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Nuclear Instruments and Methods in Physics Research B 126 (1997) 383–385

NIM B
Beam Interactions with Materials & Atoms

Coupling an optical trap to a mass separator

R. Guckert [a,b,*], E.P. Chamberlin [a], D.W. Preston [a,c], V.D. Sandberg [a], D. Tupa [a], D.J. Vieira [a], H. Wollnik [a,b], X.X. Zhao [a]

[a] *Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[b] *II. Phys. Institute, Justus Liebig University, 35392 Giessen, Germany*
[c] *Physics Department, California State University, Hayward, CA 94542, USA*

Abstract

The efficient coupling of a magneto-optical trap to a mass separator is being developed to undertake high-precision electroweak interaction measurements in a series of radioisotopes. The use of ion implantation and subsequent heated-foil release is being pursued as a suitable way of introducing radioactive samples into the ultra-high vacuum region of an optical trap without gas loading. In this paper we discuss the layout of the mass separator, the coupling to a magneto-optical trap, and the implantation and release scheme.

PACS: 28.60.+s; 32.80.Pj
Keywords: Mass separator; Optical trap

1. Introduction

There are at least two important experiments in the area of electroweak interactions which can be performed in a magneto-optical trap. One is the study of atomic parity nonconservation in heavy alkali atoms and the other is β-spin correlation measurements with polarized nuclei. In both cases a large number of trapped, highly-polarized radioactive atoms are envisaged as the ideal source for the next generation of high-precision experiments.

A magneto-optical trap (MOT) consists of six circular polarized, counterpropagating laser beams which in combination with a pair of anti-Helmholz coils enable cooling and trapping of atoms (see Ref. [1] for more details). A standard MOT can easily trap 10^{10} atoms out of the vapor state. Trapping efficiencies of 6% have been achieved using a dryfilm-coated cell [2] and more recently we have obtained trapping efficiencies of 20% using a more optimized cell geometry [3]. The trapping of radioactive atoms, however, requires modifications to the standard trapping technique. Experiments which trap radioactive atoms suffer from an additional loss due to exchange processes when radioactive atoms strike the wall and knock out a stable atom that is used to "cure" defects in the dryfilm coating. Thus, for trapping efficiency measurements using stable species, it is often difficult, if not impossible, to tell the difference between a atom that hits the wall and knocks off an identical isotopic atom from the process where an atom just bounces off the wall without atomic exchange. When trapping radioactive atoms, however, this exchange process would lead to the replacement a radioactive atom with a stable atom that is not trapped. A second concern is the efficient loading of the MOT that does not degrade the ultrahigh vacuum as needed to obtain high trapping numbers and long storage times. We have developed a method of coupling a MOT to a mass separator which introduces the radioactive species of interest by ion implantation onto a small catcher foil with subsequent release via inductive heating of the foil.

2. Mass separator

The layout of the separator is shown in figure 1. Our goal was to design a robust system featuring high transmission which is capable of handling relatively intense radioactive samples. For alkali and alkali earth species we use a thermal ion source in which a tungsten crucible containing the sample is heated by electron bombardment to high temperatures. Adjusting the temperature of the crucible by controlling the electron bombardment power allows operation at a setpoint where vaporization and

* Corresponding author. Fax: +1-505-665-4955; e-mail: guckert@lanl.gov.

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PII S0168-583X(97)01065-8

ionization is low for ^{82}Sr ($t_{1/2}$ = 25 days), for example, and high for its daughter ^{82}Rb ($t_{1/2}$ = 75 s). Operating in such a condition helps to minimize radioactive contamination of the system by the long-lived parent.

Ions are extracted using an extractor lense mounted 25 mm from the ion source. The divergence of the ion beam is determined by the potential of the extractor lense. A pair of x–y electrostatic steering plates are installed 30 cm from the ion source to correct for any misalignment of the extracted beam. In between the pair of steering units a Faraday cup and a scanning wire detector are used to measure beam quality and verify high transmission through the separator. Following the electrostatic steering plates, the beam enters an electrostatic quadrupole triplet which has an aperture of 60 mm and an effective length of 160 mm for each quadrupole. Mass separation is achieved in a 90° C-type magnet with a gap of 10 cm and a bending radius of ρ = 1.6 m with normal entrance and exit angles. Detailed information about the magnet can be found in [4]. Field clamps have been installed at the entrance and exit of the magnet to define the fringing field region. At the focal plane a variety of diagnostics devices are installed. These include CsI coated screens to visualize the beam, Faraday cups to measure the beam current and a scanning wire detector to measure the beam profile. A pair of stabilization pins enables the feedback stabilization of the magnet for long-term operation. Finally, a slit arrangement is used to select one mass species which is than passed into a second quadrupole triplet to focus the mass-selected beam onto the catcher foil.

