Nuclear Science and Transmutation Research Division
Nuclear Spectroscopy Laborarory

1. Abstract

The research group has conducted nuclear-physics studies utilizing stopped/slowed-down radioactive-isotope (RI) beams mainly at the RIBF facility. These studies are based on the technique of nuclear spectroscopy such as β-ray-detected NMR (β-NMR), γ-PAD (Perturbed Angular Distribution), laser, and Mössbauer among other methods that takes advantage of intrinsic nuclear properties such as nuclear spins, electromagnetic moments, and decay modes. In particular, techniques and devices for the production of spin-controlled RI beams have been developed and combined to the spectroscopic studies, which enable high-sensitivity measurements of spin precessions/resonances through a change in the angular distribution of radiations. Anomalous nuclear structures and properties of far unstable nuclei are investigated from thus determined spin-related observables. The group also aims to apply such techniques to interdisciplinary fields such as fundamental physics and materials science by exploiting nuclear probes.

2. Major Research Subjects

(1) Nuclear spectroscopy utilizing spin-oriented fast RI beams
(2) Nuclear/Atomic laser spectroscopy & SLOWRI R&D
(3) Application of RI probes to materials science
(4) Fundamental physics: Study of symmetry

3. Summary of Research Activity

(1) Nuclear spectroscopy utilizing spin-oriented fast RI beams

Measurements of static electromagnetic nuclear moments over a substantial region of the nuclear chart have been conducted for structure studies on the nuclei far from the β-decay stability. Utilizing nuclear spin orientation phenomena of RIs created in the projectile-fragmentation reaction, ground- and excited-state electromagnetic nuclear moments been determined by means of the β-ray-detected nuclear magnetic resonance (β-NMR) and the γ-ray time differential perturbed angular distribution (γ-TDPAD) methods. In particular, a new method developed for controlling spin in a system of rare RIs, taking advantage of the mechanism of the two-step projectile fragmentation reaction combined with the momentum-dispersion matching technique, has been developed and employed making fully use of world's highest intensity rare RIBs delivered from BigRIPS for rare isotopes.

(2) Nuclear/Atomic laser spectroscopy & SLOWRI R&D

The group has 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, under installation in collaboration with the SLOWRI Team. This slowed-down RI-beam scheme enables to perform high-precision laser spectroscopy even with fast-fragmentation-based RIBs without the elemental limitation problematic in the ISOL-based RIBs.

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.

(3) Application of RI probes to materials science

The application of RI and heavy ion beams as a probe for condensed matter studies is also conducted by the group. The microscopic material dynamics and properties have been investigated through the deduced internal local fields and the spin relaxation of RI probes based on various spectroscopies utilizing RI probes such as β-NMR/NQR spectroscopy, Mössbauer spectroscopy, the γ-ray time differential perturbed angular correlation (γ-TDPAC) spectroscopy. Furthermore, studies on the control of electrical conductivity of diamond by boron and nitrogen implantation are ongoing.

Provided that highly spin-polarized RI probes are produced independently of their element properties and doped into a substance as an impurity, the constituent particle of the substance can be substituted by the same element RI probe without changing the material structure. This scheme provides a new opportunity for materials-science researches, but a key technology, production of element-independent highly spin-polarized RI beams, has not yet been achieved. In this subject, the group has conducted R&D studies to realize an ultra-slow & highly-spin-polarized RI beams, based on the technique of the atomic beam resonance.

(4) Fundamental physics: Study of symmetry

The nuclear spins of stable and unstable isotopes sometimes play important roles in fundamental physics research. New experimental methods and devices have been developed for studies of the violation of time reversal symmetry (T-violation) using spin-polarized nuclei. These experiments aim to detect the small frequency shift in the spin precession arising from new mechanisms beyond the Standard Model.

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List of Publications & Presentations

Publications

[Original Papers]

M. Tajima, A. Takamine, M. Wada, and H. Ueno, "Offline ion source for laser spectroscopy of RI at the SLOWRI," Nucl. Instrum. Methods Phys. Res. B **486**, 48–54 (2021).

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Presentations

[International Conferences/Workshops]

A. Takamine (invited), "SLOWRI rf gas catcher development toward symbiotic mass measurement at F11," RIBF User Meeting 2020, online, September 2–10, 2020.

M. Mukai, "In-gas-jet laser spectroscopy of $^{199–202}$Pt, $^{195–198}$Ir, $^{193–198}$Os," SSRI-PNS Collaboration Meeting 2020, online, Japan, September 3, 2020.

