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

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[Original Papers]

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Presentations

[International Conferences/Workshops]

T. Abe (oral), "Alpha-cluster structure from first principles," YIPQS long-term workshop "Mean-field and Cluster Dynamics in Nuclear Systems 2022" (MCD2022), Kyoto, Japan & Online (Hybrid), May 9–June 17, 2022.

T. Abe (oral), "Alpha-cluster structure from first principles," RIKEN-YITP Workshop "Physics of RI: Recent Progress and Perspectives," Wako (RIKEN), Japan & Online (Hybrid), May 30–June 1, 2022.

K. Nakamura (oral), S. Nagase, T. Nakashita, T. Hayamizu, T. Aoki, H. Nagahama, N. Ozawa, K. Yamane, M. Fukase, D. Uehara, A. Takamine, and Y. Sakemi, "400-m-Long polarization-maintaining fibers for magneto-optical trapping of francium atoms," The 15th Pacific Rim Conference on Lasers and Electro-Optics (CLEO Pacific Rim, CLEO-PR 2022); International Symposium on Imaging, Sensing, and Optical Memory 2022 (ISOM'22); and the 13th International Conference on Optics-photonics Design and Fabrication (ODF'22), Sapporo, Japan, July 31–August 5, 2022.

K. Kikuchi (poster) *et al.*, "Optimization of the stopping position of a highly energetic ^{84}Rb atoms injected into superfluid helium," 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan & Online (Hybrid), August 18–24, 2022.

H. Endo (poster) *et al.*, "LIF spectrum analysis for measurement of Rb atomic bubble relaxation time in superfluid helium," 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan & Online (Hybrid), August 18–24, 2022.

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K. Imamura (poster) *et al.*, "Laser spectroscopic method for the investigation of nuclear structure utilizing superfluid helium as a host matrix of radioisotope atoms," 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan & Online (Hybrid), August 18–24, 2022.

S. Go (invited), "Overview of RIBF" and "Spectroscopy of exotic nuclei," The 21st CNS International Summer School (A3F-CNSSS22), Kumagaya, Saitama, August 20–24, 2022.

R. Mitsuyasu (poster) *et al*., "Spectral optimization of laser for excitation of Rb atoms in superfluid helium in accelerator experiments," The 25th Congress of the International Commission for Optics (ICO), Dresden, Germany & Online (Hybrid), September 5–9, 2022.

S. Akimoto (poster) *et al*., "Development of an efficient fluorescence detection system for radioisotope atoms generated at accelerators," The 25th Congress of the International Commission for Optics (ICO), Dresden, Germany & Online (Hybrid), September 5–9, 2022.

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S. Go (oral), "High-spin states in ^{35}S: the promotion of isoscalar pair at high spin," 28th International Nuclear Physics Conference (INPC 2022), Cape Town, South Africa, September 11–16, 2022.

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M. Mukai (oral), "Laser ionization spectroscopy of neutron-rich Ir isotopes and recent works at KISS," Workshop on Laser Spectroscopy/Analysis of Radioactive Isotope and Related Topics, Nagoya, Japan, October 20, 2022.

M. A. Syakuur (poster), A. R. Noviyanti, U. Widyaiswari, T. Saragi, Risdiana, and I. Watanabe, "Sample synthesis of a single phase $Nd_2Ru_2O_7$," Asia-Pacific Conference on Condensed Matter Physics 2022 (AC2MP2022), Sendai, Japan & Online (Hybrid), November 21–23, 2022.

M. A. Syakuur (poster), A. R. Noviyanti, A. R. Noviyanti, U. Widyaiswari, T. Saragi, Risdiana, D. P. Sari, H. Sakai, N. Hanasaki, and I. Watanabe, "Sample synthesis of a single phase $Nd_2Ru_2O_7$," The 6th International Conference on Functional Materials Science 2022 (ICFMS 2022), Bali, Indonesia & Online (Hybrid), November 29–30, 2022.

T. Otsuka (invited), "Emerging of alpha clustering due to nuclear forces," Mean-field and Cluster Dynamics in Nuclear Systems 2022 (MCD2022) First Week, Kyoto, Japan & Online (Hybrid), May 9–13, 2022.

T. Otsuka (invited), "Alpha clustering from first principles for Be and C isotopes including the Hoyle state," 8th Workshop on Level Density and Gamma Strength, Oslo, Norway, May 9–13, 2022.

