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Ordered States in Strongly Interacting Rydberg Gases

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Abstract:

The experimental combination of laser-cooled atomic gases with the well known properties of Rydberg atoms has led to a new field of research, typically subsumed as "Frozen Rydberg Gases". We have extended these systems to magnetically trapped samples of much higher densities and much lower temperatures. This approach revealed during the last three years a variety of new physical phenomena, from which I will present two findings in some detail.

First I will report on the observation of ultra long-range molecules bound by low energy scattering of Rydberg electrons from polarisable ground state atoms. This novel binding mechanism leads to well defined internuclear separations of some thousand Bohr radii. Rydberg states between 34S and 40S are excited in a dense cloud of magnetically trapped Rubidium and the resulting excitation spectra give a clear evidence for dimer as well as trimer molecules in the vibrational ground states and vibrational excited states. The measured binding energies coincide very well with theoretical calculations taking into account s- and p-wave scattering. The low energy s-wave electron scattering length of a Rubidium atom with an electron could be determined precisely. Comparison of the lifetimes for the pure Rydberg state and the molecular dimer state show a decreased lifetime of the molecular state, which is presently sudied in some more detail. Further we have investigated the coherence properties of the excitation dynamics by a rotary echo experiment for the dimer states and compared it to the results for atomic Rydberg states.

In the second part I will report on the observation of a universal scaling behavior near a quantum critical point in a gas of strongly interacting Rydberg atoms. The experiments are performed, as in the case for the molecules, with a dense cloud of magnetically trapped atoms, but now resonantly driven into a Rydberg state. Due to the strong van-der-Waals interaction and the high number density, the excitation dynamics into Rydberg states is strongly blocked. We have observed in this regime coherent and collective excitation dynamics. By applying universal theories to the experimental data, we find that all data collapse to universal scaling functions in one single dimensionless parameter. Such a behavior is expected in the vicinity of a quantum critical point and the existence of a quantum phase transition in such systems has already been predicted theoretically. With our results at hand it will be now possible to investigate this new kind of quantum phase transition in some more detail.