

References

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