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Nuclear Physics A 746 (2004) 459c–462c
NUCLEAR PHYSICS A

Francium developments at Stony Brook

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Radioactive beams of Fr isotopes of up to $\approx 10^7/sec$, produced at the Stony Brook Superconducting Linac, are being used for experiments in atom and ion trapping. An improved batch-filled atom trapping system is an order of magnitude more efficient than the previous system. A proposed g-factor measurement is planned with polarized nuclei in an ion trap.

1. INTRODUCTION

The radioactive element francium is of great interest because, as an alkali, it is the heaviest atom in which the atomic properties can presently be calculated to better than 1%. The electron-nucleus interactions in heavy atoms are stronger than in lighter alkalis, and are more sensitive to weak interaction effects in nuclei, such as anapole moments, electric dipole moments and other parity violating effects. The ability to trap large numbers of atoms, $> 10^6$, would make possible precision measurements of these effects. Stony Brook[1] and Legnaro[2] now have the capability to produce and trap radioactive Fr produced with heavy ion reactions, and experiments are planned at KVI(Groningen) and at TRIUMF. There is also interest in using cold atomic beams to look for atomic parity violating effects[3].

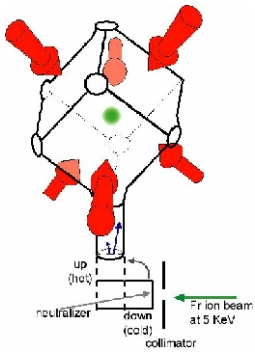

Figure 1: New system for trapping Francium

2. NEW ATOM TRAPPING SYSTEM

The number of trapped atoms, N, is given by $N = I\eta t$, where I is the initial Fr beam intensity, η the trapping efficiency, and t the lifetime of an atom in the trap. At Stony Brook, we initially worked with Fr beams of the order of 10^{5-6} Fr/sec. The lifetime of the trap is determined by the quality of the vacuum, with $t \approx 10$ sec for pressures 10^{-9} Torr. In our initial work, the trapping efficiency was of the order of 10^{-3}, so we would typically have about 10^{3-4} atoms in the trap. In the last year, a new approach to trapping has made an order of magnitude improvement in the trapping efficiency[4]. Along with evolutionary improvements in the Fr production and vacuum, we can now trap 10^5 atoms routinely, and when everything is working optimally, should be able to achieve 10^6 trapped atoms. Figure 1 shows the new apparatus[5]. The system works in "batch" mode, with Fr accumulating on a cold neutralizer for a fixed time. After accumulation, the neutralizer is rotated so that it covers the only opening in the trapping

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2004.09.135

cell, and the neutralizer is then heated to evaporate the Fr atoms into the cell. Because there are no exit holes, the Fr has longer to be trapped in the cell before it is lost to either a defect in the cell coating, or it finds the small cracks around the neutralizer to diffuse out of the cell. With this system, the overall trapping efficiency is now $> 1\%$. The "batch" nature of the trap is ideal for the planned transfer to a second trap. If the second trap has a much longer lifetime, then the number accumulating there will be proportional to that lifetime, and even larger numbers of atoms should be accumulated.

3. NEW BEAM LINE

Another problem that we had with our original trapping system was that because the target was located within about 2m of the trap, the neutron background precluded our working at the trap, and everything had to be remotely controlled, or tediously changed by turning off the beam and entering the target room. We have solved this problem with the new setup which is shown in Figure 2. The primary 100 MeV ^{18}O beam from the Stony Brook LINAC impinges on a Au target, which is in the shielded target room, while the trap and all of the laser systems are in a separate laboratory. Fr is transported as an ion beam through a small hole in the shielding wall, and the low energy alpha, beta and gamma activities are easily shielded in the trapping area. The target is heated by the beam and by an auxiliary heater to just below the melting point for fast diffusion of the Fr to the Au surface, where it is emitted as an ion. By adjusting the beam power, we can melt the target, and there is a corresponding large increase in the Fr beam because of the enhanced diffusion in the liquid. For longer life of the target, we generally work just below the melting point. We have observed the melting with a CCD camera, since the emissivity of the liquid is about 5% higher than that of the solid. The ions are transported at 5 keV in the all-electrostatic beam line. The transport is mass independent, so that we can tune

