

# An enriched $^{40}\text{K}$ source for fermionic atom studies

B. DeMarco, H. Rohner, and D. S. Jin<sup>a)</sup>

*JILA, National Institute of Standards and Technology and Physics Department, University of Colorado, Boulder, Colorado 80309-0440*

(Received 29 September 1998; accepted for publication 15 December 1998)

We have developed a novel, enriched potassium source for use in trapping and cooling of the fermionic isotope  $^{40}\text{K}$ . The source is clean, easily controllable, and consistent with high vacuum applications. With this enriched source, we are able to collect  $10^8$   $^{40}\text{K}$  atoms in a vapor cell magneto-optical trap. © 1999 American Institute of Physics. [S0034-6748(99)00304-4]

## I. INTRODUCTION

Vapor cell magneto-optical traps (MOT) provide a relatively simple apparatus for laser cooling and trapping.<sup>1</sup> For alkali atoms, the atomic vapor is often derived from a reservoir containing a small amount of alkali metal. This reservoir may be controlled to some extent with temperature. Heating the source will increase the vapor pressure above the inherent room-temperature value while cooling the source can be used to reduce the background pressure. If additional control is desired, a valve may be used to separate the reservoir from the rest of the MOT vacuum chamber.

We are interested in studying an ultracold, trapped gas of the fermionic isotope  $^{40}\text{K}$ . While this isotope is essentially stable (with a half life of  $10^9$  years) the natural abundance is only 0.012%. With the usual type of source, this low abundance would limit the number of atoms that could be collected in a vapor cell MOT. Therefore, we have developed an enriched source.

Potassium enriched in  $^{40}\text{K}$  is available commercially in the form of a salt, KCl, rather than as a pure metal.<sup>2</sup> In addition, the cost of the enriched material is quite high (roughly \$2000 for 100 mg of K) compared to the cost of unenriched potassium metal. For this reason the ideal source should deliver potassium vapor for a MOT efficiently using only a small amount of material. This introduces new design concerns when compared to the usual case of an alkali metal reservoir containing on the order of 1 g of metal. For example, losses due to continuous exposure of the source to the vacuum pumps or due to adsorption of the alkali atoms onto metal surfaces in the chamber may be significant.

## II. CONSTRUCTION OF THE ENRICHED SOURCE

Our enriched source is based on the design of commercially available alkali metal dispensers by SAES Getters.<sup>3</sup> These dispensers, developed primarily for use in the manufacture of photosensitive devices, have been used previously for vapor cell MOT's<sup>4</sup> and have even been used successfully in a Bose-Einstein condensation apparatus.<sup>5</sup> The dispenser contains an alkali salt as well as a reducing agent and delivers small amounts of pure alkali metal through chemistry that

occurs inside the vacuum chamber. The metal is released, or evaporated, simply by Ohmic heating of the dispenser. The vapor pressure can then be controlled with the current applied to the device; the source is essentially turned off completely if there is no applied current. Unfortunately we were unable to find a company willing to make dispensers for enriched isotopes upon request, presumably because the commercial dispensers are generally mass produced.

Our  $^{40}\text{K}$  source contains enriched KCl plus calcium (Ref. 6) for the reduction reaction. The KCl contains K that is 4.5%  $^{40}\text{K}$ , 29.1%  $^{41}\text{K}$ , and 66.4%  $^{39}\text{K}$ .<sup>7</sup> (Natural abundances are 0.012%  $^{40}\text{K}$ , 6.73%  $^{41}\text{K}$ , and 93.26%  $^{39}\text{K}$ .) Upon heating the source, the enriched K is released while the Cl as well as other contaminants are captured by the Ca.

The Ca must be very pure, especially since its dominant contaminant tends to be alkali metals. If proper care is not taken, these alkali contaminants will be released when the source is activated, leading to higher background pressures as well as a reduced relative abundance of the desired isotope. The Ca used in our source was baked at 400 °C under vacuum for four days in order to drive out any impurities. As a check on the purity of the Ca, we performed a yield measurement (described below) and verified that a source containing only the clean Ca did not release a noticeable amount of alkali metal.

We prepared a 5:1 molar mixture of Ca and enriched KCl, with both chemicals in a powdered form. Since the reaction depends on adequate fresh calcium surface area, we used a powder of Ca prepared using a jeweler's file and sieved through a woven wire mesh (0.07 mm wire with 0.15 mm apertures).<sup>8</sup> The mixture was put into a small "boat" made from 0.125 mm thick Nichrome (Ref. 9) (80%–20% nickel–chromium alloy) foil that had been flame annealed, then mechanically cleaned and electropolished (see Fig. 1). Electrical leads, 1 mm nickel wires, were spot welded to the foil tabs on both sides of the boat. Several sources were made, each containing approximately 2.1 mg of KCl. These sources can be incorporated into a glass arm for use in an ultrahigh vacuum chamber.

