

Novel rubidium atomic beam with an alkali dispenser source

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We describe a novel atomic beam apparatus with a resistively heated alkali dispenser source and a cold-pumped intermediate chamber. Using laser fluorescence spectroscopy we have measured the atomic density to be 3×10^{11} atoms/m³ and the total flux to be 5×10^8 atoms/s in a 0.3 cm diameter beam. We have also characterized the velocity distribution of the source based on the Doppler-shifted fluorescence spectrum. The compact geometry, flexibility, and simplicity of the beam may make it useful as an optical frequency reference or for experiments on atom-cooling. © 2004 American Vacuum Society. [DOI: 10.1116/1.1806440]

I. INTRODUCTION

A typical atomic or molecular beam apparatus¹ consists of three chambers. The source chamber contains a relatively high density of gas atoms produced by some means such as from a separate pressurized storage tank, or by laser ablation, or, most typically for rubidium and other alkali metals, by evaporation from a heated sample of the pure metal. Atoms leave the source chamber through a small opening into an intermediate chamber, and some of these travel freely across to a second small opening, producing a collimated beam into the experimental chamber. Note that only a fraction of the atoms entering the intermediate chamber will exit the second opening and that these atoms (and also any other gas) must be rapidly removed so that the freely traveling atoms do not suffer collisions. We have constructed a compact and versatile rubidium beam apparatus for experiments on laser-cooling and on the interaction of atoms with magnetized surfaces.

II. APPARATUS

In our beam apparatus, the source is an alkali-metal dispenser² which is sold commercially for coating applications, such as producing photocathodes. These have been adapted by several researchers to provide vapor for loading magneto-optic traps³⁻⁵ but to our knowledge have not been used in an atomic beam apparatus. The dispenser contains a mixture of rubidium chromate and a reducing agent held inside a channel of folded metal about 1 mm wide and 12 mm long. Metal straps at either end allow electrical connections so that a current of several amps can be passed through, which heats the dispenser and its contents. This initiates a reduction reaction in the mixture so that Rb vapor is released. The temperature sensitivity of the reaction and the small thermal mass of the source make the turn-on and turn-off times fairly short, on the order of 45 s. We contrast this with a typical Rb oven, which takes many minutes to heat up and even longer to cool down. The dispenser can be easily changed in our system, allowing one to convert the beam to another alkali metal if desired. The turnaround time is less than 45 min (including 25 min for venting and pump-down). The dispensers must not be exposed to air for long periods or they will degrade, but our experience is that they work well

even after 4 h of exposure to room air. We store extra dispensers in a valved-off vacuum tee attached to our vacuum system. The total usable mass of Rb in each dispenser is only 4.5 mg, which limits the flux-lifetime product of the source.

The dispenser is physically attached to the pins of an electrical feedthrough using screw-type clamps, and the feedthrough mounts onto a tiny chamber made from a 1.33 in./2.75 in. Conflat®-style adapter and a 2.75 in. extender. The assembly is shown as part of the beam apparatus in Fig. 1.

Our intermediate chamber consists simply of a short length of 0.75 in. diam tubing with 1.33 in. flanges on either end. Apertures for defining a beam are two stainless steel plates drilled with 0.125 in. diam holes, and are located just before and after the intermediate chamber. The first aperture mounts inside the tiny source chamber 2 cm distant from the dispenser, and is clamped to the wall adjacent the intermediate chamber. The second aperture is placed inside the experimental region, also clamped to the side adjacent the intermediate chamber. Gas can flow between chambers around the sides of the aperture plates, but the only straight path through is via the aperture holes. The tube of the intermediate chamber is cooled to 0 °C by thermoelectric coolers (TEC's). These are glued with high thermal conductivity epoxy (DeltaBond 155, Wakefield Engineering) to aluminum blocks that clamp securely to the tube. The warm side of each TEC is glued to a heatsink/fan combination similar to those used to cool computer processor chips. All parts except the aluminum block are stock commercial items.

The cold surfaces of the intermediate chamber, and to a lesser extent, of the apertures attached, serve as cold adsorption pumps for the Rb vapor exiting the source. Only Rb atoms streaming straight through the aperture holes are able to reach the experimental chamber without striking a surface. The cold pumping is a key feature of our system, and it eliminates the need for an external pump for the intermediate chamber.

