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II. 6. A Beam Transportation of Radioactive Francium for Magneto-Optical Trapping Experiments*

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To perform the experiment trapping of a large amount of Fr atoms, we have been constructing a factory of laser-cooled radioactive Fr atoms at Cyclotron and Radioisotope Center (CYRIC) at Tohoku University[1)]. A non-zero electric dipole moment (EDM) shows the violation of the time reversal symmetry. Francium (Fr) is a promising candidate for a high precision measurement of the electron EDM, because it possesses a large enhancement factor of 895[2)]. A factory of laser-cooled radioactive Fr atoms consists of a thermal ionizer, Fr beamline, neutralizer, and magneto-optical trapping system. Recent developments of this factory are focusing on an ion beam transportation.

Fr atoms are produced by the nuclear fusion reaction $^{18}O + {}^{197}Au \rightarrow {}^{215-x}Fr + xn$. The 100 MeV $^{18}O^{5+}$ beam supplied from an AVF cyclotron through a primary beamline is incident on the ^{197}Au target installed in a thermal ionizer (TI). Figure 1 shows a schematic view of the TI. This TI consists of the ^{197}Au target, extraction electrode and the first and second einzel lenses. The first solid state detector (SSD1) is installed immediately above the second einzel lens to measure extracted Fr ions. A gold is heated by a tungsten heater surrounding a target holder. Fr atoms produced inside the target move to its surface by thermal diffusion. Then, Fr atoms are ionized at the surface. Fr ions are extracted to the secondary beamline by an electrostatic potential of typically 1.5 kV. Recently, we observed an extraction 2.4×10^5 ions/s of ^{210}Fr isotopes when the temperature and the primary beam current were 718°C and 2 eμA, respectively. Figure 2 shows the α decay spectrum of the

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*Condensed from the article in Proceedings of 7th International workshop on Fundamental Physics Using Atoms (FPUA2014) extracted Fr isotopes at SSD1.

A beamline is designed to transport the Fr ions from the TI to the region of magneto-optical trap (MOT) as shown in Fig. 3. The main components of the beamline are an electrostatic deflector, three electrostatic quadrupole triplets, and several steerer electrodes. The beamline is entirely constructed by electrostatic optics. The ion optics has also been optimizing with the aid of a computer code SIMION 3D[3)].

We performed two things to improve the transportation since the efficiency from SSD1 to SSD4 was approximately 2% at the beginning of the beamline development. Firstly, we optimized the parameters of electrostatic optics to transport ions to the yttrium target. The parameters were modified to maximize the beam current on the target. In addition, we installed new steerer electrodes. Consequently, 18% of the transport efficiency for ^{210}Fr was achieved. At present, 4.3×10^4 pps of ^{210}Fr could be delivered at the yttrium target.

To increase even the efficiency of trapping in MOT, we also need to focus on the process of the Fr ion extraction. As the gold temperature increases, the thermal diffusion of Fr atoms is promoted. Therefore, the more the temperature rises, the higher the extraction efficiency becomes. However, in fact, a background beam current is drastically increased in the case of our apparatus at the higher target temperature. When the temperature of the gold is 1000°C, a typical background current is on the order of 10 enA in contrast with Fr ions of 10^{-5} enA. The amount of the background ion is not reproducible with respect to the temperature. The background component emitted from the yttrium is transferred to the trapping cell in the same process as Fr atoms. Thus, the collision of Fr atoms with background component must deteriorate the trapping efficiency. To realize a high extraction without degrading the trapping efficiency, we plan to install a Wien filter. If the velocity of a certain ion satisfies the condition $v = \frac{E}{B}$, the ion is not deflected by the filter. In other words, this filter is in principle a velocity filter. In our experiment, every ion possesses almost the same kinetic energy. Thus, we can operate a Wien filter as a mass separator. The ion transportation parameters must be optimized again when the Wien filter is installed.

Fr trapping experiment for the precise EDM measurement has been prepared at CYRIC. We achieved Fr transportation in the efficiency of 18%. In the next step, we will install a Wien filter to remove the background current. To increase the efficiency of Fr trapping in MOT, a pure Fr ion beam is desired. A Wien filter will improve the purity of the ion beam.

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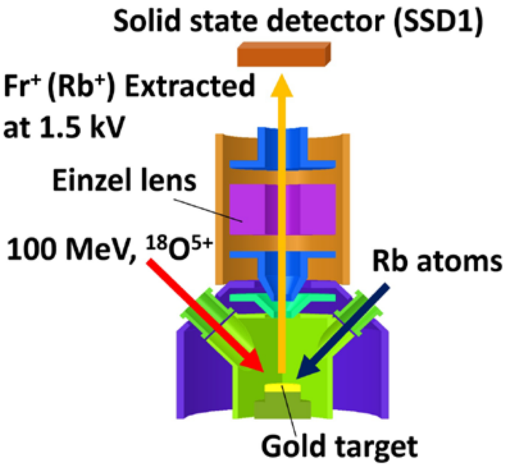

Figure 1. Thermal ionizer.

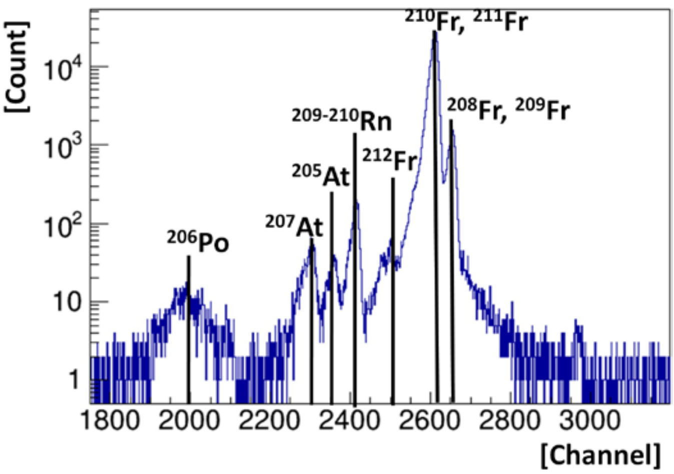

Figure 2. Typical α decay spectrum detected by SSD1.

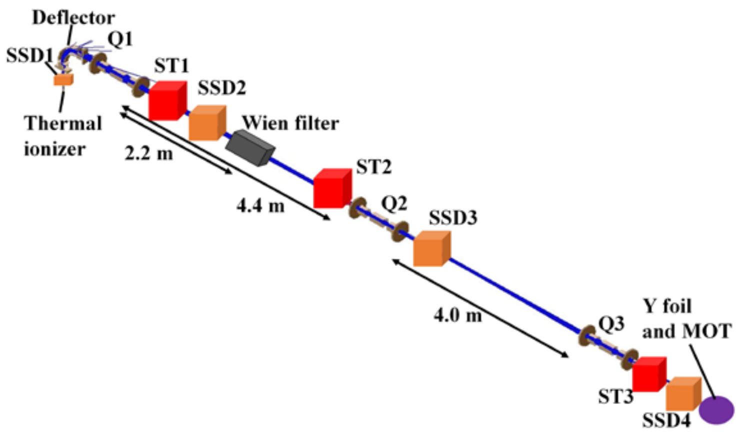

Figure 3. Fr beamline designed by SIMION including a deflector, quadrupole triplets (Q1, Q2, and Q3), steerers (ST1, ST2 and ST3). Solid state detectors are installed at 4 places in the beamline (SSD1-SSD4). We plan to install a Wien filter at the middle of Q1 and Q2.