Typically operation of the separator utilizes a vertical crossover in the magnet that produces a small vertical line (1×5 mm) at the focal plane. This solution minimizes aberrations and maximizes the transmission through the system. This setup features a mass resolution $\delta M/M$ (fwhm) of 5×10^{-4} at the focal plane. The spot size at the final focus position is less than 2 mm in diameter; ions are implanted into a 5 mm diameter catcher foil.

3. Coupling a magneto-optical trap to a mass separator

High-efficiency considerations in the trapping region require the use of a non-stick coating which minimizes the sticking time of atoms onto the wall of the vacuum vessel. A study of different wall coatings suitable for optical trapping can be found in Ref. [2]. Silane-based dryfilm-coated glass cells can achieve trapping efficiencies of more than 30%. Unfortunately suitable coatings of metal surfaces have not yet been found. Our cell consists of a Pyrex cube with two in-line tubes through which the ion beam enters the cell and is implanted into the catcher foil. A schematic drawing is shown in the inset of Fig. 1. Both ends of the glass tubes are ground to allow optical flats to close off the trapping vessel upon command. In this design all wall surfaces can be dryfilm coated leaving only the

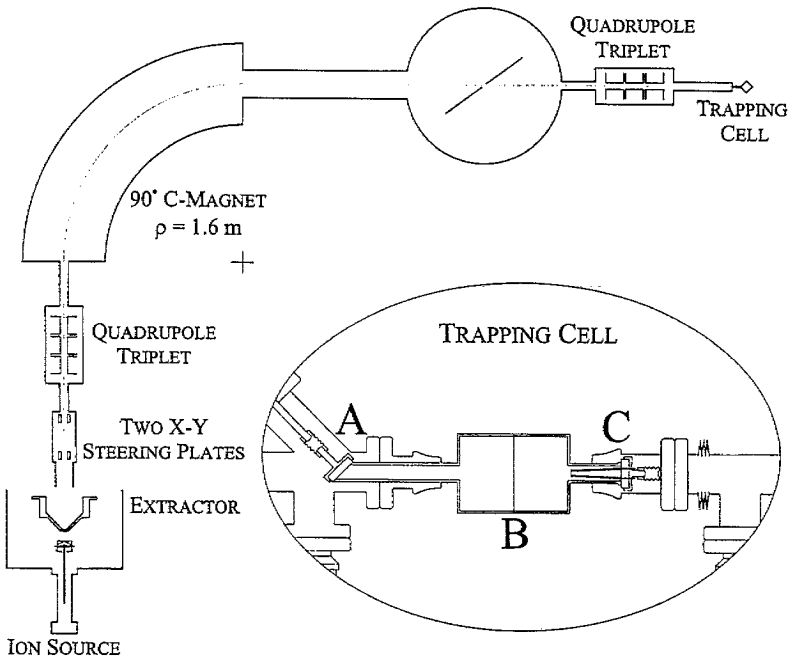

Fig. 1. Overview of the mass separator and the coupled magneto-optical trap. The ion source region is enlarged by a factor of 10. The inset shows an enlargement of the trapping cell region. The beam enters thru a 45° valve (A), passes thru the trapping cell which is a 80 mm Pyrex cube (B) and is implanted in the catcher foil (C). The entire region is maintain at UHV by two 20 l/s ion pumps.

catcher foil uncoated. The ratio of uncoated to coated surface area is $\sim 7 \times 10^{-4}$ which, on average, will enable more than 1000 "wall bounces" before the atom hits the foil and is lost from the trapping process. A large number of "wall bounces" is needed to obtain multiple chances of trapping the atom and consequently achieving high trapping efficiencies.

Inductive heating of the foil is a suitable way of releasing the implanted atoms. A small coil is wrapped around the tube that surrounds the catcher foil. Driving the coil with a 25 W, 8 MHz amplifier through a simple LC circuit heats the foil to temperatures of 1300°C in less than 300 ms. We are presently testing the implantation and release process with Pt and Y foils using a stable Rb beam. In the near future we will attempt to implant and trap radioactive ^{82}Rb using a ^{82}Sr sample placed in the ion source. Our near term goal is to trap 10^6 atoms of ^{82}Rb with an overall efficiency of $\geq 1\%$ so that a high-precision β-asymmetry measurement can be undertaken.

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