Three-Body Förster Resonances in a Few Interacting Rb Rydberg Atoms

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Three-body Förster resonances at long-range interactions of Rydberg atoms were first predicted and observed in Cs atoms [1]. In these resonances, one of the atoms carries away an energy excess preventing the two-body resonance, leading thus to a Borromean type of Förster energy transfer. The experiment in [1] was done with an ensemble of $\sim 10^5$ Cs atoms in an interaction volume of $\sim$200 μm in size. Therefore, the three-body Förster resonance was in fact observed as the average signal for the large number of atoms $N \gg 1$.

In this report we present the first experimental observation of the three-body Förster resonance $\mathrm{Rb}(nP_{3/2}) + \mathrm{Rb}(nP_{3/2}) \to \mathrm{Rb}(nS_{1/2}) + \mathrm{Rb}([n+1]S_{1/2})$ for a few Rb Rydberg atoms with n=36, 37. In our experiment, N=2-5 Rydberg atoms in the initial $nP_{3/2}$ Rydberg state interact in a single volume of $\sim$20-30 μm in size. This volume is formed at the intersection of the two tightly focused laser beams that excite Rydberg states at the center of the cold Rb atom cloud in a magneto-optical trap [2]. Using the selective field ionization technique with the detection efficiency of 70%, the measured Förster resonance spectra are post-selected over the number of the detected Rydberg atoms N=1-5 [3] and then additionally processed to extract the true multi-atom spectra taking into account finite detection efficiency. The spectra represent the measured dependence of the fraction of atoms in the final $nS_{1/2}$ state on the applied dc electric field, which controls the Förster resonance detuning, for various N.

Figure 1 shows the Stark-tuned Förster resonance in Rb atoms observed for N=2-5. In Fig.1(a) the atoms are in the initial state $37P_{3/2}(|M_J| = 1/2)$. The main peak at 1.79 V/cm is the ordinary two-body resonance that occurs for all N=2-5 [2-4]. The additional peak at 1.71 V/cm is the three-body resonance that is absent for N=2 and appears only for N=3-5.

The feature at 1.71 V/cm can in principle be caused by the imperfection of the electric-field pulses used to control the Förster resonance [4]. In order to check for this effect, the resonance has also been recorded for the atoms in the initial state $37P_{3/2}(|M_J| = 3/2)$, as shown in Fig.1(b). Here we see again that the main peak at 2.0 V/cm is the ordinary two-body resonance that occurs for all N=2-5. The additional peak at 2.14 V/cm is the three-body resonance that is absent for N=2 and appears only for N=3-5. We conclude that the three-body resonances really take place, as their positions and behavior well agree with theoretical calculations.

As a result, we have found clear evidence that there is no signature of the three-body Förster resonances for exactly two interacting Rydberg atoms, while it is present for the larger number of atoms. As the observed three-body resonance appears at the different dc electric field with respect to the two-body resonance (the difference increases for the lower n [1], and we have checked for it at n=36), it represents an effective three-body operator, which can be used to directly control the three-body interactions. This can be especially useful in quantum simulations and quantum information processing with neutral atoms in optical lattices.

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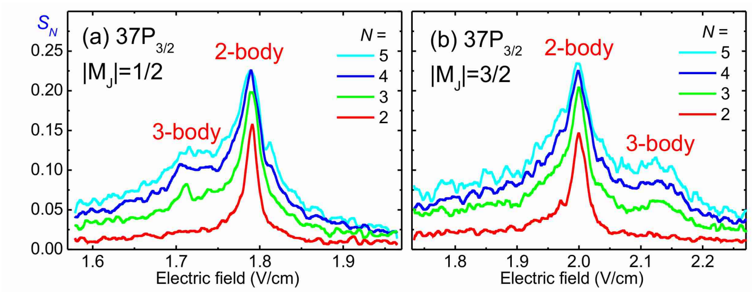

Fig. 1: Förster resonance in Rb Rydberg atoms observed for various numbers of atoms N=2-5: (a) in the initial state $37P_{3/2}(|M_J| = 1/2)$; (b) in the initial state $37P_{3/2}(|M_J| = 3/2)$.

References

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