The experimental chamber⁶ has the shape of a squat cylinder with eight small ports on 1.33 in. flanges located symmetrically around the perimeter. The atomic beam enters through one small port on the side, while the other seven small ports have windows that allow optical access, e.g., for

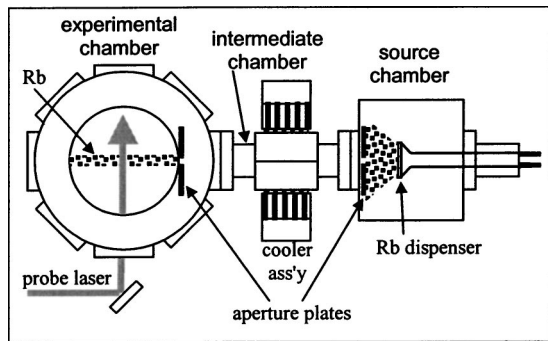


FIG. 1. Overview of the atomic beam apparatus. For clarity, the source chamber is shown in cross-section, while the rest of the apparatus is shown as an exterior side view.

laser beams. The two flat sides of the chamber have larger ports on $4\frac{1}{2}$ in. flanges, one of which leads via flexible bellows to a 250 l/s turbopump. The other large port (seen in Fig. 1) has a window which gives wide-angle optical access (NA=0.7) to the atomic beam.

Figure 2 is a CCD camera image taken through the large window showing the atomic beam crossing a probe laser beam. Such imaging of the atomic fluorescence allows us to verify the existence of the atomic beam and to properly align the probe laser and fluorescence detection equipment.

III. RESULTS AND DISCUSSION

In order to characterize the beam, we performed laser fluorescence spectroscopy on the $5S_{1/2}-5P_{3/2}$ Rb transition. The probe laser wavelength λ is 780 nm produced from a tunable external cavity diode laser. The laser is chopped by an acousto-optic-modulator (AOM) at 50 kHz chop frequency. A pair of 50 mm diam, 50 mm f.l. lenses was placed 50 mm from the laser-atom intersection region. Fluorescence light was focused onto a 13 mm² amplified silicon photodiode. The output of the photodiode was then detected synchronously using a lock-in amplifier.

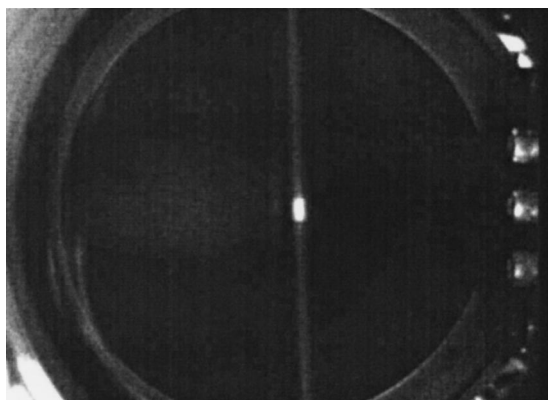


FIG. 2. CCD camera image of beam fluorescence. The atomic beam enters from the right, the probe laser enters from below, and the bright spot at center is fluorescence at the intersection. The laser beam path is faintly visible due to background Rb vapor, present when operating the source at high current.

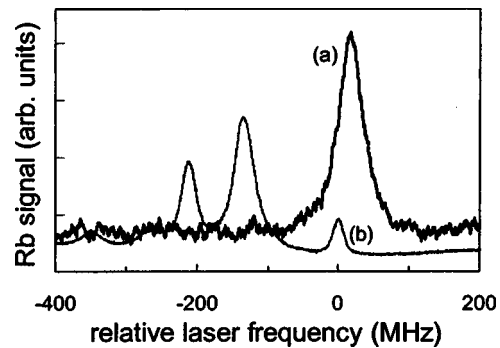


FIG. 3. (a) Atomic beam fluorescence spectrum when stimulated by a perpendicular laser probe tuned near a transition in ^{87}Rb . (b) Simultaneously obtained reference spectrum of a rubidium vapor cell saturation signal. The frequency scale zero in this and all spectra shown is set to the ^{87}Rb $F=2 \rightarrow F'=3$ peak of the cell spectrum. The atomic beam spectrum is shifted by +10 MHz in frequency relative to the cell spectrum due to offsets introduced by the AOM's used to control the laser beams.

