Interactions of laser-cooled atoms in a high-magnetic-field atom trap

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We are investigating highly magnetized, cold Rydberg-atom gases and magnetized plasmas. In our experiments, we use a particle trap that operates at magnetic fields up to 6 Tesla and that can simultaneously function as a ground-state atom trap, Rydberg-atom trap and nested Penning ion and electron trap. Ground-state ^{85}Rb atoms that have been laser-cooled and collected in the trap are laser-excited into clouds of magnetized Rydberg atoms or cold plasmas. The combination of low temperatures, strong magnetic fields, and substantial collision rates leads to a rich variety of atomic and plasma processes, such as Rydberg-atom-electron collisions and three-body recombination. Our studies relate to the physics of atoms and plasmas in astrophysical environments, in magnetized man-made plasmas, and in anti-hydrogen research.

Recently, we have demonstrated the trapping of a strongly-magnetized two-component cold plasma of ^{85}Rb$^+$-ions and electrons in a nested Penning trap at a background field of 2.9 T, particle densities up to 10^7cm^{-3}, and particle numbers up to 10^6. Electrons remained trapped in this system for several milliseconds. The trap loss results from $\mathbf{E} \times \mathbf{B}$ drift, and is well understood. Early in the evolution, the dynamics are driven by a breathing-mode oscillation in the ionic charge distribution, which modulates the electron trap depth. The modulation in electron-trap depth causes a periodic electron "shake-off" signal, which can be observed. The shake-off signal exhibits reproducible structures that develop with increasing density; we believe that these structures are a manifestation of plasma waves. Over longer time scales, the electronic component undergoes significant cooling; the origin of the electron cooling is under investigation.

At higher Rydberg-atom or plasma densities, collisions and / or recombination lead to the formation of atoms in gyration-center states, which exhibit distinct cyclotron, bounce and magnetron motions of the Rydberg electron. These drift-state atoms have large z-components of the angular momentum, high densities of states, and long lifetimes. They are well-suited for magnetic trapping, as has recently been demonstrated in this project. Trapped Rydberg atoms can be used to measure atomic properties such as polarizabilities, cyclotron quantum numbers, and decay rates.

In studies of low-angular-momentum Rydberg atoms directly excited by high-resolution lasers, we are interested in coherent single-atom dynamics and in coherent interactions in many-body Rydberg-atom systems. Coherent effects of the internal motion include spin oscillations of the Rydberg electron induced by spin-orbit coupling. We report on our first high-resolution ($<$ 5MHz linewidth) spectroscopic studies of laser-cooled atoms in strong magnetic fields, at energies below and above the absolute photo-ionization threshold.