Present Status of the Search for Fr EDM

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An Electric Dipole Moment (EDM) of the elementary particle is a good prove to study the fundamental symmetry and observe the phenomena beyond the Standard Model (SM). A finite value of the EDM means the evidence of the time reversal violation, and it suggests the CP violation (matter-antimatter asymmetry) based on the CPT invariance. The SM predicts quite small EDM such as less than 10^{-37} e・cm for the electron. A non-zero EDM is considered as a background free signal of CP violation beyond the SM. However the EDM is considered to be quite small, and many ideas to detect the tiny signal from EDM are considered. We decided to search for the EDM on the radioactive atoms with large atomic number, since in paramagnetic atoms an electron EDM results in an atomic EDM enhanced by the factor ~ $Z^3\alpha^2$ [1]. The element which has largest enhancement factor is a heaviest alkali element and the radioactive atom francium (Fr). So we will search for the Fr EDM, although the EDM for the Fr have not yet been measured because it is difficult to make a concentrated sample due to a short life time for the experiment.

The overview of the experimental apparatus is shown in Fig. 1. The development and construction of the laser cooled Fr factory was started since the summer in 2009. The Fr is produced with the newly developed thermal ionizer, where the primary beam of ^{18}O from the AVF cyclotron is injected with 45 degree through the swinger magnet, which has been originally used for the charge exchange (p,n) reaction, and the produced Fr from the fusion reaction with ^{197}Au target is extracted to the vertical direction. Based on the results of the prototype of the thermal ionizer, this structure is designed to avoid for the ^{197}Au target material to be lost due to the melting and flowing down of the target head. The extracted Fr ion beam is bended 90 degree with the electrostatic prism and transported with about 10 m to the neutralizer and the MOT located at the TOF room. This beam transport system is effective to reduce the background such as the neutrons and gamma rays produced from the fusion reaction together with the Fr, which damage a certain kind of the detectors. Also the structure of the beam line is designed to achieve the high vacuum 10^{-9} Torr in the end of the beam line with the differential pumping. The Fr is produced at the 51 course of the TR5, and produced Fr is transported from the TR5 to TOF room, and finally the Fr atoms are accumulated and its EDM is measured at TOF room. The goal of this project is to establish the experimental technique to produce and collect the Fr atoms, transport to the trapping chamber with high transmission efficiency, and to get more than10^7 Fr atoms/s which is the highest production rate in the world.

At present, the new thermal ionizer is developed and the offline test is in progress. The Fr is produced with a heavy-ion fusion reaction between an oxygen beam and a gold target ($^{18}O+^{197}Au \rightarrow\ ^{210}Fr$ +5n etc.) with the primary beam energy (E_{18O}~100 MeV) just above the coulomb barrier. The target consists of a lump of gold melted and flattened onto the end of a tungsten rod. The target is surrounded by the oven, which is heated by coil heater made by tungsten wire, and the target itself is heated by the radiant heat from the oven up to 1500 degree in the design. The target rod is also cooled by the cooled air from the bottom, and we can control the temperature of the target and oven with/without the primary beam. The embedded Fr from fusion reaction diffuses rapidly to the surface and evaporates. The francium desorbs from the target surface as atoms and ions according to the Langmuir-Saha equation:

$$\frac{n_+}{n_0} = \frac{\omega_+}{\omega_0} \exp\left(\frac{E_{WF} - E_{IP}}{k_T} \right),$$

