Production and mean-lifetime measurement of metastable Ar^- ions

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Lifetime measurements of the theoretically predicted metastable state ^4S of the Ar^- ion favor the existence of only one state with a mean lifetime of 260±25 nsec. The Ar^- was produced from a 600-keV Ar^0 beam by a single electron capture from an Ar gas target. In similar collisions between Ne^0 and Ar no (metastable) Ne^- ions were detected.

I. INTRODUCTION

The first measurement of metastable Ar^- ions was reported by Bae *et al.*[1] following a theoretical prediction by Bunge *et al.*[2] They used an Ar^+ beam in the energy range of 8–18 keV passing through a Cs vapor target. The Ar^- ions were produced in the metastable state ^4S by a two-step electron capture. They also found that the Ar^- had a single decay rate with a mean lifetime of 350±150 nsec, consistent with the single $J=\frac{3}{2}$ fine-structure level of a ^4S state. In this paper we report a different way to produce the Ar^- ions and a more precise measurement of its mean lifetime, and stronger evidence of a single metastable state.

II. EXPERIMENT

The experimental apparatus used is shown in Fig. 1 and is similar to the one described in a previous paper by Heber *et al.*[3] A 600-keV Ar^+ beam from the Technion 1-MV Van de Graaff accelerator was neutralized in a gas target beyond the analyzing magnet. An electrostatic deflector D0 positioned near the gas target cell enabled only the neutral projectiles to reach the gas-target volume. A thin Ar gas target was formed in a differentially pumped cell in which the pressure was $(1-5)\times10^{-3}$ Torr, while the background pressure was less than 10^{-6} Torr.

The projectiles emerging from the gas target were separated according to their charge states by a horizontal deflector D2. The negatively charged projectiles were detected by a surface-barrier detector SB1, while the neutral atoms were directed to a thin gold foil. Ar ions scattered from the gold foil to an angle of 30°±10° were detected by a second surface-barrier detector SB2 used as a monitor. This detection setup for the neutral projectiles was needed to reduce both the counting rate and the damage to the detector.

The distance between the target cell and the electrostatic analyzer D2, used to separate the charge states,

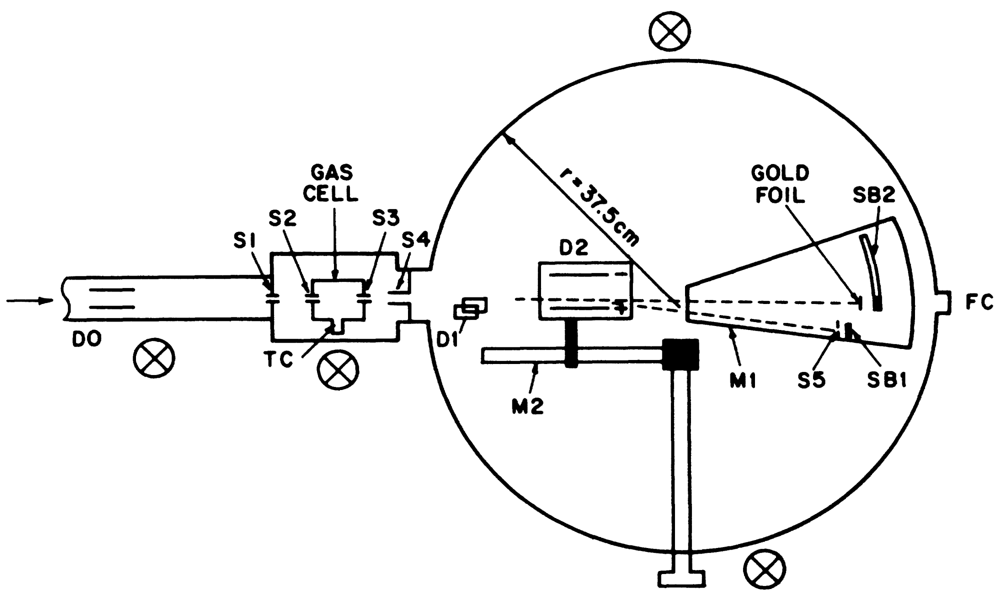

FIG. 1. Schematic view of the experimental apparatus. Included is the differentially pumped gas cell and the scattering chamber. D0, D1, and D2 are electrostatic deflectors and ⊗ is a symbol for a high-vacuum diffusion pump. Slits S1–S4 are beam defining slits, M1 and M2 are movable arms, SB1 and SB2 are silicon surface-barrier detectors.