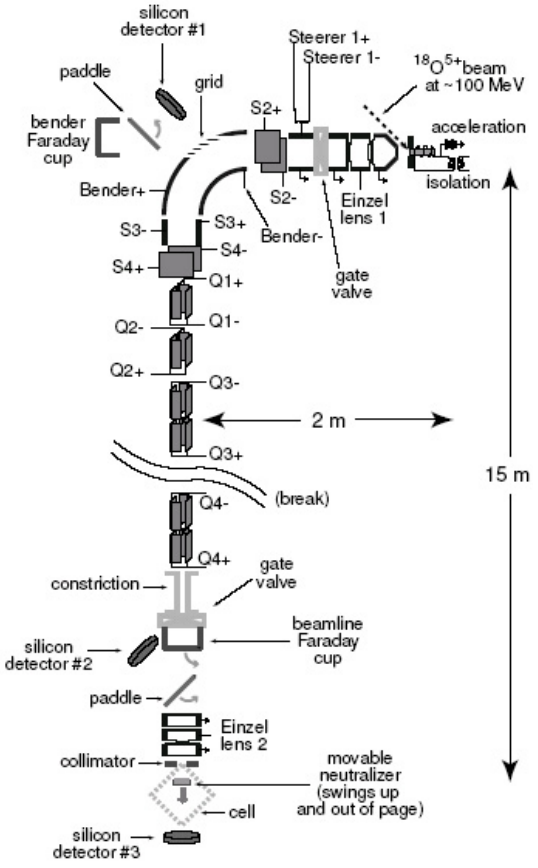

Figure 2: New beamline for transporting Francium away from the target area.

everything with a Rb^+ beam generated by spraying Rb atoms onto the hot Au target, or from the inevitable impurity alkali atoms present in even the highest purity Au.

4. PROPOSED PRECISION NUCLEAR g-FACTOR MEASUREMENT

The hyperfine interaction constant is an important testing ground for ab-initio atomic calculations of Fr. While the nuclear g-factor has been previously measured with a precision of 2%, a more precise measurement is necessary for testing the atomic wave functions that are used for weak interaction measurements in Fr. We propose to measure the nuclear g-factor with Fr^+ ions, in which the much larger electron magnetic moment is removed. We are developing an apparatus, similar in concept to the TRIUMF polarized Li beam: we start with a Fr^+ beam, neutralize it, polarize it by optical pumping, and then re-ionize the atoms to form a polarized Fr^+ beam. We will then slow, cool, and confine the ions in an ion trap. We will measure the nuclear magnetic moment to high precision by resonantly destroying the spatial anisotropy of the alpha-particle decay distribution.

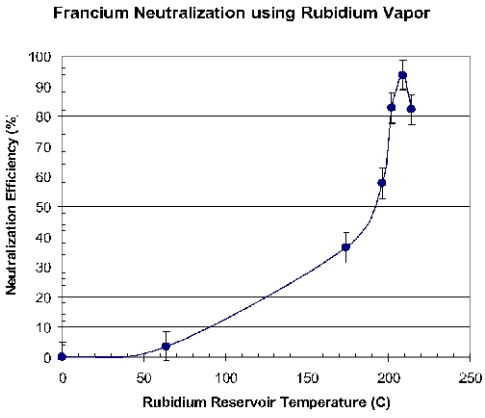

Figure 3: Neutralization of Fr ions with Rb vapor

The g-factor measurement apparatus is presently under construction. The neutralization step has been successfully accomplished with Rb vapor as a neutralizer. We simultaneously injected both a Rb^+ beam and a much weaker Fr^+ beam through a Rb vapor and determined the Rb ion/atom ratio by measuring the Rb^+ ion current in Faraday cups before and after the vapor region. The Fr ion/atom ratio was determined by stopping the Fr beam in front of an alpha-particle detector, and deflecting the Fr^+ ions after the vapor region with a transverse electric field. The neutral fraction vs Rb reservoir temperature is shown in Figure 3. With this system, we have established that the charge exchange cross section for $Fr^+ + \mathrm{Rb}$ is larger than the corresponding cross section for $Rb^+ + \mathrm{Rb}$, and 90% of Fr^+ are neutralized with 4cm of Rb vapor at $T \approx 115°C$ at the neutralization chamber with atom density of $1.5 \times 10^{13}/cm^3$.

E. G. is supported by CONACYT, Mexico. This work has been supported by NSF.

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