Hyperfine structure measurement of ^{133}Cs atoms in superfluid helium

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The study of nuclear structure via laser spectroscopy techniques has contributed to significant progress in nuclear physics[1)]. To extend the applicability of laser spectroscopy techniques for the study of low-yield exotic nuclei whose production rate is less than 100 pps, we have been developing OROCHI (Optical RI-atom Observation in Condensed Helium as Ion-catcher)[2)]. OROCHI is based on a combination of superfluid helium (He II) as an effective stopper for high-energetic ion beams and in situ laser spectroscopy of atoms. In OROCHI, an energetic ion beam produced at an accelerator facility is directly injected into He II. The injected ions are neutralized during the stopping process and are trapped as isolated atoms. The trapped atoms are subjected to a circularly polarized laser light and driven to the spin polarized state. The Zeeman/hyperfine splittings (ZMS/HFS) of atoms are measured using a laser-RF/MW (radio-frequency/microwave) double resonance method to deduce nuclear spins and moments. So far, a series of experiments using the $^{84\text{-}87}$Rb ion beam have been performed at the RIKEN Nishina Center. The feasibility of the principle of OROCHI has been successfully demonstrated by measuring the ZMS of $^{84\text{-}87}$Rb[3)]. For further development of OROCHI, it is indispensable to ensure the applicability of OROCHI for the measurement of HFS of atoms in He II. In particular, the following two issues have to be confirmed i) How the He II environment affects the HFS of an introduced atom, and ii) What is the highest level of measurement accuracy that can be achieved. To investigate the above mentioned issues, we conducted an experiment using ^{133}Cs atoms that are introduced into He II using the laser ablation technique.

The experimental setup is similar to the one in ref.[4]. An open-topped quartz cubic cell (70 × 70 × 70 mm^3) filled with He II liquid was placed inside the cryostat. A solid CsCl was placed approximately 1 cm above the liquid surface. In this experiment, Cs atoms were introduced into He II using two pulsed lasers[4)]. The introduced Cs atoms were pumped into the spin polarized state using circularly polarized laser tuned to the D1 transition line of Cs atoms in He II (876 nm)[5)]. In this experiment, several gauss of static magnetic field was applied to the trapped atoms using a pair of Helmholtz coils to maintain spin polarization. To observe HFS resonance of Cs atoms, MW was irradiated to the spin polarized Cs atoms and its frequency was scanned. The emitted laser induced fluorescence (LIF) during the scanning of MW frequencies was detected using a photomultiplier tube. To suppress stray light from the laser beam, the wavelength of LIF (892 nm)[5)] was selected using a monochromator. Figure 1 shows the obtained spectra in this experiment. We can clearly observe the resonance peaks in the figure. Since the resonance frequencies are shifted by ZMS owing to the applied magnetic field, the resonance frequencies are measured for both cases i.e., using σ^+ and σ^- polarized lasers. The HFS of Cs atoms in He II is calculated by averaging the two measured resonance frequencies. We obtain the preliminary value of 9 250.58(2) MHz as the HFS of Cs atoms in He II. This result shows that the HFS of Cs atoms in He II is approximately 0.63(2) % larger than that in vacuum owing to the effect of the surrounding helium. The achieved measurement accuracy is 6 digits in the current system. Since the accuracy of the HFS of Cs atoms in He II is limited owing to the fluctuation in the intensity of the applied magnetic field, it can be improved by one or two orders of magnitude by installing stabilized power supply for the magnetic field. In the near feature, we will conduct systematic measurement of HFS using $^{84\text{-}87}$Rb to demonstrate the feasibility of OROCHI for the study of low-yield exotic nuclei.

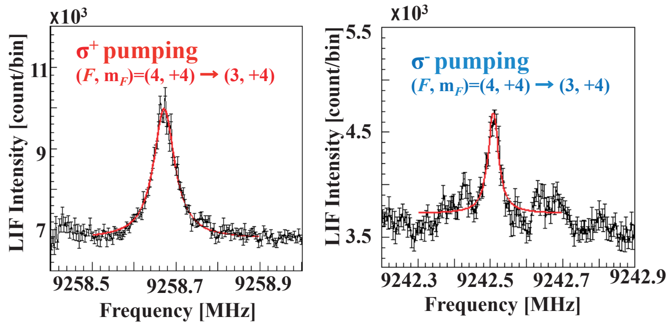

Fig. 1. Observed spectra in this experiment. (a) when using the σ^+ pumping laser. (b) when using the σ^- pumping laser.

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