JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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SPP 1929 – PhD Tutorials

22. Mai 2017, 10:30 Uhr

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Field metrology with Rydberg atoms
High-precision measurements with Rydberg atoms
Giant Rydberg molecules and Rydberg-atom imaging

Field metrology with Rydberg atoms

The response of atomic quantum systems to external fields is of interest both in field-sensing applications and in fundamental physics. Due to their weak atomic binding, highly excited Rydberg atoms exhibit a particularly strong response to perturbations, such as external RF and magnetic fields. Topics of current studies include the design of calibration-free sensors for electric and magnetic fields that are based on invariable atomic theory. From a fundamental-physics point of view, Rydberg atoms in strong RF or magnetic fields are of interest because their classical counterparts exhibit chaotic dynamics.
In this talk, an overview is given over approaches to employ electromagnetically-induced transparency to map Rydberg-level structures in strong microwave and magnetic fields. For microwave fields, a non-perturbative Floquet analysis is used to model the field-induced level-shifts, the state-mixing effects and the Floquet-state excitation strengths of the strongly driven system. Calculated Floquet spectra are employed to derive the microwave-field distribution present in the measurement volume. The method allows for high spatial resolution is also applied to fields in the 100MHz-range.

High-precision measurements with Rydberg atoms

The interaction between an atom and a light field is commonly described by an $\mathbf{A}\cdot\mathbf{p}$ and an $\mathbf{A}\cdot\mathbf{A}$ term. Here, a novel approach to Rydberg atom trapping and high-precision atomic spectroscopy is introduced. There, the $\mathbf{A}\cdot\mathbf{A}$ interaction gives rise to a ponderomotive trapping potential, a new paradigm of optical-lattice atom traps specifically suited to Rydberg-atom trapping. The same term can also be employed to drive microwave transitions of Rydberg atoms trapped in an optical lattice. This is achieved owing to the strong spatial variation of the lattice intensity within the volume of the atom, and by amplitude-modulating the lattice intensity in time at the atomic transition frequency [1]. Selection rules in this type of spectroscopy are greatly relaxed in comparison with standard optical selection rules, allowing access to previously forbidden transitions [2, 3]. More recently, we have driven transitions at higher harmonics of the drive; this provides convenient access to sub-Terahertz transitions between Rydberg levels [4]. Further, we have shown that optical-lattice Rydberg atom traps support “magic” transitions [4]. Related, recent measurements of g-state quantum defects and the polarizability of the Rb^+ ion will also be discussed.

In a second experiment on Rydberg atoms in an optical lattice, we employ doubly-resonant two-photon excitation into the 74S Rydberg state to spectroscopically measure the dynamic scalar and tensor polarizabilities of the rubidium $5P_{3/2}$ level [5]. To reach the necessary high intensities, we employ a cavity-generated 1064-nm optical-lattice light field, allowing us to obtain intensities near $2x10^{11}$ W/m^2. In the evaluation of the data we use a self-referencing method that renders the polarizability measurement largely free from the intensity calibration of the laser light field. We obtain experimental values of -1149 +/- 2.5% and 563 +/- 4.2% for the scalar and tensor parts, in atomic units. These results serve as an experimental test for validating theoretical models for the polarizability, which are needed, for instance, to characterize black-body shifts in optical atomic clocks [6] and to interpret atomic parity non-conservation experiments [7,8].

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Giant Rydberg molecules and Rydberg-atom imaging

Cold atomic systems have opened new frontiers at the interface of atomic and molecular physics. These include research on novel types of Rydberg molecules. In this talk, three types of molecules will be reviewed. Long-range, homonuclear Rydberg molecules, first predicted in [1] and observed in [2], are formed via low-energy electron scattering of the Rydberg electron from a ground-state atom that is present within the Rydberg atom's volume. The binding mostly arises from S-wave and P-wave triplet scattering. In the presented analysis [3,4,5] we use a Fermi model that includes S-wave and P-wave singlet and triplet scattering, the fine structure coupling of the Rydberg atom and the hyperfine structure coupling of the $5S_{1/2}$ atom (in rubidium). In the talk I will further discuss ultra-long-range Rydberg-Rydberg molecules of Rb and Cs. These molecules, which have even larger bonding length than Rydberg-ground molecules, are formed via electrostatic multipole interactions. The leading interaction term of neutral Rydberg-Rydberg molecules is between two dipoles, with a scaling ~ bond length^(-3), while for ionic Rydberg molecules it is between a dipole and a monopole, which has a scaling ~bond length^(-2). Experimental methods that allow the direct spatial imaging and mapping of such molecules will be discussed.

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