T. Otsuka (oral), "New facets of alpha-clustering and deformation towards driplines depicted by nuclear forces," Mean-field and Cluster Dynamics in Nuclear Systems 2022 (MCD2022) Third Week, Kyoto, Japan & Online (Hybrid), May 23–27, 2022.

T. Otsuka (invited), "Emerging concepts in nuclear structure based on the shell model," Symposium "Frontiers in Nuclear Structure Theory" on the Occasion of the 90th Birthday of Prof. Jan Blomquist, Online, May 23–25, 2022.

T. Otsuka (invited), "Prevailing triaxiality of heavy deformed nuclei," Shapes and Symmetries in Nuclei: from Experiment to Theory (SSNET'22), Paris, France, May 30–June 3, 2022.

T. Otsuka (invited), "Structure evolutions towards neutron driplines," Mean-field and Cluster Dynamics in Nuclear Systems 2022 (MCD2022) Fifth Week, Kyoto, Japan, June 6–10, 2022.

T. Otsuka (invited), "Monopole-quadrupole interplay in nuclear structure and resulting self-organization phenomena," Mean-field and Cluster Dynamics in Nuclear Systems 2022 (MCD2022) Sixth Week, Kyoto, Japan & Online (Hybrid), June 13–17, 2022.

T. Otsuka (oral), "What locates neutron driplines?" Direct Reactions with Exotic Beams 2022 (DREB2022), Santiago de Compostela, Spain, June 27–July 1, 2022.

T. Otsuka (invited), "Prevailing triaxiality in nuclear shapes," 55th Zakopane Conference on Nuclear Physics, Zakopane, Poland, August 29–September 2, 2022.

T. Otsuka (invited), "Shell evolution and emerging paradigm changes," 28th International Nuclear Physics Conference (INPC 2022), Cape Town, South Africa, September 11–16, 2022.

T. Otsuka (invited), "Prevailing triaxiality in heavy deformed nuclei and possible experimental observation by M1 excitation," SFB 1245 Annual Workshop, Darmstadt, Germany, October 4–7, 2022.

T. Otsuka (invited), "Knocking out nucleons and alphas to see novel nuclear structures," REIMEI Workshop "Unveiling Nuclear Shells and Correlations in Exotic Nuclei through Knockout Reactions," Darmstadt, Germany, October 10–12, 2022.

T. Otsuka (invited), "(A) Triaxial ellipsoids probed by the RHC and a possible paradigm change in nuclear structure (B) Progress report on ^{96}Zr and ^{96}Ru," EMMI Rapid Reaction Task Force (RRTF) "Nuclear physics Confronts Relativistic Collisions of Isobars," Heidelberg, Germany, October 12–14, 2022.

T. Otsuka (invited), "Prevailing triaxiality driven by the tensor force," The 6th Topical Workshop on Modern Aspects in Nuclear Structure (BORMIO-2023), Bormio, Italy, February 6–11, 2022.

T. Otsuka (invited), "New aspects of nuclear structure (Impacts from modern Shell Model)," INTPART School 2023, Okinawa, Japan, February 20–March 3, 2023.

[Domestic Conferences/Workshops]

今村慧 (依頼講演), 「RI 原子線共鳴装置の開発:イオントラップ部」, 新学術領域研究「宇宙観測検出器と量子ビームの出会い. 新たな応用の架け橋. 」領域研究会 (第 4 回領域全体会議), オンライン, 2022 年 5 月 20–21 日.

上野秀樹 (依頼講演), 「計画研究 B03 班 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. 新たな応用の架け橋. 」領域研究会 (第 4 回領域全体会議), オンライン, 2022 年 5 月 20–21 日.

光安陸大, 高峰愛子, 今村慧, 秋元彩, 伊藤愛美, 螺良健太, 菊地快, 上野秀樹, 松尾由賀利, 「加速器実験における超流動ヘリウム中 Rb 原子励起用レーザーのスペクトル最適化」, 第 18 回原子・分子・光科学 (AMO) 討論会, 東京 (東京大学本郷キャンパス) & オンライン ハイブリッド開催, 2022 年 6 月 10–11 日.

菊地快, 今村慧, 高峰愛子, 螺良健太, 秋元彩, 伊藤愛美, 光安陸大, A. Gladkov, 田島美典, 郷慎太郎, 向井もも, 遠藤宏紀, 長谷正司, 川田敬太, 西畑洸希, 市川雄一, 北川敦志, 涌井崇志, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中レーザー分光のための不安定核原子 ^{84}Rb の停止位置最適化」, 第 18 回原子・分子・光科学 (AMO) 討論会, 東京 (東京大学本郷キャンパス) & オンライン ハイブリッド開催, 2022 年 6 月 10–11 日.