where n_+/n_0 is the ratio of ions to atoms desorbed, w_+/w_0 is the ratio of the statistical weights and equals 1/2 for alkali atoms, E_{WF} is the work function of the surface, and E_{IP} is the ionization potential of the desorbed atom. Since for gold E_{WF} is 5.1 eV and 4.08 eV for $E_{IP,}$ we have $E_{WF}>E_{IP,}$ and consequently the target emits primarily Fr ions. While Fr isotopes can be produces in other fusion reaction, we choose to use gold as a target since it is a noble metal, naturally monoisotopic, and provides an ionizing surface for alkali atoms. Many other radioisotopes are produced in the fusion reaction, but the ionization potential of those RIs are large compared with the work function of the target material gold, so only the Fr is emitted from the surface. The produced Fr ions are extracted from the electrode which is located to the upper direction, and the focusing electrodes are configured after the extraction electrodes. We can achieve the small emittance Fr ion beam thanks to the curvature and shape of the electrode designed in detail by TOSCA simulation code. The structure of the surface ionizer is shown in Fig. 2. We also make a port to inject the Rb atomic beam to the target surface for the offline calibration and optimization of the operation parameters with Rb beam whose chemical properties are similar to the Fr atom. The offline test by the Rb beam was done to check the operation of the new thermal ionizer and the beam profile of the Rb ion beam was successfully observed as shown in Fig. 3.

We are providing the TR5 and TOF with the developed experimental apparatus, performing the repair of the floor, and constructing the clean room. The construction of the thermal ionizer, the beam transport system, and the neutralizer will be completed in 2010, and the Fr production and beam transport test will be done in the autumn in 2010. The MOT and laser cooling will be also completed in 2010 and tested with Rb. All the equipments will be shaken down until the summer of 2011.

Reference

1) Sandars P.G.H., Phys. Lett. **14** (1965) 194.

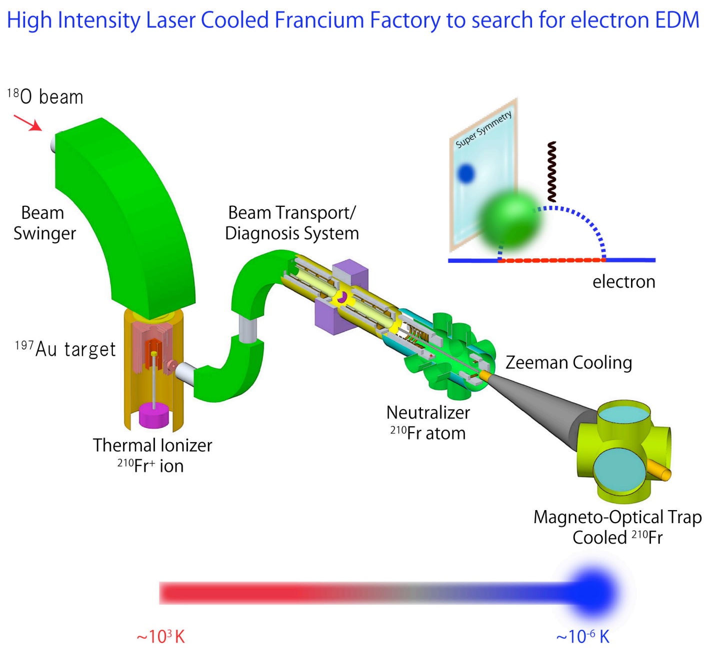

Figure 1. The overview of the laser cooled Fr factory at CYRIC. The Fr is produced by the fusion reaction and extracted from the thermal ionizer. The transported Fr is accumulated in the MOT in the final stage.