H. Ueno (invited), "Nuclear spectroscopy with spin-polarized RI beams," The International School for Strangeness Nuclear Physics 2020 (SNP School 2020), online & J-PARC, Ibaraki, Japan, December 2–5, 2020.

[Domestic Conferences/Workshops]

上野秀樹 (依頼講演), 「高偏極 RI ビームの生成と核・物質科学研究への応用」, 新学術領域研究「宇宙観測検出器と量子ビームの出会い。新たな応用への架け橋。」第 2 回領域研究会, オンライン開催, 2020 年 7 月 27–28 日.

今村慧 (口頭発表), 「RI 原子線磁気共鳴に向けた中性化装置開発」, 新学術領域「宇宙観測検出器と量子ビームの出会い．新たな応用への架け橋. 」第 2 回領域全体会議，オンライン開催, 2020 年 7 月 27–28 日.

飯村俊，高峰愛子，M. Rosenbusch，和田道治，S. Chen，J. Liu，W. Xian，D. Hou，S. Yan，P. Schury，園田哲，小島隆夫，渡辺裕，小田原厚子，石山博恒，「理研 BigRIPS SLOWRI における RF カーペットガスセルの開発」, 日本物学会 2020 年秋季大会, オンライン開催, 2021 年 9 月 14–17 日.

三原基嗣, 松多健策, 福田光順, 若林諒, 沖本直哉, 福留美樹, 泉川卓司, 野口法秀, 生越瑞揮, 大坪隆, 西村太樹, 髙橋弘幸, 菅原奏来, Aleksey Gladkov, 北川敦志, 佐藤眞二, 「短寿命酸素 NMR プローブ核 ^{19}O の物質科学利用」, 日本物学会 2020 年秋季大会, オンライン開催, 2021 年 9 月 14–17 日.

角田佑介, 大塚孝治, 清水則孝, 本間道雄, 宇都野穣, 「モンテカルロ殻模型による $Z = 28$ 近傍の核構造の研究」, 日本物学会 2020 年秋季大会, オンライン開催, 2021 年 9 月 14–17 日.

阿部喬 (口頭発表), "Ab initio description of light nuclei from no-core Monte Carlo shell model," 第 5 回クラスター階層領域研究会, オンライン開催, 2020 年 9 月 24–25 日.

上野秀樹 (依頼講演), 「RI・重イオンビームの学際的利用に向けた研究開発」, 新領域開拓課題 物質階層原理 & ヘテロ界面研究合同年次成果報告会, オンライン開催, 2021 年 2 月 8–9 日.

市川雄一 (招待講演), 「低エネルギースピン物理」, 日本のスピン物理学の展望研究会, 島根県松江市, オンライン開催, 2021 年 2 月 23–24 日.

田島美典, 高峰愛子, 飯村秀紀, 和田道治, H. A. Schuessler, 上野秀樹, 「コリニアレーザー分光による四重極変形度測定を通した原子核構造研究にむけた開発 II」, 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

小澤直也, 長濱弘季, 早水友洋, 中村圭佑, 佐藤幹, 永瀬慎太郎, 小高康照, 鎌倉恵太, 田中香津生, 大塚未来, 青木貴稔, 市川雄一, 高峰愛子, 羽場宏光, 上野秀樹, 酒見泰寛, 「フランシウム原子の電気双極子能率探索のための表面電離イオン源の開発」, 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

飯村俊，高峰愛子，M. Rosenbusch，和田道治，S. Chen，D. Hou，J. Liu，W. Xian，S. Yan，P. Schury，木村創大，庭瀬暁隆，伊藤由太，園田哲，小島隆夫，渡辺裕，N. Sara，道正新一郎，西村俊二，小田原厚子，石山博恒，「理研 BigRIPS SLOWRI における RF カーペットガスセルの開発—オンライン実験と質量測定—」, 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

大谷優里花, 三原基嗣, 松多健策, 福田光順, 若林諒, 沖本直哉, 福留美樹, 木村容子, 高山元, 泉川卓司, 野口法秀, 生越瑞揮, 佐藤弥紗, 高津和哉, 大坪隆, 西村太樹, 髙橋弘幸, 菅原奏来, Aleksey Gladkov, 北川敦志, 佐藤眞二, 百田佐多生, 奥村寛之, 森口哲朗, 小沢顕, 「^{19}O の偏極ビーム生成と固体燃料電池研究への応用」, 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

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