

Beam of metastable krypton atoms extracted from a rf-driven discharge

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A rf-driven discharge is used to produce a beam of metastable krypton atoms at the $5s(3/2)_2$ level with an angular flux density of $4 \times 10^{14} \text{ s}^{-1} \text{ sr}^{-1}$ and most probable velocity of 290 m/s, while consuming 7×10^{16} krypton atoms/s. When operated in a gas-recirculation mode, the source consumes 2×10^{15} krypton atoms/s with the same atomic-beam output. © 2001 American Institute of Physics. [DOI: 10.1063/1.1328400]

Thermal beams of metastable noble gas atoms have a wide range of applications including atom lithography,¹ atom holography,² atom optics,³ atomic collision studies,⁴ and precision measurements.⁵ Sources of such beams have been developed based on electron-impact excitation in which energetic electrons are produced in various ways such as an electron beam,⁶ a dc glow discharge,⁷ or a surface-wave-sustained plasma.⁸ These sources produce intense metastable atomic beams with angular flux densities in the range of $10^{13} - 10^{15} \text{ s}^{-1} \text{ sr}^{-1}$. The gas consumption rate, however, has not been a primary design concern, and has so far been neglected in the literature. This is because the aforementioned applications use gases that are readily available in large quantities [$>1000 \text{ cm}^3$ standard temperature and pressure (STP)]. The recent demonstration of Atom Trap Trace Analysis,⁹ in which laser manipulation of metastable krypton (Kr^*) atoms was used to count atoms of rare krypton isotopes, has motivated our development of an efficient source of Kr^* atoms that can accommodate a small amount of gas ($\sim 1 \text{ cm}^3$ STP).

In this source Kr atoms are excited to the $5s(3/2)_2$ metastable level (lifetime $\approx 40 \text{ s}$) in a rf-driven discharge. As schematically shown in Fig. 1, Kr gas flows through a discharge region that fills the inside of a quartz-glass tube. The pressure in the source chamber is 3 mTorr and the pressure in the intermediate chamber is about 10^{-5} Torr. The discharge is driven by a coaxial rf resonator that consists of a copper coil enclosed in a brass shield (Fig. 2).¹⁰ The resonator resonates at 155 MHz with an unloaded Q of 38, and typically receives 7 W of rf power.

We determine the flux and the velocity distribution using laser spectroscopy techniques with a diode laser whose wavelength is tuned to the resonance of the $5s(3/2)_2 - 5p(5/2)_3$ transition at 811 nm. Two laser beams

intersect the atomic beam at a distance 66 cm downstream from the exit of the discharge tube (Fig. 1). Figure 3 shows the atomic fluorescence signal detected by a photodiode detector as the laser frequency is scanned through the resonance. One of the laser beams, directed perpendicular to the atomic beam, provides the zero-Doppler-shifted fluorescence signal that appears as narrow peaks. Based on this signal, we calculate that 4×10^5 $^{84}\text{Kr}^*$ (isotopic abundance = 57%) atoms are present in the fluorescing volume of 0.2 cm^3 . The other laser beam, directed at an angle 45° to the atomic beam, provides the Doppler-shifted fluorescence that appears as a broad peak. Based on this signal, we calculate that the most probable velocity is 290 m/s. The density of Kr^* atoms in the fluorescing region ($4 \times 10^6 \text{ cm}^{-3}$), multiplied by the most probable velocity, gives flux density of $1 \times 10^{11} \text{ s}^{-1} \text{ cm}^{-2}$. Given that the fluorescing region is 66 cm from the source exit, we conclude that the angular flux den-

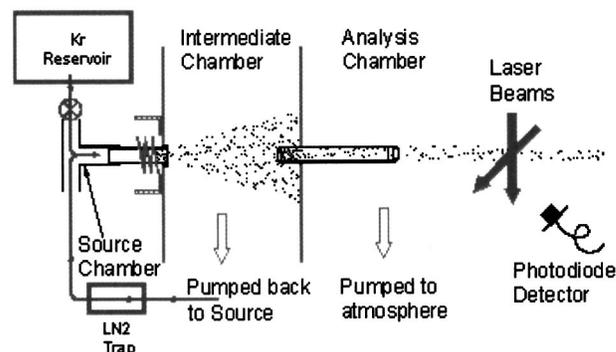


FIG. 1. Schematic of the experimental setup.