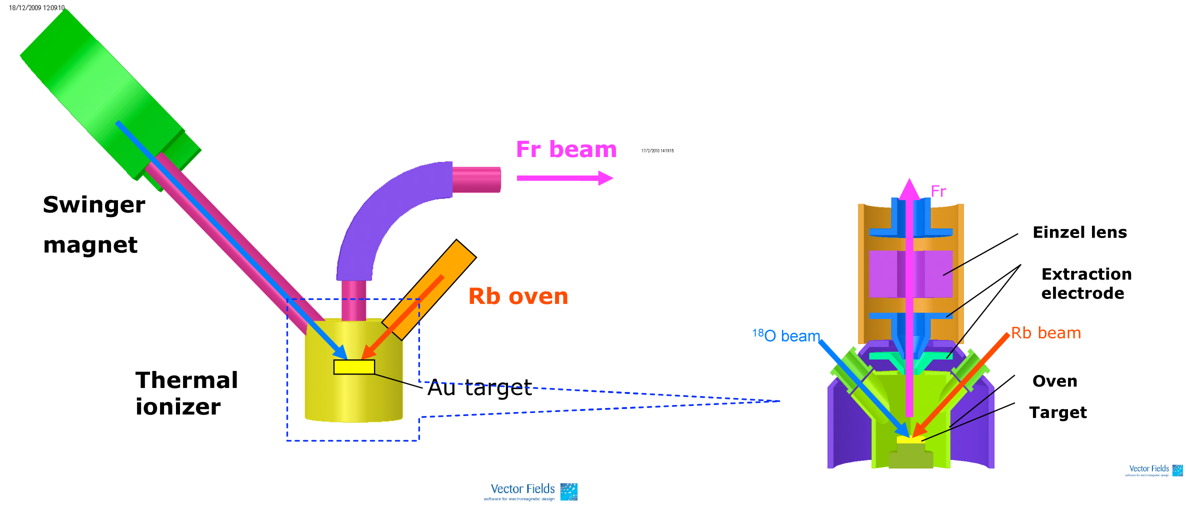

Figure 2.　The structure of the newly developed thermal ionizer.

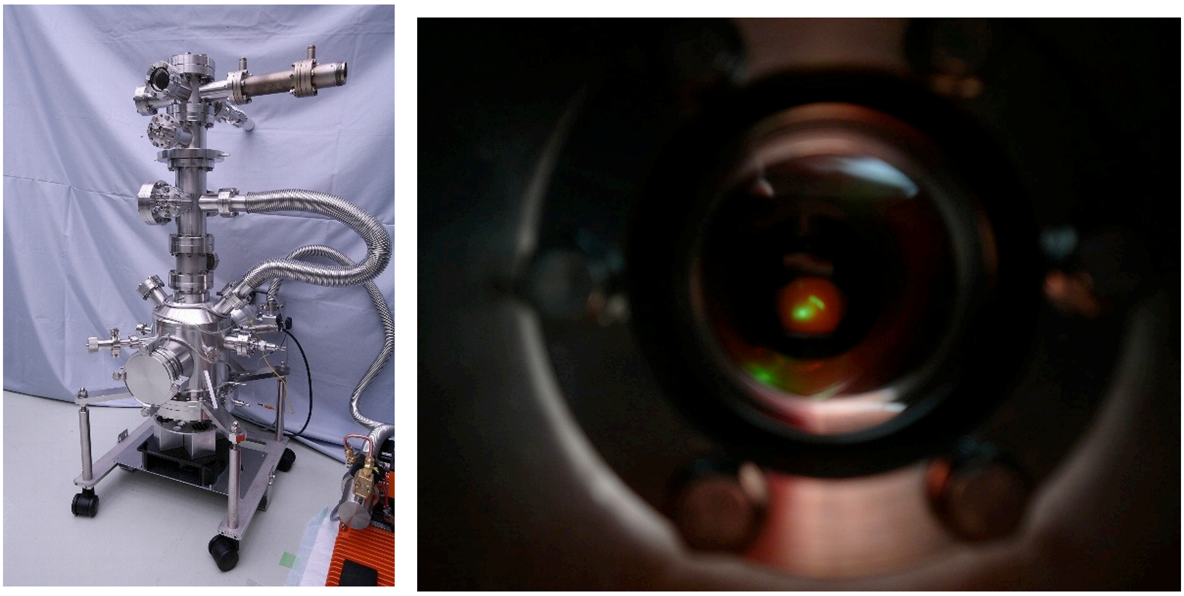

Figure 3.　The left picture shows the developed thermal ionizer, and right picture shows the Rb beam profile which was observed from the thermal ionizer for the first time.