The beam fluorescence spectrum of ^{87}Rb for a perpendicular laser probe is shown in Fig. 3. Also shown is a simultaneously obtained saturation-spectroscopy signal from a Rb reference cell. The beam fluorescence lines up with the $F=2 \rightarrow F'=3$ peak of the saturation spectrum, which is a cycling transition. The large peaks in the cell spectrum are "crossover" resonances (due to the 2-beam arrangement in saturation spectroscopy) and do not show up in the atomic beam spectrum. The beam fluorescence peak has a Lorentzian shape with 40 MHz width (FWHM). We estimate that about 8 MHz of this is due to the atomic beam angular divergence and the remainder is due to power broadening. The laser power was 4 mW in a circular Gaussian beam of 3.5 mm $1/e^2$ diameter, which results in about 30 MHz power broadening for this transition. Figure 4 shows the beam fluorescence spectrum using a frequency modulation (FM) scheme, and covers a much wider frequency range, showing fluorescence of both ^{87}Rb and ^{85}Rb .

In order to measure the longitudinal velocity of atoms in the beam we have also done spectroscopy with the probe laser propagation direction at 45° to the atomic beam. We moved the laser steering mirror shown in Fig. 1 so that the laser entered the lower left window of the experimental chamber. The atomic resonance frequency is then Doppler-

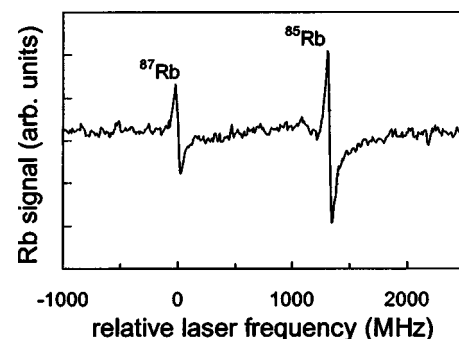


FIG. 4. Frequency-modulation spectrum showing signals from the two naturally occurring isotopes of Rb in the beam.

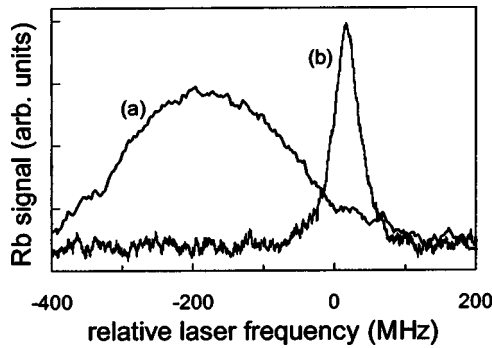


FIG. 5. (a) Fluorescence spectrum of the atomic beam probed at 45° . (b) Fluorescence spectrum for probe angle of 90° , shown for reference.

shifted by the amount $f = v \cos \theta / \lambda$, where θ is the angle of the laser probe light relative to the atomic velocity \mathbf{v} . Figure 5 shows the measured fluorescence signal, which is shifted down in frequency for this geometry and is also broadened due to the distribution of atomic velocities. We expect the signal $S(f)$ to be proportional to the density which is described by a thermal velocity distribution hence

$$S(f) \propto f^2 \exp\left(-\frac{\lambda^2 f^2}{(2kT/m)\cos^2 \theta}\right)$$

which is written in terms of the Doppler shift frequency f . We have fit the signals at several operating currents to this form and find T in the range 300–400 K, much less than the source temperature, which we estimate as 800–1000 K, based on its slight orange incandescence. Because of this, we believe that the vapor inside the small source chamber comes into equilibrium with the room-temperature walls before it exits the first aperture.

Using the size of the fluorescence signal in Fig. 3, we estimate the density of ^{87}Rb atoms in the $F=2$ state at roughly 4×10^{10} atoms/ m^3 , with a factor of 2 uncertainty due to limitations of our modeling of the laser/atomic-beam volume and knowledge of the optical and electronic efficiencies. Taking into account both hyperfine levels and the two isotopes present in the beam (^{87}Rb and ^{85}Rb), we calculate the total rubidium density as 3×10^{11} atoms/ m^3 and the total flux we estimate to be 3×10^8 atoms/s in a 0.3 cm diameter beam. All of these values are for a source heating current of 5.9 A. This flux is considerably smaller than obtained in some contemporary beam machines⁷ but adequate for our purposes, and we believe that the flexibility and compact design of our apparatus offer significant advantages. In principle we could increase the current and so increase the atomic flux, but there are two limitations, the lifetime of the source and the background gas pressure. While we have not made a detailed study of the operating lifetime, we have found that at a current of 7 A we have emptied a new dispenser in about 4 h. Operating at 5.9 A over the same time period shows no reduction in source strength. Using information on emission rates provided by the manufacturer for similar potassium dispensers, we would estimate a lifetime for our rubidium dispenser of $1\frac{1}{2}$ –2 h when run at 6.5 A,

