Simultaneous observation of Fr-ion beam current and α decay of Fr

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The charge conjugation parity symmetry must be violated to explain the matter-antimatter asymmetry observed in the current universe.[1)] As the electric dipole moment of an electron (eEDM) violates fundamental symmetries, the eEDM is an important clue for unravelling the origin of the matter; thus, we are aiming at its appropriate measurement. The eEDM is enhanced in heavy paramagnetic atoms. In particular, it has been calculated that an enhancement factor of francium (Fr) is 799.[2)] Therefore, we are developing an apparatus of ^{210}Fr magneto-optical trap (MOT) for precise eEDM measurement.

The Fr MOT apparatus being developed at RIKEN RIBF comprises four segments as follows: Fr production, Fr-ion beam line, neutralization, and MOT. The developed equipments are tested in the beam time. In the first stage, Fr is produced by the fusion reaction $^{197}\mathrm{Au}(^{18}\mathrm{O}, xn)^{215-x}\mathrm{Fr}$. To facilitate the reaction, a gold target is irradiated with a 7 MeV/nucleon $^{18}\mathrm{O}^{6+}$ primary beam supplied by the AVF cyclotron of RIKEN RIBF. The gold target is heated by an infrared heater. Consequently, the produced Fr thermally diffuses in the target. Most of the Fr that reaches the surface of the target is extracted as a 100 eV secondary ion beam via surface ionization. In the second stage, the secondary beam is controlled by an electrostatic beam transport system (BTS), and an yttrium (Y) foil target is irradiated with the secondary beam. Subsequently, the Fr is accumulated in the Y target. Thereafter, the Y target moves to the MOT chamber. In the third stage, an infrared heater heats the Y foil target and the neutral Fr atoms are thermally desorbed. In the last stage, a fraction of desorbed Fr atoms is guided to the trapping region.

It is necessary to improve efficiency in each stage to achieve a large number of Fr MOT. Regarding the secondary beam transport, the parameters of the BTS must be optimized to maximize the intensity of Fr in the secondary beam. The relative change in the secondary Fr-ion beam purity must be measured because the impurity reduces the efficiency and worsens the reproducibility in the subsequent stages. In the experiments during the beam time, in order to optimize the secondary beam, we observed the beam current and α decay of Fr in the beam simultaneously without stopping the extraction of the beam by using a simultaneous beam diagnostic system (SBDS).

The structure of the SBDS is shown in Fig. 1. The SBDS was installed at the end of the BTS. The Faraday cup (FC) comprised a stainless disk electrode with a hole of ϕ10 mm diameter in the center and a 1-μm-thick gold foil electrode covering the hole. The gold foil electrode played an important role in the SBDS. First, because the secondary beam energy is sufficiently low, the particles in the beam were stopped in the gold foil. Therefore, the gold foil properly functioned as the FC electrode. However, the observed value of the beam current may include the effect of the secondary electron emission from the electrodes. Second, α particles produced by α decay of Fr stopped in the gold foil have sufficiently high energy to go through the foil. Thus, a silicon solid state detector (SSD) on the other side of the foil from the secondary beam can detect the α particles. Finally, the FC electrodes blocked stray light from the infrared heater for the gold target, thus, the noise of the SSD owing to the stray light was greatly suppressed. In the previous study in 2022, we confirmed that the SBDS measured the secondary beam current and α decay of Fr in the beam simultaneously.[3)] Analysis of the experimental data at the 2023 beam time is in progress.

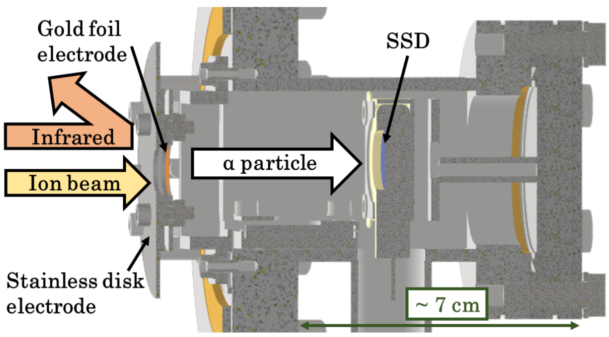

Fig. 1. Simultaneous beam diagnostic system. Infrared rays are blocked by the electrodes but α particles can go through the gold foil electrode.

In 2024, the SBDS will continue to be used for optimizing the secondary beam.

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