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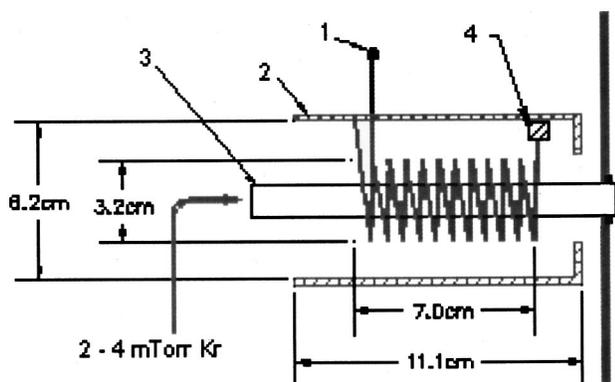


FIG. 2. Schematic of the rf resonator. (1) Copper wire; 11 turns, wire diameter=1.5 mm. (2) Brass shield. (3) Quartz-glass tube; 1.0 cm inner diameter. (4) Ceramic spacer.

sity of the Kr^* atomic beam is $4 \times 10^{14} \text{ s}^{-1} \text{ sr}^{-1}$. We attempted to increase the flux by doubling the rf power and by adding a longitudinal magnetic field. In each case, a brighter discharge was visually observed but the flux was increased by less than 20%. It seems that the operating condition is near the equilibrium between the excitation and the ionization processes.

Higher source efficiencies are achieved with gas recirculation.¹¹ Depending on the valve settings, the gas in the intermediate chamber can either be pumped out (Fig. 1), or be redirected back to the source chamber, via a 150 l/s

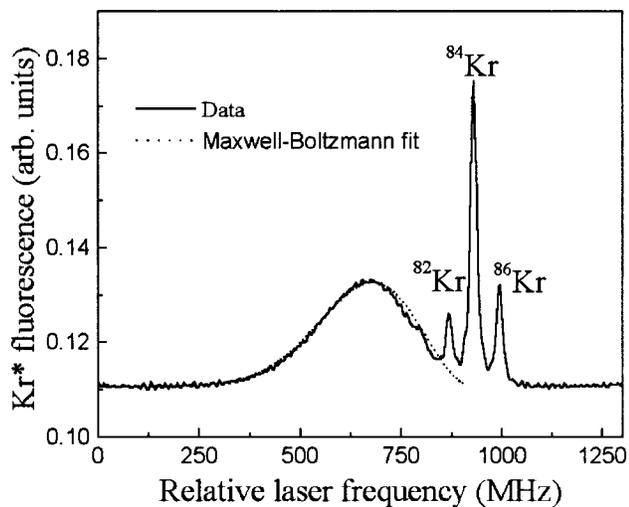


FIG. 3. Kr^* beam fluorescence vs laser frequency. The three zero-Doppler-shifted peaks are due to three isotopes, $^{82}\text{Kr}^*$, $^{84}\text{Kr}^*$, and $^{86}\text{Kr}^*$, whose isotopic abundances are 11%, 57%, and 17%, respectively. At the low-velocity side, the measured velocity distribution deviates from the Maxwell-Boltzmann distribution, possibly due to a velocity-dependent quenching effect.

turbopump. The conductance between the source chamber and the intermediate chamber is limited, by a collimator, to 1.3 l/s. The recirculated gas is purified with a LN_2 -cooled trap. We measure that the source consumes 7×10^{16} Kr atoms/s ($3 \times 10^{-3} \text{ cm}^3 \text{ STP/s}$) without recirculation, and 2×10^{15} Kr atoms/s ($1 \times 10^{-4} \text{ cm}^3 \text{ STP/s}$) with recirculation. Therefore, the recirculation helps improve the source efficiency by a factor of 35. Further improvement is possible by optimizing the geometry of the collimator between the two chambers. The flux density of Kr (ground-level) atoms in the forward direction is measured roughly by noting the change of vacuum pressure in the analysis chamber. We estimate that the ratio of Kr^* flux over Kr flux is approximately 10^{-3} in the forward direction.

This source is easy to operate and maintain. The discharge can be started at the operating gas flow condition by raising the rf power to 14 W for a few seconds. Once ignited, the discharge and the metastable beam flux are stable. Moreover, this source uses no electrodes and needs less maintenance compared with other types of discharge sources that often require regular changes of electrodes due to sputtering problems.

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