Few-body interactions in cold Rydberg gases

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Observing the transition between 2-body and many-body physics in complex systems is challenging because it is difficult to isolate few-body interactions from many-body interactions. Cold Rydberg atoms, which are known for their strong interaction properties [1], constitute in this prospect an interesting system to study many-body physics. In our set-up in Laboratoire Aimé Cotton, we have succeeded [2] to isolate a 4-body interaction process appearing as a specific resonance of energy exchange between Rydberg atoms:

$$4 * 23p_{3/2} \rightarrow 2 * 23s_{1/2} + 23p_{1/2} + 23d_{5/2}, \qquad (1)$$

resonant at an electric field of ~80.0 *V/cm*. The appearance of the $23d_{5/2}$ state was a key signature for observing this process. This achievement was possible due to the proximity of two separate 2-body Förster [3] resonances:

$$2 * 23p_{3/2} \rightarrow 23s_{1/2} + 24s_{1/2}, \qquad (2)$$

$$2 * 24s_{1/2} \rightarrow 23p_{1/2} + 23d_{5/2}, \qquad (3)$$

resonant at electric fields of ~79.95V/cm and ~80.4V/cm respectively.

Because it relies on the coincidence of these two resonances, this process only works for a specific principal quantum number. Therefore, we are now investigating new 4-body processes involving Rydberg atoms initially in different Zeeman sublevels, as for example:

$$np_{3/2}, m_{1/2} + 3 * np_{3/2}, m_{3/2} \rightarrow 2 * ns_{1/2} + 2 * (n+1)s_{1/2}, \qquad (4)$$

which is a combination of two resonances, similar to the one presented in Eq. 2. As the magnetic sublevels are always close in energy, this 4-body resonance exists over a large range of principal quantum numbers, which enables the tuning of the 4-body interaction strength. We will also show that this 4-body interaction is better separated from the 2-body interactions and could thus be applied without enhancing much the 2-body interactions.

Finally, we will present prospects firstly on the possibility to observe higher order terms (6 or more-body interactions) and secondly on RF-assisted or micro-wave assisted resonances, which should enable the design of new N-body interaction schemes from a single initial Rydberg state.

These few-body interactions are an interesting path to study the transition between 2-body interactions and the appearance of many-body properties in a complex system. They may also help designing 4-atom quantum gates or provide a means for the preparation of tetramers.

References:
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