II. 1. A Wien Filter as a Mass Filter to Purify the Francium Beam

Kawamura H.[1,2], Aoki T.[2], Arikawa H.[2], Harada K.[2], Hayamizu T.[2,], Inoue T.[1,2], Ishikawa T.[2], Ito S.[2], Itoh M.[2], Kato K.[2], Koehler L.[2], Mathis J.[2], Sakamoto K.[2], Uchiyama A.[2], and Sakemi Y.[2,†]*

[1]Frontier Research Institute for Interdisciplinary Sciences (FRIS), Tohoku University
[2]Cyclotron and Radioisotope Center, Tohoku University

A factory of radioactive francium (Fr) atoms has been developed in order to better search for an electron's electric dipole moment and study the nuclear anapole moment[1,2)]. We can produce francium via a fusion-evaporation reaction of a gold target and an oxygen beam from 930 AVF cyclotron, and produce Fr ions with a thermal ionization on the surface of the hot gold. Various impurities, and gold itself, as well as francium will be ionized and become background components. Since electrostatic fields are used to extract and transport the produced ions, any ion can be extracted and transported independently of its mass. The low beam purity might negatively affect experimental processes, as the purity of the Fr beam was roughly 10^{-6}. The beam purity should be improved by using a Wien filter, which can separate the desired components from the others.

Figure 1 shows the aspect of the Fr factory, which has been built at the 51-beam course. The Wien filter was installed between the 1st and 2nd electrostatic quadrupole triplets. Figure 2 indicates the configuration of the filter electrodes. The beam component was analyzed using the filter. This study utilized the fact that the mass-charge ratio of the ion passing through the filter can vary by scanning the intensity of the electrical field with the fixed magnetic field. A typical result is shown in Fig. 3[4)]. The transverse axis shows the voltage difference between the electrodes with a gap of 60 mm, so the 100 V corresponds to the electric field 1.67 V/mm. The relation of the coil current to the magnetic field intensity is shown in Fig. 4. This result was obtained with the ions produced only by heating the target without the primary beam from the AVF cyclotron.

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[*]*Present address: University of British Columbia, Vancouver, Canada*
[†]*Present address: Center for Nuclear Study (CNS), the University of Tokyo*

We can irradiate the gold target with a rubidium atomic beam and control the intensity of the rubidium ion. The beam current was measured with a copper plate (used as a Faraday cup) in a beam diagnosis system at just after the 2nd triplet. In Fig. 3, gray and black lines show events with and without the rubidium atomic beam, respectively. The peaks at ~600 V and ~500 V correspond to the rubidium ion and cesium ion, respectively, according to the mass-charge ratio expected from the intensity of the applied fields and the composition ratio of the rubidium source (Table 1[5)]). Also, the peaks at ~900 V and ~1200 V are expected to be potassium and sodium as alkali elements. Potassium and sodium originate in the impurities of constructional elements of the apparatus because their peaks are not sensitive to being with/without a rubidium source. Massive gold is the best possible matter for this because every impurity of the gold target has a large ionization potential and is difficult to ionize (Table 2[6)]). The peak corresponding to the mass-charge ratio ~200 had been observed by Stancari et al[7)].

We confirmed that the Fr ion beam can be transported by removing light elements with the Wien filter. The transportation efficiency, which is defined as the ratio of the beam intensity reached the first diagnosis system and the final one, was 26%, while the transportation efficiency without the Wien filter was 15%. The facts that the beam condition was not so stable and that the transport efficiency had a fluctuation demonstrate why using the Wien filter led to better efficiency. The other possible reason is the fact that the electromagnetic field of the filter acts as a kind of focusing lens[8)].

The beam purity is defined as the ratio between the number of francium measured by α-ray spectroscopy with a solid state detector and the total beam current measured by the copper plate. The beam purity was roughly 10^{-6} without filter and 10^{-3} with filter. This experiment demonstrated that the Wien filter can increase the beam purity thousandfold, though the intensity of the background components will vary with the surface condition of the gold target.

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References

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Table 1. Composition ratio of the rubidium source from KURIETO SHOUJI Ltd.[5)].

Rb	99.9%
Na	< 13 ppm
K	< 13 ppm
Cs	639 ppm

Table 2. Composition ratio of the gold target from FURUYA METAL Co., Ltd.[6)].

