Absolute optical absorption cross-section of Rb atoms injected into superfluid helium using energetic ion beams†

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An in-situ laser spectroscopy method utilizing atomic impurity in superfluid helium (He II) has been developed for the application of nuclear structure study of rare-isotopes. The method is named Optical RI-atom Observation in Condensed Helium as Ion-catcher (OROCHI). The key feature of the technique is that the center wavelengths of the absorption spectra of atoms in He II are largely blue-sifted from those of emission spectra. The feature is significantly advantageous for the detection of fluorescence signals from atoms in He II with ultra-low background. Moreover, He II works as an effective stopper for highly energetic ion beams. The stopping efficiency of He II reaches nearly 100% for the beam energy of several tens of MeV/nucleon. Considering the above reasons, OROCHI has proven to be an efficient method for the study of nuclear structure of low production yield rare-isotopes. We have demonstrated the feasibility of OROCHI using $^{84–87}$Rb ion beams with up to 66 MeV/nucleon energy and 10^4 pps intensity, so far.[1)] However, unexpected laser stray light limits the signal detection sensitivity. To efficiently separate the signal from background, we developed a new fluorescence detection system (FDS) that realizes low background signal detection using double monochromator. The first demonstration of the new FDS was performed using ^{85}Rb^{31+} ion beam delivered from RIPS. We deduced the optical absorption cross-section from the result of fluorescence intensity dependence on beam intensity and applied laser power.

The experimental setup was the same as that in Ref. 2). A 66 MeV/nucleon ^{85}Rb ion beam was passed through two aluminum energy degraders to adjust the stopping position in He II. During beam stopping position adjustment using various degraders thickness, we confirmed that the injected ions were stopped within 1 mm injection depth. The energy degraded ion beam was introduced into He II. Rubidiums that were diffused from the observation region with approximately several hundred miliseconds after stopping in He II were subjected to a laser light from the Titanium sapphire laser (780 nm, $\phi \approx 2$ mm). The laser induced fluorescence (LIF) from Rb atoms was focused on the optical fiber bundle with an entrance of 5×2 mm^2 using the lens unit of the FDS. The LIF guided using the optical fiber bundle was introduced into the double monochromator. Rb D1 emission light (793 nm in He II) was selected using the double monochromator and detected using a photo-multiplier tube.

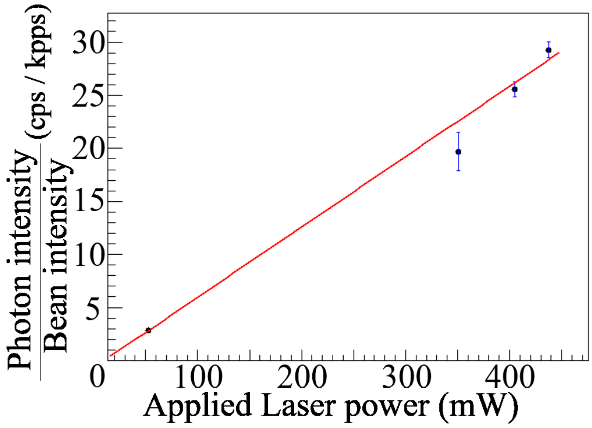

Fig. 1. Measured fluorescence intensity dependence normalized by injected beam intensity.

The measured LIF dependence on beam intensity and applied laser power is shown in Fig. 1. The vertical axis was normalized by the beam intensity and the horizontal axis shows the applied laser power. The observed LIF intensity I_{LIF} was obtained using the equation $I_{\mathrm{LIF}} = N_{\mathrm{obs}}\, \sigma\, \Phi_{\mathrm{Laser}}\, \epsilon_{\mathrm{det}}$, where N_{obs}, σ, Φ_{Laser} and ϵ_{det}, denote the number of atoms in the observation region, optical absorption cross-section, photon flux of the laser, and detection efficiency of FDS, respectively. N_{obs} was estimated from the beam intensity I_{beam} and diffusion time of Rb atom. Φ_{Laser} was proportional to the applied laser power P_{Laser}. Thus, the equation for normalized LIF intensity $I_{\mathrm{LIF}}/I_{\mathrm{beam}}$ can be written as a function of P_{Laser}. The value of $\epsilon_{\mathrm{det}} \approx 10^{-7}$ obtained from the result of experiment using Rb enclosed gas cell was used for the deduction of σ. As a result of our analysis, we deduced $\sigma = 3.59(16) \times 10^{-15}$ cm^2 as the optical absorption cross-section of Rb in He II. The successful derivation of the quantitative value attributes to the improvement of detection efficiency by two orders of magnitude using the new FDS, as compared to previous work.[1)] We conclude that 200 pps is a sufficient ion beam intensity to detect LIF from Rb atoms in He II in accordance with our experimental result.

References
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