Development of laser-cooled Fr atom source for the electron Electric Dipole Moment search

Tomohiro HAYAMIZU*
Department of Physics, Cyclotron and Radioisotope Center (CYRIC)
Tohoku University, Sendai, Miyagi, Japan
*hayamizu@cyric.tohoku.ac.jp

(Abstract) A permanent electric dipole moment (EDM) in an elementary particle indicates the violation of the time-reversal (T) symmetry violation, related to the baryon asymmetry in our universe. Since an heavy alkaline atom, Francium (Fr, Z=87) has a large sensitivity to electron EDM, we have developed laser-cooled Fr source which applied laser-cooling and trapping techniques and a nuclear fusion reaction \(^{197}\text{Au}\) (\(^{180}\text{x}, \text{xn}\)) \(^{212}\text{Fr}\) with an AVF cyclotron in CYRIC. We built an Fr ion beam line and transport and neutralized Fr ions to the end of it. We shows the present status of these Fr source.

**Electric Dipole Moment (EDM)**

Permanent EDM in an elementary particle

1 violation

CP violations (via CPT conservation)

Baryon asymmetry in our universe (via Sakharov conditions)

Enhancement factor

\[ K = \frac{d_{\text{atom}}}{d_s} \ll 2.\alpha^2 \]

Why Francium?

1. Large enhancement factor \(d_{\text{atom}}/d_s\)

2. Availability of laser-cooling (718 nm)

EDM search: Apply field B and E to atoms and measure its larmor frequency

\[ \Delta L = \frac{RF}{K E^2} \] for \( \sigma < 10^{-26} \text{ emc} \)

\( \gamma \): Enhancement \(d_{\text{atom}}/d_s\) \( \approx 855 \text{ (Fr)} \)

\( E \): External electric field \( > 100 \text{ kV/cm} \)

\( \gamma \): Interaction time \( \approx 1.4 \text{s} \) (optical trap)

\( N \): Number of atoms \( > 10^6 \)

\( m \): Measurement time \( > 10^6 \)

**Francium for EDM**

Laser-cooled Fr source for e-EDM @ CYRIC

\(^{180}\text{Au} (^{180}\text{x}, \text{xn})^{212}\text{Fr} \) (Nuclear fusion reaction)

\(^{180}\text{O}^+\) beam (\( E_{\text{lab}} = 100 \text{ MeV} \)) + \(125\text{mm} \) Au target

\( 212\text{Fr} \) Production rate: \( 3.5\times10^7 \text{pps/\muA}^2 \)

**Cooled Fr atom source**

Cooling & Trapping to Fr atoms

Laser cooling

Cooling by a photon absorption & emission every 20 µs

Magneto-optical trap (MOT)

Capture atoms using 6-way cooling laser and anti-Helmholtz coil

Overview of MOT

Captured Rb

\( \sim 10^8 \) atoms

**Present status**

Fr ion production & transport and conversion to atom

Ion production area

Fr: 2.7 \times 10^8 \text{ pps}

Rb: \sim 40 \text{ nA}

Ion to atom converter

Fr: 1.3 \times 10^9 \text{ pps}

Rb: \sim 2 \text{ nA}

Neutral Fr peak (Talk by H. Kawamura)

\( \Rightarrow \) Observed neutralized Fr

**Summary**

We have developed laser-cooled Fr source for the electron EDM search. We transported Fr\(^{+}\) to the ion to atom converter and observed neutral Fr atoms from it. As next steps, we will improve each apparatuses to confirm Fr trap in the MOT. Also we start to develop of the EDM measurement system in the optical dipole trap.