Nuclear Spectroscopy Laboratory
Chief Scientist: Hideki Ueno (D.Sci.)

(0) Research field
CPR Subcommittee: Physics
Keywords:
experimental nuclear physics, accelerator-use experiment, radioactive-isotope beams, radiation measurement, nuclear spin orientation

(1) Long-term goal of laboratory and research background

Atomic nuclei are substances governed by the nuclear forces, and are thus separated from atoms or other macroscopic external substances governed by electromagnetic interactions. However, nuclei interact with the external substances through hyperfine interactions owing to the nuclear spin accompanied with electromagnetic properties. Utilizing the characteristic of the hyperfine interaction, the research group investigates the properties of nuclei, and develops methods to manipulate nuclear spin, through the response of the external substances, or conversely investigates the properties of the external substances using nuclei as microscopic probes. For this purpose, the group has been developing new experimental techniques based on various nuclear spectroscopic methods, aiming at extending nuclear-physics technologies to cross-disciplinary research subjects in, e.g., fundamental physics and materials science.

(2) Current research activities (FY2019) and plan (until Mar. 2025)

We have conducted R&D research of the nuclear spin-oriented RI Beams induced by the fragmentation reaction, and applied the technique to the measurement of nuclear magnetic-dipole (μ) and electric-quadrupole (Q) moments of rare RIs. In FY2019, the μ-moment measurement of a metastable excited (isomeric) state in ^{99}Zr at RIBF was published and press-released. Also, the isomeric-state μ moments of the neutron-rich nuclei ^{124,125}Ag and the ground-state Q moment of ^{21}O were both measured. The measurement of ground-state nuclear moments of RIs has been so far performed combining the technique of fragmentation-induced spin-polarized RI beams with the β-ray-detected NMR (β-NMR) method. Provided that the β-NMR method can be combined with *spin-aligned* RI beams, ground-state nuclear-moment measurements, which have never been performed at RIBF-BigRIPS, will become possible. Its technical development was carried out at the NIRS-HIMAC accelerator facility, where an NMR spectrum was successfully obtained in this scheme (activities mainly at RNC).

This nuclear-reaction-based method has produced many results owing to its advantageous feature of element-independent spin polarization. However, it is difficult to extend the observation to further rare RIs and to other research fields such as materials science and fundamental physics, due to the limited magnitude of polarization. Thus, we are developing new methods/apparatus for nuclear laser spectroscopy (at CPR/RNC) and RI atomic beam resonance spectroscopy (at CPR) that can produce highly spin-polarized RI beams. We aim to complete the system development within the period of the mid-term plan. In FY2019, in the former theme, we constructed a prototype of collinear laser spectroscopy and demonstrated its performance through the observation of the isotope shifts of natural tin isotopes. The system will be finally installed downstream the universal slow RI beam system SLOWRI at RIBF, which is currently being developed jointly with the RNC Instrumentation Development Group. As another approach, we are also developing a nuclear laser spectroscopy system utilizing superfluid He (He II) as a stopping medium of GeV-energy RI beams, taking advantage of the Stokes shift in atoms introduced into He II. In FY2019, we evaluated the performance of a constructed prototype to catch a high-energy heavy-ion beam in a thin layer of He II at HIMAC. Furthermore, in collaboration with the CPR Molecular Spectroscopy Laboratory, we are also working on direct observation of the time evolution of the Stokes shift in He II. In the latter theme, RI atomic beam resonance spectroscopy, the development of the RI-ion trap and neutralization system, which forms a

key component of the system, is ongoing. The construction of the ion trap part has been almost completed, and the laser development for sympathetic cooling of trapped RI atoms, which will be integrated into the ion trap part, was carried out.
We are also working on the application of heavy-ion/RI beams to materials-science research (at CPR/RNC). Utilizing the above-noted ^{21}O as a nuclear spin probe, the first β-NMR experiment with a CuO single crystal was performed at RIBF. In addition, in collaboration with the CPR Condensed Molecular Materials Laboratory and the RNC Accelerator Group, experimental studies to control of the electrical conductivity of diamond were also conducted. We also performed materials-science studies based on Mössbauer spectroscopy, where dilute magnetic semiconductors and gas matrix samples were studied at HIMAC through the in-beam method with ^{57}Mn beams, and battery electrode materials were studied with ^{99}Ru produced at RIBF.