<sup>a)</sup>Also with the Quantum Physics Division, National Institute of Standards and Technology; electronic mail: jin@jilau1.colorado.edu

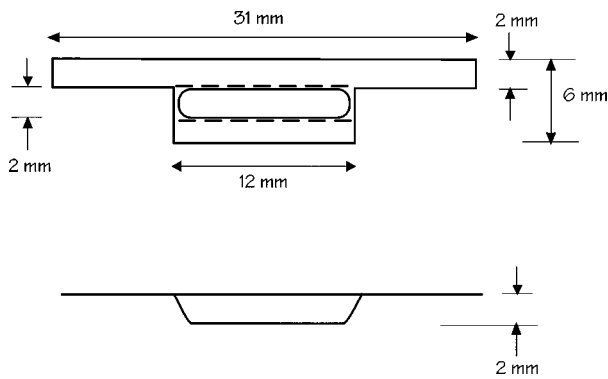


FIG. 1. Schematic of the enriched K dispenser. The longer flap and then the shorter flap are folded over and gently crimped to form the top of the boat.

### III. PERFORMANCE OF THE ENRICHED SOURCE

To characterize our source, we have examined the level of contaminants, the total potassium yield, and the relative abundance of  $^{40}\text{K}$ . In addition, we have used this source successfully in a vapor cell MOT.

A major concern for ultrahigh vacuum studies is that the level of contaminants released from the source be sufficiently low. We fired one of our sources, as well as a commercial SAES K dispenser,<sup>9</sup> into an uncalibrated residual gas analyzer. With our source, we detected levels of released contaminants, such as Cl, water,  $\text{CO}_2$ , and other alkalis, that were no higher than that seen for the commercial dispenser.

Another concern is that the useful lifetime of the source, which is directly related to the total yield, is reasonable. For a Rb vapor cell MOT, a commercial getter containing 4.5 mg of metal has been shown to provide more than one year of regular use in a glass cell.<sup>5</sup> We performed a yield measurement of our source and compared this to a commercial dispenser. Using a triode arrangement, we measured the amount of released potassium by ionizing the gas and counting the collected ion current.<sup>3</sup> The source was mounted along the axis of a helical tungsten filament inside a water-cooled Kovar<sup>9</sup> tube. The filament was heated to roughly  $1400^\circ\text{C}$  and maintained at 30 V relative to the source, while the Kovar was held at  $-400\text{ V}$ . After baking the apparatus under vacuum and degassing the tungsten filament, the yield measurement was performed by activating the source and monitoring the ion current as a function of time. For calibration, we performed a similar test using a purchased SAES potassium dispenser<sup>9</sup> having a nominal yield of 4.5 mg. Assuming this nominal yield is accurate, we found that our dispenser, containing  $2.1 \pm 0.3\text{ mg}$  of KCl, released a total of 0.39 mg of alkali metal, giving an efficiency of  $19\% \pm 3\%$  (see Fig. 2). Upon inspection of a spent source we found that the efficiency appears to be limited by the availability of fresh Ca surface area for the required reduction reaction.

While the above tests show that our source efficiently delivers potassium, they do not provide a measure of the relative abundance of the isotope of interest  $^{40}\text{K}$ . To make this determination, we fired one of our sources into a small glass cell. Then, using this cell and a 767 nm diode laser, we performed saturated absorption spectroscopy. The results of this test, as well as a saturated absorption spectrum for a cell

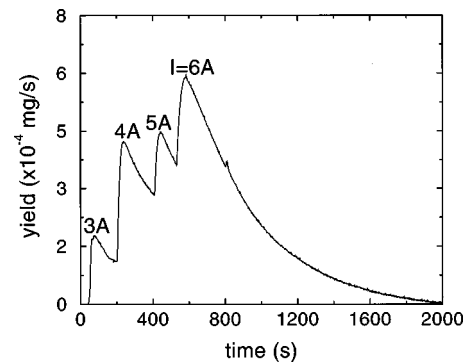


FIG. 2. Yield measurement of the enriched source. The jumps in the rate of K release correspond to suddenly increasing the current  $I$  through the dispenser. Integrating this curve gives a total K yield of 0.39 mg.

containing unenriched potassium, is shown in Fig. 3. The enriched source clearly delivers potassium with a higher abundance of both  $^{40}\text{K}$  and  $^{41}\text{K}$ . In particular, the  $^{40}\text{K}$  lines, which are imperceptible for the unenriched source, clearly appear in the spectrum for the enriched source. The frequency axis in Fig. 3 was calibrated using the known hyperfine splittings for K.

