High sensitivity CCD camera detection for weak radioactive atoms MOT

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I. INTRODUCTION

The field of nuclear investigation with spectroscopic tools is continuously growing. In particular trapping techniques open the possibility to prepare peculiar nuclear states to study nuclear symmetries through a detailed analysis of nuclear decay processes. So experiments aimed at laser cooling and trapping of neutral radioactive atoms are nowadays operative in many laboratories and precise measurements of atomic parameters as well as the study of parity violation, α and β decays are being carried out with 37,38K, 79Rb, 82Rb, 208,209,210,211Fr [1]. Francium atom is still poorly known, it has many isotopes which decay in different ways and with different lifetimes, it shows huge relativistic effects in its level structure, it is in principle the best candidate for atomic parity non conservation (APNC) experiments [2]. A magneto-optical trap for francium radioactive atoms is under optimization at the INFN Legnaro laboratories. During the last year the experimental set-up has been completed with a velocity filter in order to clean the ion beam from all the elements but Fr and signal detection has been improved with a high sensitivity CCD camera.

II. THE EXPERIMENTAL APPARATUS

Francium can be produced either by nuclear decay or through a nuclear reaction. We utilize the TANDEM accelerator that provides a high-energy 18O (charge state +6 or +7) beam which, colliding with a gold target, produces the nuclear fusion-evaporation reaction

\[ {\text{18}}^{\text{O}} + {\text{197}}^{\text{Au}} \rightarrow {\text{215}}^{-}\text{Fr} + \text{n} \]

where n stays for neutrons. The isotopes produced with the highest rate are 206,209,210,211Fr.

The experimental area and apparatus have been already described in detail elsewhere [3]. With respect to those descriptions we inserted a velocity filter between the hot room, where the primary oxygen beam is delivered to the target, and the cold room, where the MOT and the laser systems are installed. This filter allows for isotopes separation with a resolution close to 5 amu. In this way we are sure that only Fr isotopes are delivered to the MOT, cleaning the beam from light ions coming from the target area. The thermo-ionic current, that is removed by velocity filter, provokes a trap signal decrease, roughly, of a factor 2 as we could observe on a Rb MOT, that is used to define the trap region and to test the detection system.

The MOT has the standard configuration. Six laser beams, circularly polarized, cross in the center of a pyrex cell. Two coils arranged in the anti-Helmholtz configuration generate a quadrupole magnetic field. At the beginning the cell was coated with a thin film of polydimethylsiloxane (PDMS) that has the twofold property of allowing elastic bouncing of atoms at the cell surface and to desorb upon weak illumination the atoms eventually adsorbed [4]. This increases the probability for them to get trapped. Recently we changed the coating to dry-film that has physical properties close to that of PDMS, but allows for a better vacuum limit.

The resonant wavelengths are 817 nm and 718 nm for the D1 and D2 transitions, respectively. The 718 nm line is delivered by a Ti:Sapphire cw ring laser pumped by a Ar+ laser. The repumping laser is a diode laser whose beam is overlapped to the trapping laser. These two lasers are actively stabilized with the help of a stabilized He-Ne laser as no francium reference cell is available. Other two diode lasers tuned to the rubidium resonance frequencies are used to make a rubidium MOT, so to check all the apparatus working conditions. A wavelength-meter is used to measure the absolute value of the laser wavelengths. A new high sensitivity CCD camera and a photomultiplier are used to monitor the fluorescence coming from the trapped atoms. In the following is reported the calibration of the CCD camera.

III. CALIBRATION OF THE CCD CAMERA

The first important topic is how to deduce from a photogram of a cold cloud of atoms how many atoms are present in the cloud. For this we have to set a good definition for the signal S that we have deduced from the photogram. Then we have to establish the proportionality relation between S and the number of atoms.

For the choice of S the idea is to fit the spot profile along the x axis with a gaussian function and take as region of interest an area large two times the gaussian width. The signal S is then the sum of the pixels inside this region after the subtraction of the background.

The calibration procedure can be performed in two step: first the calibration of the CCD in terms of the light power entering the zoom lens. Then the calculation of how much light is emitted from a single atom and then reaches the zoom lens, i.e. calculation of the fluorescence rate and solid angle. We chose to calibrate with a spot obtained...
from a laser beam (He-Ne or Ti:Sa) incident on a black screen. Photograms were taken for different powers, at three different wavelengths 633, 721 and 779nm. This procedure allows checking the linearity of the CCD and gives an estimation of the minimum power level that can be detected.

We see in the figure an example of Rb trapped atoms cloud.

The problem is now to deduce how many atoms are present in the MOT cloud, from the value of the light power obtained from the analysis of the photogram. The Fr and Rb atoms, saturated on the D$_2$ transition, emit the following power:

\[
P^\text{sat}(\text{Rb}) = \frac{h \nu_{\text{Rb}}}{2 \tau_{\text{Rb}}} = 4.8 \, \text{pW}
\]

\[
P^\text{sat}(\text{Fr}) = \frac{h \nu_{\text{Fr}}}{2 \tau_{\text{Fr}}} = 6.6 \, \text{pW}
\]

For the geometry of our detection system the solid angle \(\Omega\) for the photons which reach the detector is

\[
\Omega = 1.5 \times 10^{-3} \, \text{sr}
\]

So for one Fr (or Rb) atom, the light power entering the detection system is 10 fW (or 7.2 fW) and 1 pW correspond to about 100 Fr atoms (or 140 Rb atoms). In order to know the sensitivity of the detection system, we also decided to evaluate the noise on the signal S. The first results show that the noise level of our detector is usually less than 100 Fr atoms, almost all due to the background light. Work is in progress to reduce the scattered light and then improve the signal to noise ratio.