(3) Members as of March, 2020

(Chief Scientist)
UENO, Hideki

(Senior Research Scientist)
YAMAZAKI, Hiroki, ICHIKAWA, Yuichi

(Research Scientist)
TAKAMINE, Aiko

(Postdoctoral Researcher)
IMAMURA, Kei
TAJIMA, Minori

(4) Representative research achievements

1. "Antiproton beams with low energy spread for antihydrogen production," M. Tajima, N. Kuroda, C. Amsler, H. Breuker, C. Evans, M. Fleck, A. Gligorova, H. Higaki, Y. Kanai, B. Kolbinger, A. Lanz, M. Leali, V. Mäckel, C. Malbrunot, V. Mascagna, Y. Matsuda, D. Murtagh, Y. Nagata, A. Nanda, B. Radics, M. Simon, S. Ulmer, L.Venturelli, E. Widmann, M. Wiesingerc, Y. Yamazaki, J. Instrum. **14**, P05009 (2019).
2. "Negative parity states in ^{39}Cl configured by crossing major shell orbits," L. C. Tao, Y. Ichikawa, C. X. Yuan, Y. Ishibashi, A. Takamine, A. Gladkov, T. Fujita, K. Asahi, T. Egami, C. Funayama, K. Imamura, J. L. Lou, T. Kawaguchi, S. Kojima, T. Nishizaka, T. Sato, D. Tominaga, X. F. Yang, H. Yamazaki, Y. L. Ye, H. Ueno, Y. Yanagisawa, K. Yoshida, Chin. Phys. Lett. **36**, 062101-1–4 (2019).
3. "Location of the neutron dripline at fluorine and neon," D. S. Ahn, N. Fukuda, H. Geissel, N. Inabe, N. Iwasa, T. Kubo, K. Kusaka, D. J. Morrissey, D. Murai, T. Nakamura, M. Ohtake, H. Otsu, H. Sato, B. M. Sherrill, Y. Shimizu, H. Suzuki, H. Takeda, O. B. Tarasov, H. Ueno, Y. Yanagisawa, K. Yoshida, Phys. Rev. Lett. **123**, 212501-1–6 (2019). [Featured in Physics] [Editors' Suggestion]
4. "*g*-Factor of the ^{99}Zr ($7/2^+$) isomer: Monopole evolution in shape coexisting region," F. Boulay, G. S. Simpson, Y. Ichikawa, S. Kisyov, D. Bucurescu, A. Takamine, D. S. Ahn, K. Asahi, H. Baba, D. L. Balabanski, T. Egami, T. Fujita, N. Fukuda, C. Funayama, T. Furukawa, G. Georgiev, A. Gladkov, M. Hass, K. Imamura, N. Inabe, Y. Ishibashi, T. Kawaguchi, T. Kawamura, W. Kim, Y. Kobayashi, S. Kojima, A. Kusoglu, R. Lozeva, S. Momiyama, I. Mukul, M. Niikura, H. Nishibata, T. Nishizaka, A. Odahara, Y. Ohtomo, D. Ralet, T. Sato, Y. Shimizu, T. Sumikama, H. Suzuki, H. Takeda, L. C. Tao, Y. Togano, D. Tominaga, H. Ueno, H. Yamazaki, X. F. Yang, J. M. Daugas, Phys. Rev. Lett. **124**, 112501-1–6 (2020).
5. "Nuclear shell evolution with shape deformation –Structure of exotic nuclei investigated by the magnetic moment– (in Japanese)," Y. Ichikawa, Isotope News **765**, 26–29 (2019).

Supplementary

Fig 1. A group photograph of the RIBF157 experiment conducted on December 2019.

Laboratory Homepage

https://www.riken.jp/en/research/labs/chief/nucl_spectro/index.html