Development of the Laser Cooled Atom Trap for the Parity Non Conservation of Fr

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I. 1. Development of the Laser Cooled Atom Trap for the Parity Non Conservation of Fr

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The parity non conservation (PNC) of the nuclear beta decay has been investigated extensively and has lead the construction of the framework for the weak interaction with the V-A (Vector – Axial vector) theory. From the microscopic point of view, the beta decay is the transition between the quarks with the different flavors within the same generation, namely 1st generation of the quark family, with the charged current which means the propagation of the charged gauge boson of the weak interaction, $W^{\pm}$ bosons. This process is occurred by the charge exchange reaction, and can be measured with the standard experimental technique. However, on the other hand, the observation of the effects from the neutral current, which is the propagation of the neutral weak boson Z, has been quite difficult due to the fact that there is no flavor and charge changes. Only the high energy electron and neutrino scattering experiments explored the neutral currents precisely thanks to the large contribution from the high momentum transfer (q) compared with the large mass of the weak boson. To understand the structure of the weak interaction more precisely, to search for the phenomena beyond the standard model, and to investigate the parity violating nuclear force in the nucleus, the experiment to detect the PNC in the small momentum transfer region is very important. The PNC for the neutral atom, therefore, is the powerful tool to explore these important topics related with the neutral current, since the flavor of the lepton and quark is not changed in the atom, and it observes the small q.

At the CYRIC, we plan to measure the PNC for the francium, which is the heaviest alkaline atom and radioactive element with the half life of about 3 min. The physics goal is to extract the parity violating nucleon-nucleon interaction to understand the weak interaction in the strongly interacting nuclear medium through the measurement of the anapole moment, which is the parity odd higher order term in the multipole decomposition of the vector potential. The heaviest alkaline element Fr is selected, since the theoretical calculation suggests that the anapole moment is enhanced with the $A^{2/3}$, where the A is the mass number of the atom. Also the new experimental method to measure the anapole moment is now introduced using the laser cooling technique. Up to now, only two measurements for Cs and Tl were done, and their measurement accuracy is limited due to the short interaction and measurement time, because they use the atomic beam. Then, we will measure the anapole moment with the cooled atom ensemble using the laser cooling/trapping technique to realize the long interaction and detection time.

We are now constructing the high intensity Fr ion source, the beam transport system, the neutralizer, and the magneto-optical trap (MOT), which will be utilized commonly to search for the electric dipole moment of Fr. However, the double MOT configuration and high sensitive photon detection are essential especially for the anapole moment measurement to obtain a subtle signal emitted with the de-excitation from the forbidden state where the parity mixed states are degenerated due to the weak interaction and stark shift effect. The developed MOT is shown in the Fig. 1. The first MOT is used for the collection and buffering of the Fr introduced from the neutralizer. The second MOT is used for the measurement with the long interaction and detection time thanks to the high vacuum. These two MOTs are connected with the narrow tube to achieve the high vacuum in the second MOT using the differential pumping. The vacuum level with 10^{-9} Torr and 10^{-11} Torr were realized in the 1^{st} MOT and 2^{nd} MOT respectively. Instead of the Fr atom, which is produced by the nuclear fusion reaction, the stable atom Rb was used to investigate the performance for the atom trapping. We have succeeded in the double MOT to collect, push, and accumulate the Rb for a long time. Then, we measured the life time of the accumulated Rb atoms in the 2^{nd} MOT as shown in the Fig. 2. The horizontal axis shows the measurement time, and the vertical axis shows the number of the Rb atoms in the MOT, which was estimated from the photon intensity measured by the CCD camera. We could observe the two components of the slopes showing the lifetime of the trapping atom. The first component, which shows the short life time with about 10 sec, means that the atoms are lost due to the collisions between trapped atoms. The second component shows the longer life time with about 40 sec, and it can be interpreted that the atoms are lost due to the collisions between the trapped atoms and background gas, which depends on the vacuum level. The development for the high sensitive photon detector is also in progress.

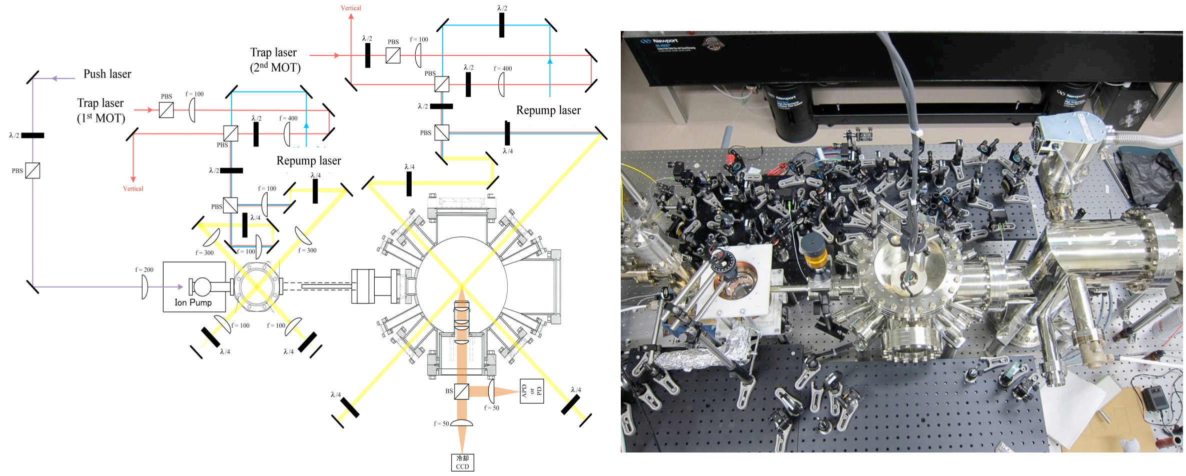

Figure 1.　The experimental setup of the double MOT. The left figure shows the configuration of the MOT chambers and laser.　The right picture shows the developed experimental apparatus of the double MOT.

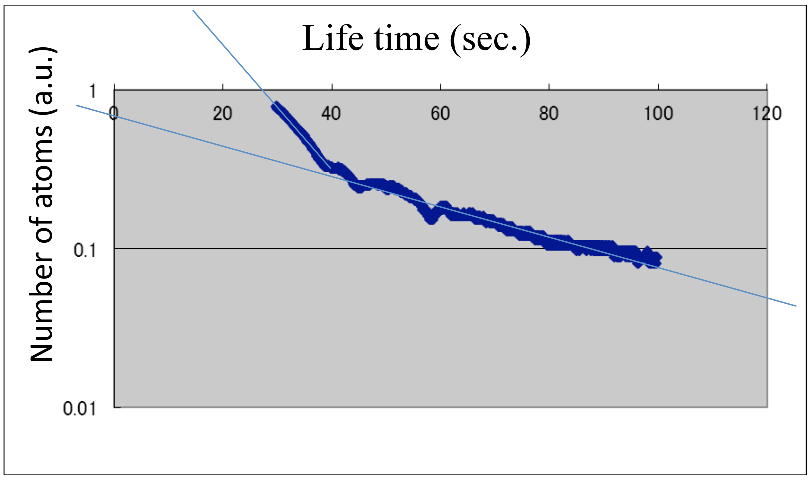

Figure 2.　The lifetime of the trapped Rb atom in the 2nd MOT.　Two components of the lifetime are observed in the plot.