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大塚孝治, 「炭素 12 の第一原理計算とホイル状態」, RCNP 研究会「原子核反応研究の最近の話題と展望」 河合光路先生を偲ぶ会, 大阪府茨木 (大阪大学吹田キャンパス), 2022 年 7 月 8–9 日.

水野るり恵, 池田時浩, 郷慎太郎, 櫻井博儀, 齋藤岳志, 新倉潤, 松崎禎市郎, 道正新一郎, 「1 MeV 陽子ビームを用いた広ダイナミックレンジ光子検出器の性能評価実験」, 第 34 回タンデム加速器及びその周辺技術の研究会, オンライン, 2022 年 7 月 21–22 日.

安藤蒼太, 市川雄一, 佐藤智哉, 篠原雄介, 西畑洸希, 岸本侃己, 山下渉, 横田望海, 立川柊平, 竹中京平, 梶原孝文, 荒殿和希, 郷慎太郎, 高峰愛子, 上野秀樹, 旭耕一郎, 「EDM 測定に向けたガラスセル中 Xe 原子のスピン緩和機構の評価 II」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大学岡山キャンパス), 2022 年 9 月 6–8 日.

篠原悠介, 市川雄一, 郷慎太郎, 西畑洸希, 安藤蒼太, 荒殿和希, 旭耕一郎, 馬場秀忠, 福田直樹, G. Georgiev, A. Gladkov, 今村慧, 梶原孝文, 岸本侃己, R. Lozeva, 向井もも, 新倉潤, M. N. Nurhafiza, 小田原厚子, 清水陽平, M. Si, K. Stoychev, 鈴木宏, 立川柊平, 田島美典, 高峰愛子, 竹田浩之, 竹中京平, 武重祥子, 上野秀樹, 若狭智嗣, 山下渉, 山崎展樹, 横田望海, 吉本雅浩, J. -M. Daugas, 「分散整合二回散乱法による ^{99}Zr アイソマー状態のスピン整列」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大学岡山キャンパス), 2022 年 9 月 6–8 日.

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角田佑介, 清水則孝, 大塚孝治, 「モンテカルロ殻模型による $N = 50$ 近傍の核構造の研究」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大学岡山キャンパス), 2022 年 9 月 6–8 日.

阿部喬 (基調講演), 「富岳で探る炭素 12 のホイル状態」, 富岳で加速する素粒子・原子核・宇宙・惑星シンポジウム, 神戸大学先端融合研究環統合研究拠点 & オンライン ハイブリッド開催, 2022 年 12 月 12–13 日.

阿部喬, 「モンテカルロ殻模型による第一原理計算の最近の進展」, 富岳で加速する素粒子・原子核・宇宙・惑星シンポジウム, オンライン, 2022 年 1 月 17–18 日

小澤直也, 長濱弘季, 中村圭佑, 佐藤幹, 中下輝士, 永瀬慎太郎, 上原大祐, 深瀬実来, 青木貴稔, 山口敦史, 高峰愛子, 上野秀樹,

酒見泰寛, 「永久電気双極子能率探索を目指した冷却フランシウム原子源の開発」, 日本物理学会 2023 年春季大会, オンライン, 2023 年 3 月 22–25 日.

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Award

K. Kikuchi (Hosei Univ.), "Optimization of the stopping position of a highly energetic ^{84}Rb atoms injected into superfluid helium," Poster Award of the 29th International Conference on Low Temperature Physics (LT29), August 23, 2022.

Press Releases

プレスリリース: 「スーパーコンピュータ『富岳』で探る炭素の起源―第一原理計算で導かれたアルファクラスターの構造」, 理研, 東京大学, 日本原子力研究開発機構共同プレスリリース, 2022 年 4 月 27 日.

新聞掲載: 「理研, C12 原子核の量子構造解明 炭素起源理解に期待」, 日刊工業新聞, 2022 年 4 月 28 日.

Outreach Activities

アウトリーチ: 高峰愛子 (理研), インタビュー記事 Web 掲載 (高校・大学生向けイベント) 「見たい! 知りたい! 原子核サイエンス最前線仁科加速器科学研究センター応援団」, 2022 年 7 月 1 日.

理研広報誌掲載: 「炭素はどのようにしてつくられたのか」, 理研クローズアップ科学道 2022 (理研, 2022 年 9 月 12 日).

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