Research Facility Development Division
Instrumentation Development Group
SCRIT Team

1. Abstract

The SCRIT Electron Scattering Facility has been constructed at RIKEN RIBF. This aims at investigation of internal nuclear structure for short-lived unstable nuclei by means of electron scattering. SCRIT (Self-Confining RI Ion Target) is a novel method to form internal targets in an electron storage ring. This is a unique method for making electron scattering experiments for unstable nuclei possible. Construction of the facility has been started in 2009. This facility consists of an electron accelerator (RTM), a SCRITequipped electron storage ring (SR2), an electron-beam-driven RI separator (ERIS), and a window-frame spectrometer for electron scattering (WiSES) which consists of a large window-frame dipole magnet, drift chambers and trigger scintillators. Installation of all components in the facility was completed in 2015. After the comprehensive test and tuning, the luminosity was reached to $3 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ with the number of injected ions of 3×10^8. In 2016, we successfully completed a measurement of diffraction of scattered electrons from ^{132}Xe nuclei and determined the charge density distribution for the first time. Through years of developments and improvements, in 2022, we successfully conducted the world's first electron scattering experiment with online-produced unstable nuclei. Using ^{137}Cs ions of 10^7 ions/pulse at 0.25 Hz, the luminosity was achieved to $0.9 \times 10^{26}/(\mathrm{cm}^2\mathrm{s})$ with about 250 mA-electron beam. In addition, we started the study of the isotope dependence of charge density distribution using Xe stable isotopes.

2. Major Research Subjects

Development of SCRIT electron scattering technique and measurement of the nuclear charge density distributions of unstable nuclei.

3. Summary of Research Activity

SCRIT is a novel technique to form internal target in an electron storage ring. Positive ions are three dimensionally confined in the electron beam axis by transverse focusing force given by the circulating electron beam and applied electrostatic longitudinal mirror potential. The created ion cloud composed of RI ions injected from outside works as a target for electron scattering. Construction of the SCRIT electron scattering facility has been started in 2009. The electron accelerators RTM and the storage ring SR2 were successfully commissioned in 2010. Typical accumulation current in SR2 is 250–300 mA at the energy range of 120–300 MeV that is required energy range in electron scattering experiment. The SCRIT device was inserted in the straight section of SR2 and connected to an ISOL named ERIS (Electron-beam-driven RI separator for SCRIT) by 20-m long low energy ion transport line. A buncher system based on RFQ linear trap named FRAC (Fringing-RF-field-Activated dc-to-pulse converter) was inserted in the transport line to convert the continuous beam from ERIS to pulsed beam, which is acceptable for SCRIT. The detector system WiSES consisting of a high-resolution magnetic spectrometer, drift chambers and trigger scintillators, was constructed, and it has a solid angle of 100 msr, energy resolution of 10^{-3}, and the scattering angle coverage of 25–55 degrees. A wide range of momentum transfer, 80–300 MeV/c, is covered by changing the electron beam energy from 150 to 300 MeV.

We successfully measured a diffraction pattern in the angular distribution of scattered electron from ^{132}Xe isotope at the electron beam energy of 150 MeV, 200 MeV, and 300 MeV, and derived the nuclear charge distribution by assuming two-parameters Fermi model for the first time. At this time, luminosity was reached to $3 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ at maximum and the averaged value was $1.2 \times 10^{27}/(\mathrm{cm}^2\mathrm{s})$ with the number of injected target ions of 3×10^8.

We are now under preparation for going to the experiments for unstable nuclei. There are some key issues for that. They are increasing the intensity of the RI beams from ERIS, efficient DC-to-pulse conversion at FRAC, improving the transmission efficiency from FRAC to SCRIT, and effective suppression of the background in measurement of scattered electrons. RI beam intensity will be improved by upgrading the electron beam power from 10 W to 60 W, increasing the contained amount of U in the target ion source, and some modifications in mechanical structure in the ion source. For upgrading the electron beam power, the RF system of RTM has been maintained intensively, and we will continue the development of RTM. For efficient DC-to-pulse conversion, we established the two-step bunching method, which is time compression at FRAC in combination with pre-bunching at the ion source using grid action. Furthermore, we will improve the conversion efficiency and the transmission efficiency from FRAC to the SCRIT device by cooling the trapped ions using minuscule amounts of a buffer gas. These improvements on FRAC were already confirmed in off-line test. Since one of significant contribution to the background for scattered electron is scattering from massive structural objects around the trapping region originated from halo components of the electron beam, we remodeled the SCRIT electrodes. The vacuum pump system at the SCRIT device has been upgraded to reduce the contribution of residual gases. Luminosity for radioactive Xe isotopes is expected to be more than $10^{26}/(\mathrm{cm}^2\mathrm{s})$ after these improvements. Then, we will be able to start experiments for unstable nuclei. When further upgrading in the RTM power planned to be 3 kW will be achieved, we can extend the measurements to more exotic nuclei.

In 2018, we developed several instruments. One is the introduction of the surface-ionization type ion source at ERIS in order to increase kinds of radioactive beam and to produce high intensity beam. Another development is the upgrading of the drift chamber located in front of the magnetic spectrometer of WiSES to improve the momentum resolution and angular acceptance. These developments help us to realize experiments for unstable nuclei.

In 2019, we installed a newly designed SCRIT electrodes. The main purpose of the replacement was to lower the background during the measurement due to the electron scattering from the SCRIT electrodes itself but not from the ion targets for the experiment. For that purpose, we employed thin metal wires to construct the electrodes rather than metal plates nor blocks. In addition, we

modified the inside structure of the SCRIT chamber to symmetrize the electric ground potential affecting the potential curve inside the electrodes.