We have now incorporated the enriched source into an apparatus designed to produce an ultracold, trapped gas of  $^{40}\text{K}$ . The source consists of four enriched dispensers mounted in a single 0.75 in. diam glass arm attached to our MOT vacuum chamber. The MOT chamber is based on a six-way glass cross with 1.5 in. diam windows. The trapping light is provided by two diode laser systems, each consisting of a diode laser injecting a tapered amplifier (from SDL, Inc.<sup>9</sup>). One laser provides trap light that is 20 MHz red detuned from the  $F=9/2$  ground state to  $F'=11/2$  excited state cycling transition while the other laser provides repumping on the  $F=7/2$  to  $F'=9/2$  transition. We have a total of 90 mW of trap light and 25 mW of repump light in three ret-

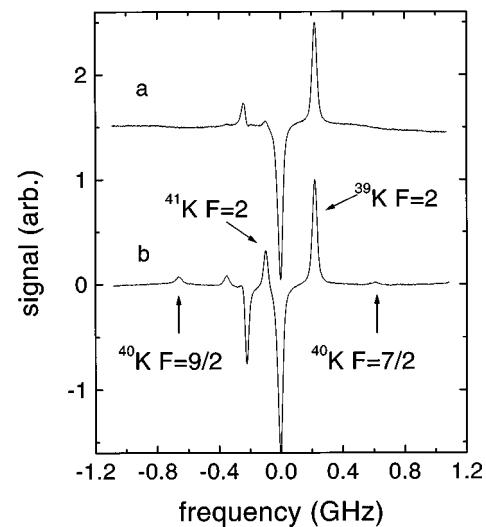


FIG. 3. Saturated absorption spectra using (b) our enriched sample compared to (a) nonenriched K. Arrows indicate the strongest line for  $^{39}\text{K}$  and for  $^{41}\text{K}$ , as well as the two absorption lines (labeled by the ground state hyperfine level) for the fermion isotope  $^{40}\text{K}$ . (The negative peaks are crossover lines located halfway between absorption lines corresponding to the two ground-states of an isotope.)

roreflected 1.3 in. diam beams. A pair of coils in an anti-Helmholtz configuration provides a magnetic field gradient of 10 G/cm for the MOT.

With our enriched source, we have seen  $(2 \pm 1) \times 10^8$  atoms in the MOT. Florescence from the trap is imaged onto a photodiode and the number of atoms is determined using a six-level model.<sup>10</sup> By appropriate choice of the two laser frequencies,<sup>11</sup> we are able to trap any of the three K isotopes. In addition to our  $^{40}\text{K}$  MOT, we have seen  $10^9$  atoms in a  $^{41}\text{K}$  MOT and in a  $^{39}\text{K}$  MOT. For each of these tests, we used a current of 2.8 A through a single enriched dispenser, which gave a MOT lifetime of roughly 4 s. The fact that the number of trapped  $^{40}\text{K}$  atoms is only down by a factor of 5 from the more abundant isotopes attests to the success of the enriched source. For  $^{40}\text{K}$  our results represent an increase in number of four orders of magnitude over previous  $^{40}\text{K}$  MOT's.<sup>10,12</sup> This increase in number will greatly facilitate future efforts to cool a gas of fermionic atoms to the quantum degenerate regime.

In summary, we have developed a novel, enriched potassium source for use in studies of the fermionic isotope  $^{40}\text{K}$ . This source is relatively simple, easily controllable, and con-

sistent with good vacuum. The design is especially useful for radioactive alkalis, which may be available only with small quantities of enriched metal in a salt form.

## ACKNOWLEDGMENTS

This work is supported by the National Institute of Standards and Technology and the National Science Foundation.

<sup>1</sup>C. Monroe *et al.*, Phys. Rev. Lett. **65**, 1571 (1990).

<sup>2</sup>Available from Isotec, Inc., <http://www.isotec.com> (see Ref. 4).

<sup>3</sup>P. della Porta, C. Emili, and S. J. Hellier, SAES Technical Report TR 18 (see Ref. 4).

<sup>4</sup>C. Wieman, G. Flowers, and S. Gilbert, Am. J. Phys. **63**, 317 (1995).

<sup>5</sup>M. R. Matthews *et al.*, Phys. Rev. Lett. **81**, 243 (1998).

<sup>6</sup>L. Hackspill, Helv. Chim Acta **11**, 1008 (1928).

<sup>7</sup>Data provided by Isotec, Inc. (see Ref. 4).

<sup>8</sup>Calcium is not normally available in a powdered form for obvious reasons. In Boulder's arid climate we were able to prepare calcium filings without using a glove box; the powder was stored in a desiccant jar.

<sup>9</sup>Isotec, SAES, Nichrome, Kovar, and SDL are trade names used for identification purposes only and do not constitute an endorsement by the authors or their institutions.

<sup>10</sup>R. S. Williamson III, Ph.D. thesis.

<sup>11</sup>R. S. Williamson III and T. Walker, J. Opt. Soc. Am. B **12**, 1393 (1995).

<sup>12</sup>F. S. Cataliotti *et al.*, Phys. Rev. A **57**, 1136 (1998).