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

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A microwave-driven discharge is used to produce a thermal beam of metastable krypton atoms at the $5s[3/2]_2$ level with an angular flux density of 7×10^{14} s^{-1} sr^{-1}, while consuming 1×10^{17} krypton atoms/s. This source of atomic beam uses commercially available microwave parts, and has achieved comparable beam flux and excitation efficiency with a previously described source that employs a rf-driven discharge [C. Y. Chen *et al.*, Rev. Sci. Instrum. **72**, 271 (2001)]. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2400014]

Thermal beams of metastable noble gas atoms have a wide range of applications. Sources based on different types of electron-impact excitation have been developed, such as an electron beam,[1] a dc glow discharge,[2] a surface-wave-sustained plasma,[3] and a rf-driven discharge.[4] There was also a recent work demonstrating the production of metastable krypton atoms (Kr^*) based on optical excitation.[5]

Atom trap trace analysis[6] (ATTA) of rare krypton isotopes has motivated us to develop a Kr^* beam with the goal of achieving both high flux and high efficiency. In ATTA, an intense beam of Kr^* atoms is necessary to insure a high counting rate of rare atoms, and a high efficiency is needed since only a small amount (~100 μl STP) of Kr gas is available in a typical geological sample. For this application, Chen *et al.*[4] developed a thermal beam of Kr^* atoms at the $5s[3/2]_2$ level extracted from a rf-driven discharge, and achieved an angular flux density of 4×10^{14} s^{-1} sr^{-1}, while consuming 7×10^{16} Kr atoms/s. The excitation efficiency, i.e., the ratio of the metastable Kr^* atom flux over the ground-level Kr atom flux in the forward direction, was approximately 10^{-3}.

We have recently investigated the use of a microwave-driven discharge, instead of a rf-driven discharge, to produce a beam of thermal Kr^* atoms in the metastable $5s[3/2]_2$ level. The schematic of the apparatus is presented in Fig. 1. In this discharge, Kr gas flows through a discharge region that fills the inside of a quartz-glass tube. The discharge is driven by microwave at 2.45 GHz coupled in through a cavity that surrounds the glass tube, and is powered by a microwave generator with a maximum output of 120 W.[7] Two types of commercially available coaxial cavities,[7] evenson cavity[8] and a McCarroll cavity,[9] were tested in the experiment. These are compact, air cooled, quarter-wave coaxial cavities with tunings on both the cavity mode and frequency. In the McCarroll design, an extension tube is added to the evenson cavity, making the cavity easier to tune for optimum coupling conditions. The atomic beam apparatus is differentially pumped by two turbopumps. The pressure is typically 10^{-2} Torr in the source chamber, 10^{-5} Torr in the intermediate chamber, and 10^{-7} Torr in the analysis chamber.

The Kr^* beam flux is measured in the analysis chamber by employing a common laser spectroscopy technique. A diode laser whose wavelength is tuned to the resonance of the cycling transition $5s[3/2]_2$-$5p[5/2]_3$ at 811.5 nm. The laser beam crosses the atomic beam perpendicularly at the center of the analysis chamber, which is 50 cm away from the exit of the discharge tube. The resonant fluorescence of the atoms is imaged onto a photodiode detector. Figure 2 shows the typical fluorescence signal as the probe laser is

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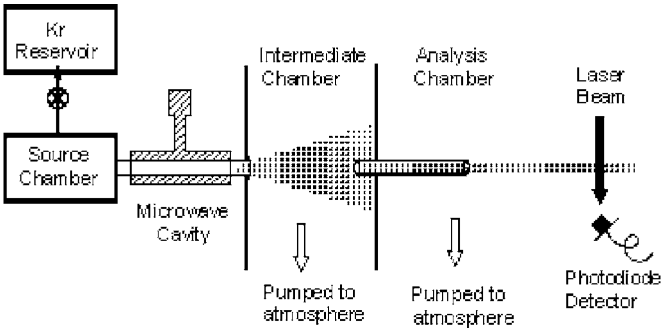

FIG. 1. Schematic of the experimental apparatus.

scanned across the resonances. Three abundant isotopes of krypton can be observed and distinguished in the spectrum. The known properties of the atomic transition allow us to calculate the atomic beam flux based on the detected fluorescence signal.

A McCarroll cavity is used to couple the microwave to the discharge of Kr gas in a glass tube of 1 cm inner diameter. An igniter coil is needed sometimes to initiate the discharge. For the maximum Kr^* beam flux, the optimum pressure in the source chamber is approximately 12 mTorr, while the Kr partial pressure in the analysis chamber is 2×10^{-7} Torr. The minimum microwave power needed to support a stable discharge is 100 W. Below this level of power, the discharge becomes weak and the Kr^* flux drops dramatically. When the microwave power is increased to 120 W, a bright purple discharge can be observed at the exit of the glass tube, and a strong Kr^* fluorescence signal is recorded. Based on the signal recorded at the microwave output of 120 W, limited only by the microwave generator available to this experiment, we calculate that there are 3.5×10^6 ^{84}Kr (isotopic abundance=57%) metastable atoms in the probe volume of 0.6 cm^3. Using the most-probable velocity of 290 m/s at room temperature, we calculate the $^{84}Kr^*$ flux density to be 4×10^{14} s^{-1} sr^{-1}, and the all-isotope Kr^* flux density to be 7×10^{14} s^{-1} sr^{-1}. Meanwhile, we measure that the source consumes about 1×10^{17} Kr atoms/s. This result is comparable to that achieved with a rf-driven discharge.[4] An evenson cavity was also used in the investigation. The flux achieved with an evenson cavity was, in general, two to three times lower than that achieved with a McCarroll cavity.

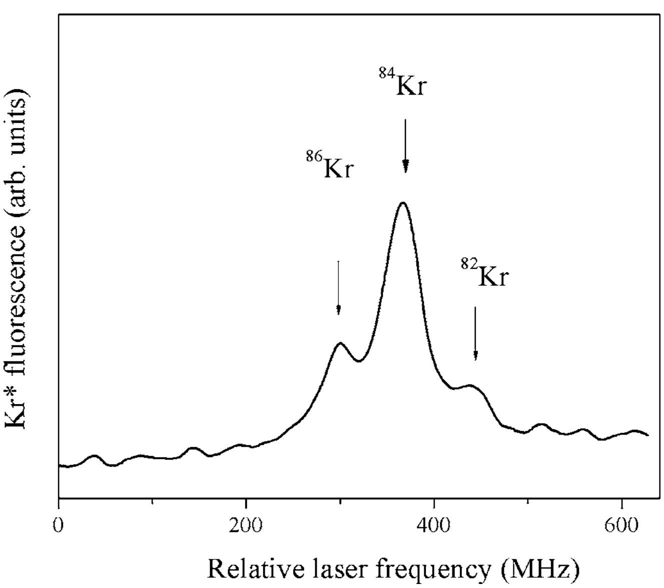

FIG. 2. Kr^* beam fluorescence vs laser frequency. The three peaks are due to three isotopes: $^{86}Kr^*$, $^{84}Kr^*$, and $^{82}Kr^*$, whose isotopic abundances are 17%, 57%, and 11%, respectively. The width of the peak is broadened by an electronic filter which is used to eliminate a 60 Hz noise coupled with the microwave source. The small fluctuations on the base line are the noise residual.

In conclusion, a microwave-driven discharge source is used to generate a beam of metastable Kr^* atoms. The Kr^* flux and excitation efficiency achieved are comparable to those demonstrated using a rf-driven discharge in a previous work.[4] There may be an advantage in that the microwave parts used in this experiment are all commercially available.

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