In 2020, we tested accelerators RTM and SR2 if they bear for long term experiment for 24 hours. In 2021, we commissioned the new SCRIT electrodes using ^{138}Ba ion beams produced by the surface-ionization type ion source at ERIS. After the RI production test, ERIS became ready to provide enough ions for the experiment of unstable nuclei.

In 2022, we successfully conducted the world's first electron scattering experiment with online-produced unstable nuclei. The ^{137}Cs ion beams, almost 10^7 ions/pulse at 0.25 Hz, produced by ERIS and FRAC was injected to the SCRIT device, and the luminosity was reached as $0.9 \times 10^{26}/(\mathrm{cm}^2\mathrm{s})$ with about 250-mA electron beam. Scattering electrons by ^{137}Cs targets were clearly analyzed and measured by WiSES, and the obtained angular distribution of ^{137}Cs is consistent to the calculated results. The paper will be published soon. In addition, we started the study of the isotope dependence of charge density distribution using Xe stable isotopes. This study will be expected to help to understand the nuclear structure precisely. First, we measured the angular distribution of $^{130, 132, 134, 136}$Xe isotopes. Those of remained Xe isotopes, $^{124, 126, 128}$Xe, will be measured soon.

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List of Publications & Presentations

Publications

[Original Paper]

T. Suda, "Study of radii of proton and nuclei by electron scattering," JAEA-Conf **2022-001**, 51 (2022).

[Review Article]

T. Suda, "Electron Scattering Off Stable and Unstable Nuclei," in *Handbook of Nuclear Physics*, I. Tanihata, H. Toki, and T. Kajino (eds), (Springer, Singapore, 2023), https://doi.org/10.1007/978-981-15-8818-1_8-1 .

[Proceedings]

J. Bernauer, R. Corliss, S. Gardner, M. Hasinoff, R. Kanungo, J. Martin, R. Milner, K. Pachal, T. Suda, and S. Yen, "Scientific opportunities at the ARIEL electron linac," Proceedings of "Workshop on New Scientific Opportunities with the TRIUMF ARIEL e-linac," J. Phys. Conf. Ser. **2391**, 012001 (2022).

T. Suda, "Low-energy electron scattering facilities in Japan," Proceedings of "Workshop on New Scientific Opportunities with the TRIUMF ARIEL e-linac," J. Phys. Conf. Ser. **2391**, 012004 (2022).

Presentations

[International Conferences/Workshops]

T. Suda (invited), "Low-energy electron scattering facilities in Japan," New Scientific Opportunities with the TRIUMF ARIEL e-linac, Vancouver, Canada, May 25–27, 2022.

T. Suda (invited), "Low-energy electron scattering—proton radius and beyond," International STRONG workshop on the Proton Charge Radius and related topics, Paris, France, June 20–23, 2022.

K. Tsukada (oral), "Electron scattering from unstable nuclei at SCRIT facility," 28th International Nuclear Physics Conference (INPC2022), Cape Town, South Africa, September 11–16, 2022.

R. Ogawara (poster), "Ion-trapping properties of SCRIT: time evolution of charge state distributions of ^{138}Ba ions," The 19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS 2022), Daejeon, South Korea, October 3–7, 2022.

T. Ohnishi (invited), "The SCRIT electron scattering facility at RIKEN RI Beam Factory," The 19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS 2022), Daejeon, South Korea, October 3–7, 2022.

[Domestic Conferences/Workshops]

塚田暁 (口頭発表), 「電子・不安定核散乱実現に向けた SCRIT 電子散乱施設の現状と展望」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大), 2022 年 9 月 6–8 日.

小川原亮 (口頭発表), 「SCRIT における ^{138}Ba 標的の価数分布とその時間発展」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大), 2022 年 9 月 6–8 日.

和宇慶ひかり (口頭発表), 「SCRIT 電子散乱施設における電荷分布の同位体・同調体依存性測定」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大), 2022 年 9 月 6–8 日.

大西哲哉 (口頭発表), 「理研 SCRIT 施設における電子ビーム RI セパレーター ERIS の現状と展望」, 日本物理学会 2022 年秋季大会, 岡山市 (岡山理科大), 2022 年 9 月 6–8 日.

和宇慶ひかり (口頭発表), 「SCRIT 電子散乱施設における電荷分布の同位体・同調体依存性測定」, 日本物理学会 2023 年春季大会, オンライン, 2023 年 3 月 23 日.

[Seminars]

T. Suda, "Electron scattering and nuclear matrix elements of the double-beta decay process," 二重ベータ崩壊核行列要に関する実験理論合同研究会, Research Center for Nuclear Physics, Osaka, Japan, October 3–4, 2022.

T. Suda (invited), "Proton Radius," Australian National University Director's Colloquium, Canberra, Australia, October 22, 2022.

T. Suda (invited), "Proton Radius," Physics Colloquium of Univ. Melbourne, Melbourne, Australia, October 26, 2022.

T. Suda, "Proton Radius," 京都大学物理学科セミナー, 京都大学, 2022 年 12 月 2 日.

K. Tsukada, "Electron scattering from unstable nuclei at SCRIT facility," GSI NUstar seminar, GSI, Germany, February 13, 2023.

K. Tsukada, "Present status and future prospects of the SCRIT project," CEA ESNT seminar, CEA-Saclay, France, February 15, 2023.

塚田暁, 「エキゾチックな原子核を造る・観る」, 京都大学丸の内セミナー, 京都大学 東京オフィス (新丸ビル 10 階), 2023 年 3 月 10 日.

Outreach Activity

須田利美, 特別講義「陽子などの物の大きさはどう測る？」, 埼玉県立熊谷高等学校, 2023 年 1 月 21 日.