ATTA-3: THE NEXT-GENERATION INSTRUMENT FOR ^{81}Kr-DATING

Yun Ding[1,2], Zheng-Tian Lu[1,2], Kevin G. Bailey[2], Peter Mueller[2], Thomas P. O'Connor[2], Robert W. Dunford[3], Linda Young[3], Andrew M. Davis[1,4], Reika Yokochi[5], Neil C. Sturchio[5], Wei Jiang[6], Shui-Ming Hu[6]

[1]Enrico Fermi Institute, University of Chicago, Chicago, IL 60637; [2]Physics and [3]Chemical Sciences and Engineering Divisions, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439; [4]Department of Geophysical Sciences, University of Chicago, Chicago, IL 60637; [5]University of Illinois at Chicago, Chicago IL 60607; [6]Hefei National Laboratory for Physical Sciences at the Microscale, University of Science and Technology of China, Hefei, 230026, China

INTRODUCTION

Atom Trap Trace Analysis (ATTA) has been used to analyze two rare isotopes: ^{81}Kr (half-life = 230,000 yr, isotopic abundance ~ 10^{-12}) and ^{85}Kr (~10^{-11}), in environmental samples. Radiokrypton dating enabled by the ATTA method can now be used to determine the ages of old groundwater in the range of 50,000–1,000,000 years. This system is based upon the atom trap trace analysis method that was first demonstrated in 1999 (ATTA-1)[1]. Since then, significant improvements have been made to increase the system efficiency and to reduce the required krypton sample size. The present apparatus (ATTA-2) has an overall counting efficiency of 0.01% and, for ^{81}Kr dating, requires a water sample of at least 1,000 liters[2]. We are developing a new apparatus (ATTA-3) to trap and count ^{81}Kr atoms with the goal of reaching a counting efficiency of 1%. The required sample size could be reduced down to 10 liters of water or ice. ATTA-3 would enable a wide range of applications in the earth sciences.

EXPERIMENTAL

Figure 1 shows schematic of the experiment setup. The krypton sample gas flows through an AlN tube, where Kr atoms can be excited from the ground level to a metastable level $5s[3/2]_2$ (lifetime~40 s) by a RF discharge. The AlN tube is equipped with a Liquid nitrogen dewar and a pair of heater, so its temperature can be controlled within 100-150 K. At this temperature, the Kr* (metastable Kr) have a better trap efficiency and the adsorption by the cold source can be ignored.

Laser trapping and cooling of Kr* based on the transition $5s[3/2]_2$ – $5p[5/2]_3$ have been realized with the laser of 811.5 nm wavelength. In the transverse cooling chamber, the Kr* beam is cooled in both transverse directions by two sets of laser beams whose wavelength are tuned to the resonance of the cycling $5s[3/2]_2$ – $5p[5/2]_3$ transition at 811.5 nm, each of which has an intensity of ~35 mW/cm^2 and is multiply reflected over a length of 20 cm along the atomic beam between two flat mirrors. The Kr* trap loading rate could be increased by a factor of ~300 with two-dimensional transverse cooling.

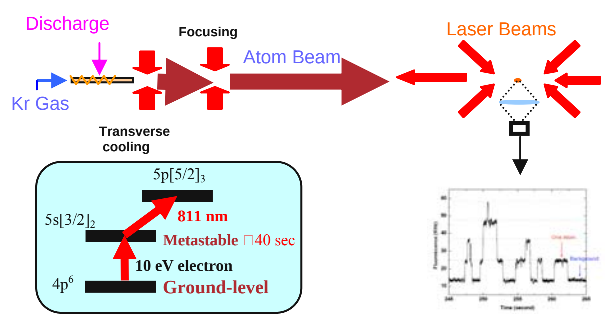
An additional laser beam whose wavelength is 6 MHz red detuned from the resonance is applied in the chopper chamber. It can focus the atom beam to the trap chamber and a factor of 2 enhancement on the loading rate is observed with one dimension focusing and 4 is expected by two-dimensional focusing. The chopper chamber also houses a rotating mechanical chopper that periodically blocks the Kr* beam, essentially turning on and off the beam going into the trap chamber. The chopper chamber also houses a residual gas analyzer (SRS, RGA200) for monitoring the partial pressures of different gases in the vacuum system.

Downstream from the chopper chamber, the Kr* atoms enter a 85 cm long Zeeman slower, where they are decelerated by a circularly polarized laser beam from a velocity of approximately 200 m/ s near the source down to 20 m/ s as they enter the trap chamber. In the trap chamber, a MOT is used to capture the slow Kr* atoms and confine them in a submillimeter region in the center of the chamber. A single trapped Kr* atom scatters photons at a rate of ~10^7 s^{-1}, 1% of which is collected and imaged by a pair of numerical aperture=0.5 lenses, through a 0.5 mm diameter aperture which spatially filters out most of the diffuse background light, and reimaged by another pair of lenses onto a 0.6 mm diameter avalanche photodiode with a photon counting efficiency of 25% at 811 nm wavelength. The resulting single atom signal is 13 kHz photon counts and the background is 13 kHz [Fig. 1].

RESULTS

With all these efforts, we could increase the system efficiency by a factor of 200 compare to the result obtained in ATTA-2. The counting rate would increase from 10 atom /hr to 2000 atoms/hr with a 100 μL STP of krypton sample. On the other hand, keep the counting rate unchanged, the required sample size could be reduced to 0.5 μL STP of krypton sample or 5 liter if water or ice.

Figure 1. Energy level and schematic of the experiment setup.



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