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Atom Trap Trace Analysis of Krypton Isotopes

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Abstract: A new method of ultrasensitive isotope trace analysis has been developed. This method, based on the technique of laser manipulation of neutral atoms, has been used to count individual ^{85}Kr and ^{81}Kr atoms present in a natural krypton gas sample with isotopic abundances in the range of 10^{-11} and 10^{-13}, respectively. This method is free of contamination from other isotopes and elements and can be applied to several different isotope tracers for a wide range of applications. The demonstrated detection efficiency is 1×10^{-7}. System improvements could increase the efficiency by many orders of magnitude.

We report a new atom-counting method, named Atom Trap Trace Analysis (ATTA) [1]. This method is based on laser manipulation of neutral atoms, and has been successfully applied to count ^{85}Kr and ^{81}Kr (Table 1) in natural krypton samples. ATTA differs significantly from all previous methods in that it is free of any contamination from different isotopes or elements. Therefore, ATTA can tolerate impure gas samples, does not require a special operation environment, and its apparatus can be made transportable for applications that require on-site analysis.

Our design (Fig. 1) is based on a type of magneto-optical trap system that had been used to trap various metastable noble gas atoms [2]. Trapping krypton atoms in the $5s[^3/_2]_2$ metastable level (lifetime = 40 sec) is accomplished by exciting the $5s[^3/_2]_2$ - $5p[^5/_2]_3$ transition using laser light with a wavelength of 811 nm generated by a Ti:Sapphire ring laser. The laser frequency, after shifting by acousto-optical modulators (AOM) to account for the isotope shift, is locked to a reference absorption line of the abundant ^{83}Kr atoms in a cell. Krypton gas sample is injected into the system through a 0.1 mm diameter nozzle, around which a DC discharge is maintained. A fraction, about 1×10^{-4}, of the atoms are excited into the $5s[^3/_2]_2$ level by the discharge and, after exiting the discharge region, remain in this metastable level until they hit walls. Two-dimensional transverse cooling is used to reduce the atomic beam divergence and amplify the atom flux in the forward direction by a factor of 20. The thermal (300°C) atoms are then decelerated with the Zeeman slowing technique [3], and loaded into a magneto-optical trap [4]. Atoms remain trapped for an average of 1.8 sec when the vacuum is maintained at 2×10^{-8} Torr. This trap system can capture the abundant ^{83}Kr (isotopic abundance = 11.5%) atoms at the rate of 2×10^{8} sec^{-1}. The ratio of the capture rate to the injection rate gives a total capture efficiency of 1×10^{-7}.

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