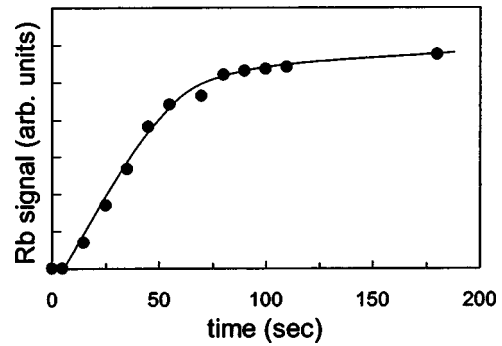


FIG. 6. (Circles) Turn-on characteristic of the beam. The dispenser current was held for some time at 3 A and was suddenly stepped up to 6 A at $t=0$. The line is provided as a guide to the eye.

somewhat shorter than our findings. At very low currents (4.5 A), the signal is quite small, but our experience with these dispensers in a magneto-optic trap is that they will last for many weeks of operating time.

The quick turn-on characteristic (see Fig. 6) allows us to operate the beam only as necessary, so that several hours of operating time may last for several days of experiments. Figure 7 shows the relative size of the Rb fluorescence signal versus drive current. Given the temperature-activated reaction of the dispenser, we would expect an exponential increase in flux and signal with temperature. The signal size does indeed increase sharply between 4 and 6 A, but more gradually above that. This may be due to the onset of radiative cooling when the source becomes incandescent, or more likely, it may be due to decreased transmission of atoms due to a rising background pressure of Rb.

Evidence of the latter is that if we allow the dispenser to operate at 7 A for more than a few minutes, we observe an accumulation of vapor fluorescence in the experimental chamber, and at higher currents we see only vapor fluorescence and a disappearance of the beamlike character. In this case the vapor lingers long after shutting off the dispenser current, but can be eliminated by venting the chamber to air and pumping back down. This oxidizes the rubidium remaining on the walls, rendering it nonvolatile. Our earlier observation that the effective source temperature is near 300 K

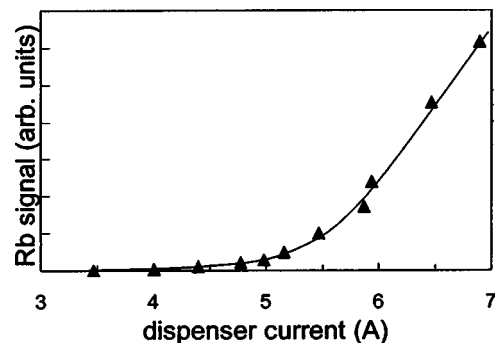


FIG. 7. (Triangles) Fluorescence signal as a function of dispenser current. Note the fairly rapid increase in signal above 5 A. Our usual operating point is near 6 A. The line is provided as a guide to the eye.

adds support to the notion that the atomic free path in the source chamber is short, even at 5.9 A current. At larger currents it is apparently shorter still, limiting the emission rate from the source chamber. We were not able to measure the pressure in any of the beam chambers, but the pressure near the inlet of the turbopump was typically about 2×10^{-7} mbar and showed little change when operating the Rb source.

IV. CONCLUSIONS

We have demonstrated a simple, yet versatile atomic beam apparatus with an alkali-dispenser source and an intermediate-chamber cold-pumping scheme. We have measured the density and velocity characteristics of the beam and have shown its application to spectroscopy of rubidium. Such a beam may be of use as an optical frequency reference or for experiments on atom-cooling and manipulation (as is our interest). Its low cost, easy-to-obtain parts and its versatility may make it also of interest for the teaching laboratory.

The limited flux may make this apparatus unsuitable for some applications, but modifications may allow considerable

increase in flux. For example, decreasing the dispenser-to-first-aperture distance may reduce the attenuation within the source chamber. In addition, insertion of baffles into the intermediate chamber and relocating the TEC's to inside the vacuum space may improve the cold-pumping so that the dispenser can be run at higher currents without gas buildup.

ACKNOWLEDGMENT

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