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Scope of Research

Atoms, nuclei, and dark matter particles in the Universe are studied with quantum electronic methods: Current research subjects are 1) search for a cosmological dark-matter candidate particle, axion, in the Universe with the Rydberg-atom cavity detector, 2) highly excited Rydberg atoms in an electric field and their applications to fundamental physics research, and 3) nuclear magnetism in 3-5 semiconductors with laser-assisted Overhauser process and optical pumping.

Research Activities (Year 2001)

Presentations

Coherent time evolution of highly excited Rydberg states in pulsed electric field, Tada M, Kishimoto Y, Kominato K, Shibata M, Ooishi C, Yamada S, Saida T, Funahashi H, Yamamoto K, and Matsuki S, Spring Meeting, Phys. Soc. Jpn., Tokyo, 24 March.

Radiative transitions in highly excited Rydberg states detected with the field ionization method, Kishimoto Y, Tada M, Shibata M, Kominato K, Funahashi H, Yamamoto K, and Matsuki S, Spring Meeting, Phys. Soc. Jpn, 24 March.

Grant

Matsuki S, Search for Dark Matter Axions, Grant-in-Aid for Specially Promoted Research(2), 1 April 1997 - 31 March 2003.

Topics

Stark structure and field ionization characteristics of highly excited Rydberg states

Rydberg atoms have been widely utilized for fundamental physics research [1,2]. Highly excited Rydberg states with the principal quantum number *n* larger than 80, however, have not been investigated in detail, partly because it is more difficult to detect selectively a particular state. We developed a quite sensitive method to detect selectively a low-angular momentum state with a newly developed field ionization method in a pulsed electric field [3]. With the new detection method, we investigated systematically the characteristics of the pulsed field ionizations in the highly excited Rydberg states. It was found that in these highly excited Rydberg states, the ionization processes proceed in two ways, that is, via 1) tunneling, and 2) autoionization-like processes. Indeed as shown in Fig.1, field ionization spectrum shows, in general, two peaks which are due to the two processes mentioned above. Lower peak is due to the autoionization-like process, while the higher peak corresponds to the ionization due to the tunneling process. The relative strength of these peaks depends on the related *n* and the slew rate and detailed pulse shape of the applied electric field. The tunneling process dominates with increasing *n* because the interactions of the bound blue state with the unbound red states coming from the higher excited *n* states, are responsible for the autoionization-like process of the bound blue state and these interactions become weaker as *n* increases.

Along with these investigations, we have developed a quantum theoretical method to calculate the Stark map of the highly excited Rydberg states based on the Hamiltonian diagonalization. Various experimental parameters then have been numerically calculated with the obtained eigenstates . Quantum theoretical predictions for the ionization field values from both processes together with the experimental results are shown in Fig.2. Here the Rydberg states in the n=117 manifold were excited with two-step laser excitation scheme and the field ionization values corresponding to each peak are plotted in the figure. Agreement between the experimental and the calculated results are good, indicating that the present theoretical method is quite satisfactory to predict various experimental observations even for such highly excited Rydberg states in alkali atoms.

Adiabatic and non-adiabatic transition probabilities at the first avoided crossing of $113p_{3/2}$ state with the 110 manifold states were also measured with the new selective field ionization method. To compare the experimental results with theoretical predictions, we have developed a new formalism to calculate the time evolution of the multi-level Rydberg system in the pulsed electric field. The theoretical results are in good agreement with the experimental results, thus indicating also the present theoretical method is quite satisfactory for predicting the time evolution of such highly excited Rydberg system in the time varying electric field and also for calculating the various experimental parameters such as an energy gap bewteen the relevant states in avoided crossings.

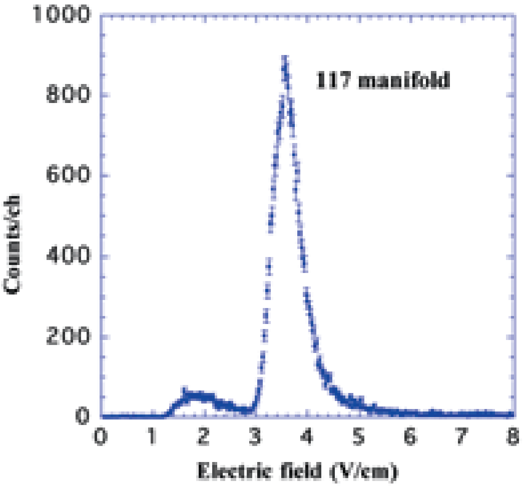

Figure 1. Typical field ionization spectrum of 117 manifold states observed with the present selective ionization scheme in the pulsed electric field.

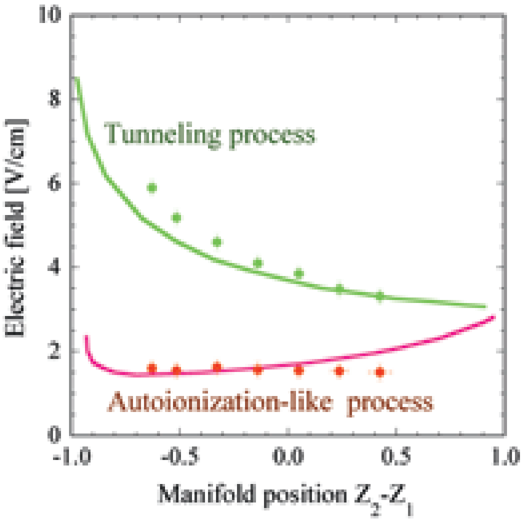

Figure 2. Field ionization values of 117 manifold states which correspond to the two peaks observed in the spectra: Z2-Z1=-1 for the bluest state, =+1for the reddest state. The higher peak is due to the tunneling process, while the lower peak corresponds to the ionization from the autoionization-like process. Solid and dashed lines are the predictions from the present theoretical calculations.

1. T. F. Gallagher, *Rydberg atoms* (Cambridge University Press, Cambridge, 1994).
2. I. Ogawa, S. Matsuki and K. Yamamoto, Phys. Rev. **D53** (1996) R1740, and references cited therein.
3. M. Tada, Memoirs of the Faculty of Science, Kyoto University, Series of Physics, Astrophysics, Geophysics and Chemistry, Vol.**43**, in press; M. Tada et al., LANL Preprint archive, Physics/0010071.