Offline collinear laser spectroscopy of barium II toward measurement of RIs at SLOWRI facility

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The laser spectroscopy of atomic transitions is sensitive to nuclear structures in ground or metastable states. In particular, the measurement of isotope shifts and hyperfine splittings by collinear laser spectroscopy has been a powerful tool to study RIs. Charge radii, quadrupole deformation, and electromagnetic moments have been elaborately measured at ISOL-type facilities such as ISOLDE at CERN. However, the available nuclei are limited by chemical properties and lifetime with the ISOL technique. On the other hand, the gas cell decelerator facility, SLOWRI,[1] which is being developed in RIKEN, will supply low-emittance and low-energy RI beams including refractory elements and short-lived ($\gtrsim$10 ms) nuclei, which are difficult to obtain from the ISOL-type facility. We are preparing for collinear laser spectroscopy by taking advantage of slow RI beams delivered from SLOWRI.

As a test of the system for collinear laser spectroscopy, we performed the spectroscopy of barium ions. Barium was chosen because its ion production is relatively easy and an existing dye laser is capable of inducing one of the strong transitions, $5d\,^2\mathrm{D}_{5/2}$-$6p\,^2\mathrm{P}_{3/2}$ (614 nm). A surface ionization source was constructed to obtain Ba^+ based on the design previously used at JAEA.[2] Barium oxide was heated up to approximately 2000 K and a few nA of Ba^+ were constantly produced. It was extracted at 10.5 keV, focused by electrostatic lenses, isotope-separated by a magnet, and focused again to enter an observation region. A continuous-wave (CW) dye laser (Coherent 899 Ring Laser) with Kiton Red pumped by a solid-state laser (Verdi V10, 6 W) was irradiated collinearly with the Ba^+ beam. The power was $\sim$0.3 mW in the observation region. The laser wavelength was locked at 614.10433 nm by utilizing feedback signals from a wavelength meter (HighFinesse WS-U-10). The full width at half maximum (FWHM) of the laser frequency was $\sim$5 MHz. In the observation region, the velocity of ions was changed using a set of electrodes. When the velocity was tuned according to the Doppler shift, the ion was at resonance, and spontaneous emission from $6p\,^2\mathrm{P}_{3/2}$ to $6s\,^2\mathrm{S}_{1/2}$ (455 nm) successively occured. This fluoresence signal was detected by a photomultiplier (Burle 8850). The quantum efficiency of the photomultiplier was about 20% at 455 nm, but the efficiency was less than 1% at 614 nm. Therefore, this measurement is almost free of background counts due to stray laser light. Figure 1 shows the count rate of the fluoresence signal as a function of the voltage applied to the Doppler-shift-tuning electrodes. Isotope shifts and hyperfine splittings for $^{135,137}\mathrm{Ba}^+$ with the nuclear spin $I = 3/2$ were successfully observed.

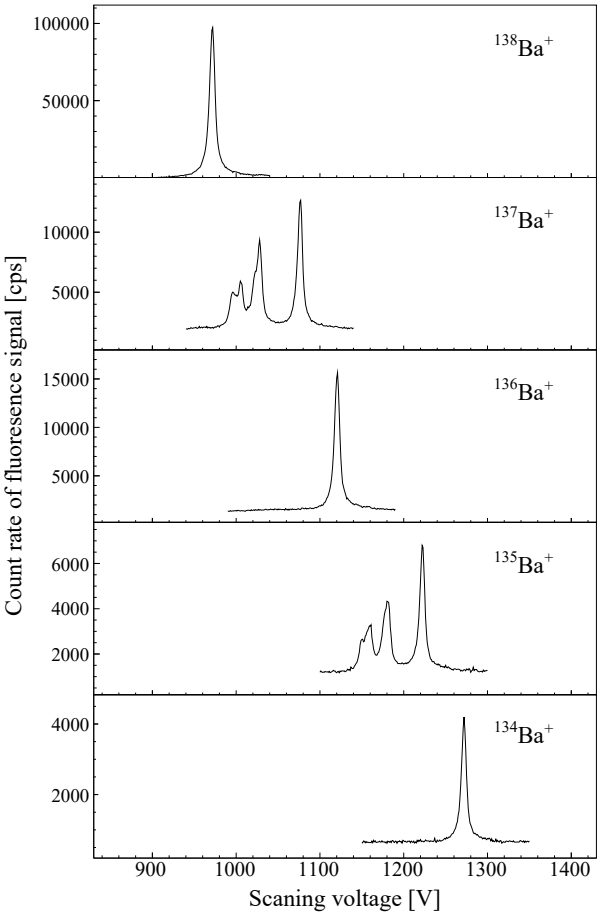

Fig. 1. Resonance spectra for the isotopes $^{134-138}\mathrm{Ba}^+$ showing the transition $5d\,^2\mathrm{D}_{5/2}$-$6p\,^2\mathrm{P}_{3/2}$.

Trajectory simulations suggest that the resonance spectrum becomes asymmetric due to misalignment of the laser and ion beams, which can be a main systematic error. Detailed analysis is ongoing. We plan to introduce a fine-tuning system of alignment before online measurement.

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