Preliminary tests of the Legnaro francium Magneto-optical trap

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I. INTRODUCTION

Experiments aimed at laser cooling and trapping of neutral radioactive atoms are nowadays operative in many laboratories. They open a bridge between atomic physics and nuclear physics making possible new and precise spectroscopic measurements and detailed analysis of nuclear decay processes.

In particular, precise measurements of atomic parameters as well as the study of parity violation, $\alpha$ and $\beta$ decays are being carried out with $^{37,38}$K, $^{21}$Na, $^{79}$Rb, $^{82}$Rb, $^{208,209,210,211}$Fr \cite{1}.

A magneto-optical trap for francium radioactive atoms is almost operative at the INFN Legnaro laboratories. During the last year the experimental set-up to trap neutral francium atoms has been completed and the apparatus for ion transport, optical set-up and signal detection was optimized. 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 \cite{2}.

Francium can be produced either by nuclear decay or through a nuclear reaction. We utilize the TANDEM accelerator that provide a high-energy $^{18}$O beam which, colliding with a gold target, produces the nuclear fusion-evaporation reaction

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

where n stays for neutrons. The isotopes produced with the highest rate are $^{208,209,210,211}$Fr \cite{3}.

II. THE EXPERIMENTAL APPARATUS

The experimental area is divided into two zones, one (hot room) where the primary oxygen beam is delivered to the target and the other one (cold room) where the MOT and the laser systems are installed. Inside the MOT cell the Fr$^+$ beam impinges on a heated zirconium foil (6 mm diameter), where it is neutralized. Details of the beam line are reported in \cite{3}. The neutralizer, placed inside a pyrex cell, is kept at a temperature high enough to allow francium neutral atoms to be desorbed and trapped.

The MOT has the standard configuration. Six laser beams, circularly polarized, cross in the center of the cell. Two coils arranged in the anti-Helmholtz configuration generate a quadrupole magnetic field. The cell is 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 \cite{4}. This increases the probability for them to get trapped.

The resonant wavelengths are 817 nm and 718 nm for the D$_1$ and D$_2$ 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. This two lasers are actively stabilized with the help of a stabilized He-Ne laser as no francium reference cell is available. The lasers are coupled to a Fabry-Perot interferometer and the stabilization procedure works in such a way that the separation between the laser peaks transmitted by the interferometer is kept constant \cite{5}. 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 CCD camera and a photomultiplier are used to monitor the fluorescence coming from the trapped atoms.

III. TEST WITH STABLE ALKALI ATOMS

The optimization of the total trapping efficiency is the fundamental issue that has to be pursued. We propose new approaches that have been tested by us with stable atoms and that seem very promising.

The first one consists on MOT loading through light induced atomic desorption (LIAD) from the PDMS coatings.

We want to use PDMS because it has, besides weak adsorption energy, also the capability to release the adsorbed atoms upon weak light illumination. At room temperature, a vapor density increase larger than one order of magnitude is obtained by using light coming from a photographic flash or from a pocket lamp. Laser light gives essentially the same feature. An atomic source of rubidium triggered by light has been realized \cite{6}. Francium atoms can be loaded inside the coating and desorbed all together by a light flash. This should give a peak density much higher than the one reachable by continuously collecting the atoms coming from the target.

In order to test this solution, we have made a preliminary experiment with a rubidium MOT \cite{7} in a PDMS coated cell. The PDMS is exposed for a while to
rubidium vapor, then the metal reservoir is cooled down so
to reduce essentially to zero the residual Rb vapor
pressure. In these conditions no trapped atoms can be
observed till a light flash illuminates the MOT cell. At this
time rubidium atoms are desorbed from the walls and
trapped. This already good result is made more interesting
by the very high loading rate and very short trapping time
measured. Figure 1 shows the fluorescence coming from
trapped atoms as a function of time when atoms are
produced by desorption (curve a) or when are trapped from
the room temperature vapour (curve b).

From Figure 1 a net difference among the loading and
decay times is evident. They in fact differ by more than
two orders of magnitude. This shows that there are no
relevant vacuum problems. Also, the decoupling between
the loading and trapping time was not observed before with
other pulsed atomic sources [8].

The MOT loading rate from a vapor is determined by
the fraction of atoms having a velocity smaller than a
critical value that is the capture velocity \( v_c \) of the trap.
When the collisions among trapped atoms can be neglected
and the background gas consists only of the alkali atoms,
the loading time and the decay time are identical. Upon
these conditions the maximum number of trapped atoms is
fixed by the dynamical equilibrium among trapping rate
and decay rate that is independent on the laser intensity
and vapor pressure. This limit can be overcome by
working with pulsed atomic sources, as already discussed.
When the vapor density is very low or the flux of atoms
injected into the trap is very small the issue becomes the
trapping rate maximization so to reduce atom losses. This
result can be obtained by making \( v_c \) as large as possible.
This can be obtained by adopting the “white-light cooling”
scheme which makes use of special broadband lasers or
“white” lasers [9]. Such lasers are instantaneously on
resonance with atoms spread across a large velocity range
so making \( v_c \) much larger. This approach has been
positively tested with lithium ions confined in a storage
ring [10]. Due to the very small flux of Fr ions it is crucial
maximize the detection sensitivity. To obtain this result we
are performing measurements with a modulated magnetic
field, in the range 0 – 500 Hz, which gave very good
preliminary results.

FIG. 1: the fluorescence coming from trapped atoms as a
function of time when atoms are produced by desorption (curve a)
or when are trapped from the room temperature vapour (curve b).

\[\text{Number of trapped atoms (10^7)}\]
\[\text{Time (s)}\]

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