Development of ion trap system for the neutralizer toward production of spin-polarized RI beam using atomic beam magnetic resonance method

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Spin-polarized radioactive isotope (RI) beams have been used for the measurements of nuclear electromagnetic moments and spins to investigate nuclear structure. In many experiments, the polarization of nuclear spin is generated via a projectile fragmentation reaction. Although the reaction mechanisms have been well studied so far, the achievable spin polarization is typically as low as several percentage points.[1)] Laser optical pumping can realize spin polarization of greater than a few tens of percentage points, but the method is element-limited. A highly efficient and universal method for producing spin-polarized RI beams is desired. For this purpose, we are developing a spin-polarized beam production apparatus using the atomic beam magnetic resonance (ABMR) method. In the method, the spin polarization of neutral atomic beams is generated by two-step spin selection using multi-pole magnets and magnetic resonance. The efficient production of a thermal energy neutral RI atomic beam is significantly difficult from a technical perspective, although the ABMR method itself is one of the conventional methods for investigating spin-related nuclear properties of nuclei near the stability region.[2)] To overcome this difficulty, we propose a new ion neutralizer which, combines ion trapping with the laser cooling technique. The main feature of the neutralizer is that it traps and cools RIs produced by nuclear reactions to decrease the beam energy.

In the system, we first prepare laser-cooled ions in a linear Paul trap. RI ions of several eV are introduced to the trap region of the laser-cooled ions and trapped using He buffer gas cooling. The trapped RI ions are sympathetically cooled down through Coulomb interaction between laser-cooled ions and the RI ions. After cooling, a neutralization gas (*e.g.*, N_2, NH_3, and so on) is blown against the RI ions. Subsequently, neutral atoms are produced by charge-exchange interaction. For the efficient extraction of the neutral atoms, we apply a swing field in the beam-propagation direction to move trapped RI ions back and forth prior to the neutralization.

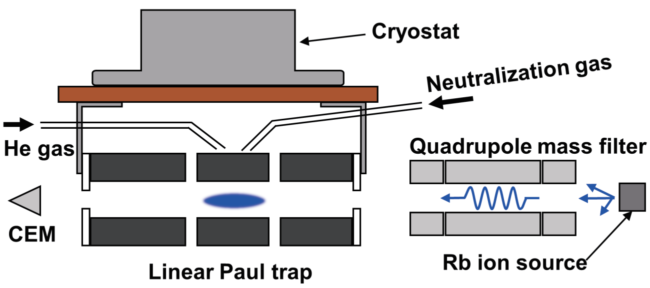

Fig. 1. Schematic diagram of the setup.

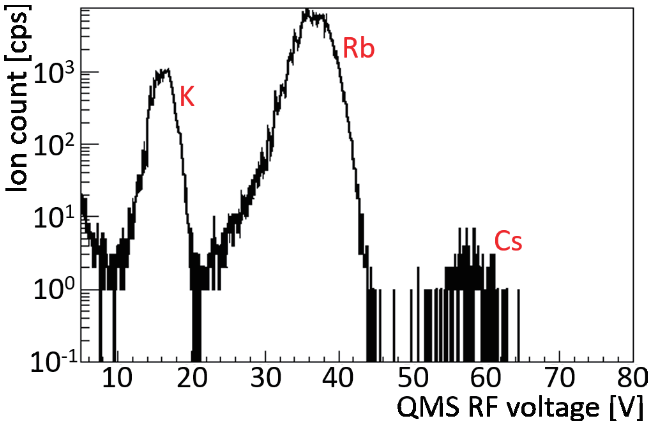

Fig. 2. Mass spectrum obtained downstream of the linear Paul trap.

In order to develop the proposed neutralizer, we initiated an offline R&D experiment using Rb by constructing a linear Paul trap system and quadrupole mass filter (QMF) for selecting ions that are introduced to the trap region. The experimental setup for the R&D experiment is shown in Fig. 1. Rb ions emitted from a surface-ionization ion source were guided to a linear Paul trap after mass selection by a QMF. The electrodes of the trap were assembled at the head of the cryostat, which is used for realizing a sufficient high vacuum to conduct the ion trapping and laser cooling experiment. We achieved a vacuum of $\sim 10^{-8}$ Pa in the current setup. Two gas lines were prepared near the center part of the trap. One is used for introducing He as the buffer gas to perform buffer gas cooling. The other is used for introducing a neutralization gas. A channel electron multiplier (CEM) detector was placed downstream of the trap to detect transported ions.

Toward the Rb ion trap experiment, we conducted an ion transportation test. Figure 2 shows a mass spectrum of the ions transported. The vertical and horizontal axes correspond to ion counts and RF voltages applied to the QMF electrodes, respectively. Three peaks correspond to singly charged K, Rb, and Cs. According to this result, we confirmed that sufficient Rb ions to test ion trapping are guided from the ion source to the trap. We will proceed to the next step of Rb ion trapping. We will then start a neutralization test in the near future.

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References
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