Attempt to measure relaxation time of atomic bubble surrounding alkaline atoms in superfluid helium

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Our research group has been developing a new type of nuclear laser spectroscopy method named OROCHI, which is based on laser spectroscopy of atoms in superfluid helium (He II). In this method, the presence of the interaction between injected atoms and surrounding helium atoms plays an important role to prepare a unique spectroscopic environment. In this study, we focus on the structure of the atoms surrounded by He.

When the atoms are introduced into He II, the surrounding helium atoms are pushed out by the exchange (Pauli) repulsion force.[1] The resulting vacuum region is called "atomic bubble." For the electronic ground state of the introduced atom, the bubble typically has a radius of 5 ∼ 10 Å. When the shape of the electron orbit of the atom changes owing to a state transition such as excitation and absorption, it is considered that atomic bubble is also deformed in He II as the shape of the orbital deforms.

Figure 1 shows the deformation process of the atomic bubble. Because the Franck-Condon principle holds true in the process of absorbing and releasing photons, the radius of the bubble is kept constant before and after the transitions. Therefore, after these short time transitions, the bubble is affected by the electron orbit of the introduced atom and deforms (relaxes) over a certain time. It is known that the wavelengths of atoms in He II shift between absorption and emission owing to this process.[2] It is estimated that it takes an order of a few pico seconds to deform the bubble but so far the relaxation time has not been measured in the time domain. To clarify the dynamics of the atomic bubble system, we will combine the laser spectroscopic technique in He II and the ultrafast laser spectroscopic technique.[3]

In this research, we decided to start with Rb as the target atom of this experiment because its characteristics in He II is well studied.[2,4] We plan to perform experiments using a detection system with a high time resolution for the relaxation time in the excited state.

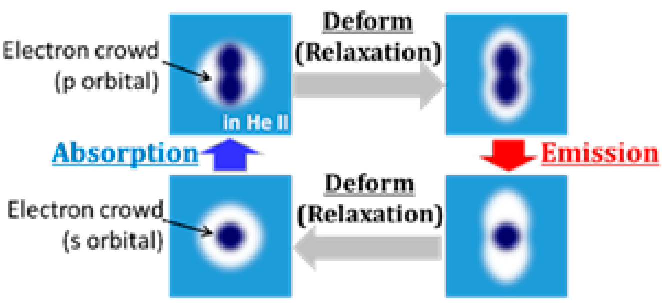

Fig. 1. Deformation cycle of an atomic bubble.

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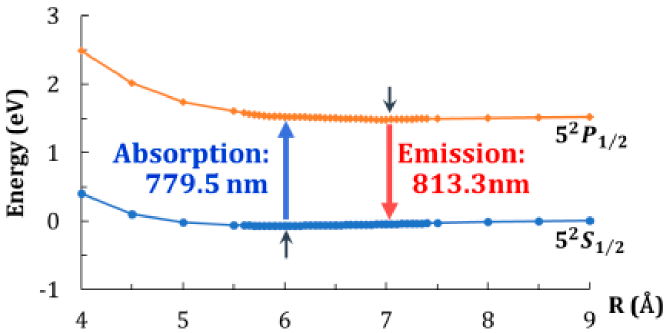

Fig. 2. Energy calculated value of Rb atomic bubble system. (18 helium, Hybrid density functional APF with the basis set Def2TZVPP was used.)

The experiment will be conducted in an offline environment using laser ablation for the introduction of atoms.[4] In the cryostat used for offline experiments, the atoms are supplied by laser ablation and laser dissociation into He II in a quartz cell installed in the upper part of the helium tank. Then, a pumping laser irradiates to Rb atoms in the observation region and fluorescence is observed using the Time-Correlated Single Photon Counting (TCSPC) system. We plan to obtain the time dependence of the intensity of fluorescence using this system that records the time difference between the irradiation of the excitation laser signal and the detection of the fluorescent photon.[5] The time resolution of the system is approximately 80 ps. It is considered that emission also occurs during the deformation process of the bubble to the energy minimum of the excited state. Therefore, if we can observe the intensity changes of fluorescence up to several tens of ns, which is the spontaneous emission lifetime, we can estimate the time required for bubble deformation. Currently, performance evaluation of picosecond pulsed Ti: sapphire laser for excitation is ongoing.

Additionally, in parallel with the preparation of the experiment, we calculated atomic energy levels using Gaussian 09 to estimate the amount of wavelength change due to the relaxation of atomic bubbles. The calculation of the energy of the atomic bubble formed by 18 helium atoms resulted in the confirmation of the broadening of the bubble radius and shifts in the atomic transition energy (Fig. 2). Besides, we will derive the influence due to the increase of the number of He atoms for bubble formation and simulate the case for other atoms such as Cs.

References

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