Nuclear Spectroscopy Laboratory

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The Nuclear Spectroscopy Laboratory was started in 2013 in at Nishina Center. In the group, five full-time researchers are working as of 2016 together with the Chief Scientist, including three Research Scientists in the fields of nuclear physics, atomic physics, and materials science as key persons in each field of study. The group has been conducting various spectroscopic studies of radiation and fluorescence emitted from slowed-down or stopped radioactive-isotope (RI) beams produced at the RIBF facility, aiming at the measurement of electromagnetic nuclear properties such as spin, isotope shift, and electromagnetic nuclear moments. In this report, we introduce these studies by roughly categorizing them into three.

The first category comprises nuclear-structure studies utilizing spin-oriented RI beams produced in in-flight nuclear reactions. This research has been conducted successively for generations, and new techniques were developed at the accelerators in RIKEN.

A spin-polarized RI beam at RIKEN was first produced in late 1970 by the experimental group led by M. Ishihara, who was a member of the Cyclotron Laboratory at that time, based on the low-energy quasi-elastic scattering reaction of a heavy-ion beam from the 160-cm Cyclotron.[1)] After the beam energy reached $E/A \sim 100$ MeV with the installation of the RIKEN Ring Cyclotron (RRC), the method was improved in early 1990 by Ishihara and K. Asahi *et al.* in the Radiation Laboratory. The method makes good use of properties of the projectile-fragmentation reaction that is dominant at this beam energy.[2,3)] Here, the RIKEN projectile-fragment separator RIPS[4)] played an important role. This method enabled the production of spin-polarized RI beams far from the β-decay stability line. Thus, systematic ground-state nuclear-moment measurements of light unstable nuclei were conducted from the late 1990s to the 2000s in the Applied Nuclear Physics Laboratory led by Asahi, based on the technique of fragmentation-induced spin polarization combined with the β-ray-detected NMR method. For instance, the isospin dependence of effective charges was first observed in these studies.[5)] Then, the RIBF facility started operation at the end of 2006. Primary beams at RIBF are delivered typically at $E/A = 345$ MeV. At this energy, we have a great advantage in the production yield of RI beams, but we simultaneously encounter difficulties in producing spin polarization owing to the properties of the fragmentation reaction. Instead of spin polarization, we have newly developed a method to produce highly spin-aligned RI beams through the two-step nuclear reaction combined with the dispersion-matching technique[6)] using the BigRIPS in-flight RI separator.[7)] Isomeric-state nuclear-moment measurements are conducted by our group as its application. To extend these observations to the ground states of extremely rare RIs, we are now attempting to develop a new method and apparatus for producing spin-polarized RI beams at RIBF.

The second category comprises nuclear laser spectroscopic studies for stopped/slowed-down RI beams. We have been conducting system development for nuclear laser spectroscopy from the following two approaches in order to realize experiments for rare isotopes at RIBF. One is collinear laser spectroscopy for a large variety of elements using slowed-down RI beams produced via a projectile-fragmentation reaction, which can be achieved only by the universal low-energy RI-beam delivery system, SLOWRI. Thus far, nuclear laser spectroscopy has intensively been conducted at the CERN-ISOLDE facility, taking advantage of quite a narrow momentum spread of low-energy RI beams, although there is an element limitation. The SLOWRI facility, under installation, can deliver such high-quality low-energy RI beams without the elemental limitation because of the difference in the RI production method. We plan to start new measurements of nuclear laser spectroscopy based on this advantageous feature.

The other approach is a new method utilizing superfluid helium (He II) as a stopping medium of energetic RI beams, in which the characteristic atomic properties of ions surrounded by superfluid helium enables us to perform unique nuclear laser spectroscopy. RI ions trapped in He II are known to exhibit a characteristic excitation spectrum significantly blue-shifted compared with the emission one. Consequently, the background derived from the excitation-laser stray light, which often causes serious problems in measurements, can be drastically reduced. This enables us to measure a Zeeman or hyperfine structure splitting with a high sensitivity by applying the laser-RF/MW double resonance method to the trapped atoms.[8)] These R&D studies are conducted under the supervision of Professor Y. Matsuo (Hosei Univ.), Senior Visiting Scientist of our Laboratory.

The last category comprises the application of RI and heavy-ion beams as a probe for condensed matter studies. The microscopic material dynamics and properties have been investigated through the deduced internal local fields and the spin relaxation of RI probes

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based on various spectroscopic studies, aiming at utilization of the RIBF facility in a wide range of research fields of, in particular, materials science. We have already conducted β-NMR/nuclear quadrupole resonance (NQR) spectroscopy, in-beam Mössbauer spectroscopy, and the γ-ray time-differential perturbed angular correlation (γ-TDPAC) spectroscopy in collaboration with Univ. of Electro-Comm., ICU, Tokyo Univ. of Sci., Osaka Univ. among the others. Among them, we note that in-beam Mössbauer spectroscopy using a ^{57}Mn RI beam was developed in the Nuclear Chemistry Laboratory led by F. Ambe.9)

Recently, we started studies on diamond superconductivity by high-density doping through heavy-ion implantation as well as low-density, low-field oxygen NMR/NQR studies utilizing ^{21}O as an RI probe. They are partly conducted together with several Chief-Scientist Laboratories outside the Nishina Center under the framework of a RIKEN competitive interdisciplinary-research budget program.

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