Au	> 99.99%
Ag	7 ppm
Cu	< 1 ppm
Fe	3 ppm
Pb	< 10 ppm
Pd	2 ppm

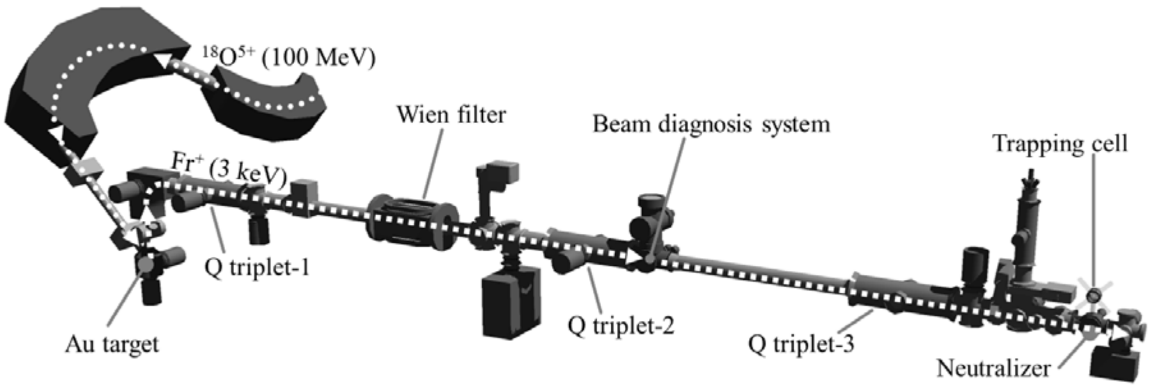

Figure 1. A factory of laser-cooled radioactive francium atoms.

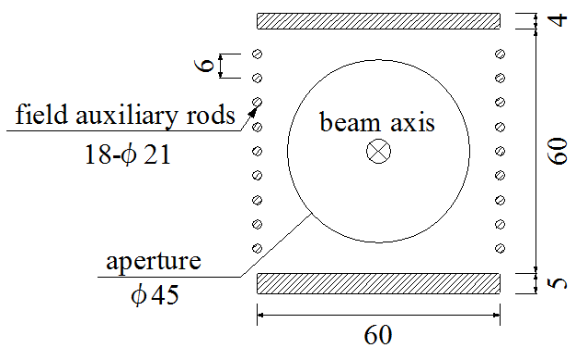

Figure 2. Transverse cross-section of main electrodes of the Wien filter (in units of mm) [3)]. The auxiliary rods connect the two main electrodes with stepwise voltages. The longitudinal length is 260 mm.

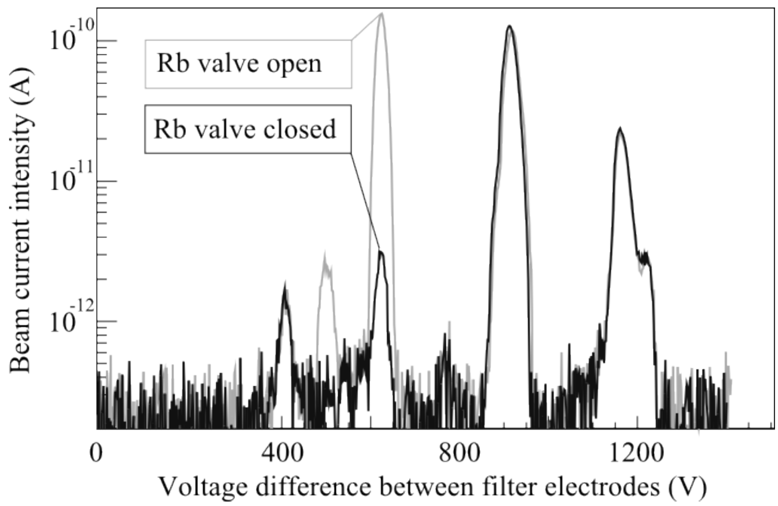

Figure 3. Mass spectra of the ion beam analyzed using the Wien filter[4]. In this measurement, the acceleration voltage of the beam was 3000 V and the current of the magnetic coils was fixed at 40 A corresponding to 1200 Gauss.

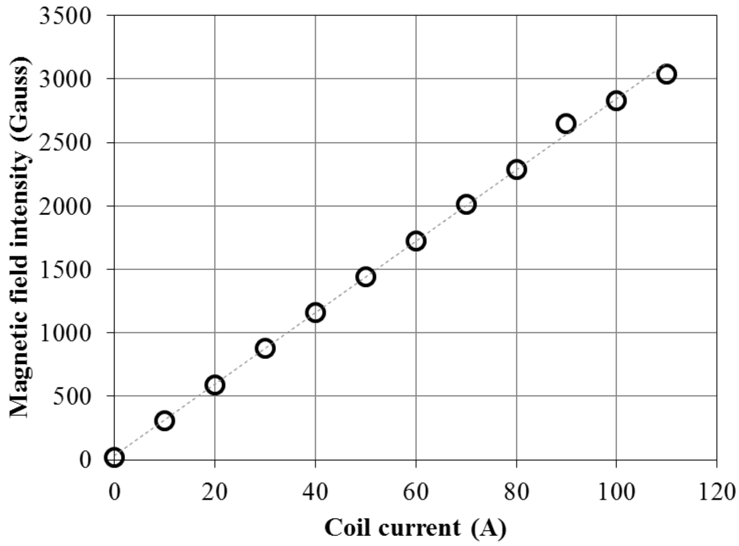

Figure 4. Coil current vs. magnetic field intensity of the Wien filter[3].