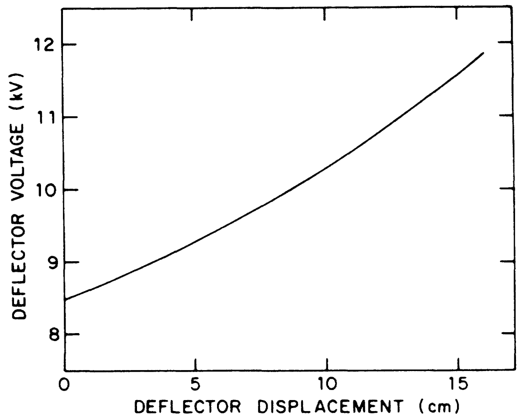

FIG. 2. Relation between the deflector position and appropriate voltage needed for the Ar^- beam to hit the detector center.

could be varied by a manual manipulator. The deflection voltage needed to bring the Ar^- beam of less than 1 mm diameter to the detector center for each deflector position is given in Fig. 2. The deflector position is given by its displacement from the closest position from the target cell. A vertical electrostatic deflector D1 was also used to ascertain that no particles were lost in the space between the detectors.

III. RESULTS AND DISCUSSION

The mean lifetime of the Ar^- ions was measured by comparing the integral intensities at different positions of the deflector D2, keeping the neutral counts constant for normalization of all data points. In Fig. 3 we present the total number of Ar^- ions for each deflector distance that was measured and normalized to the same number of neutral atoms. A significant reduction of the Ar^- intensity as a function of the deflector displacement can be clearly seen; furthermore, the linear fit to the data favors a single metastable state.

The mean lifetime of the metastable Ar^- ions could be determined by using the exponential decay formula

$$\ln[N(t)] = -t/\tau + \ln[N(t=0)] , \quad (1)$$

where $N(t)$ is the number of Ar^- ions, t is the elapsed time from the ion formation, and τ is the mean lifetime. The slope of $\ln N(t)$ as a function of the deflector displacement ΔX, is given by the self evident formula

$$\text{slope} = -1/(v\tau) , \quad (2)$$

where v is the ion velocity.

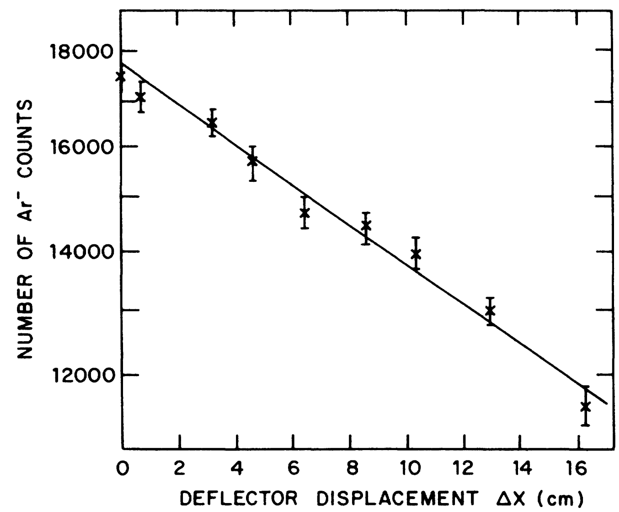

FIG. 3. Dependence of the Ar^- counts on the movable deflector position (note the ordinate is in a log scale).

A least-squares fitting of a straight line to the data points in Fig. 3 gives the following result for the mean lifetime:

$$\tau = 260 \pm 25 \text{ nsec} .$$

This result is in agreement with the previous measurement of Bae *et al.*[1] (350±150 nsec), but with significantly better precision, a fact that reduces the possibility of more than one metastable state.

The mechanism for Ar^- production used in this experiment was a single-step electron capture from an Ar gas target,

$$Ar^0 + Ar^0 \rightarrow Ar^- + Ar^{q+} + (q-1)e^- ,$$

which is an additional mechanism for Ar^- production to the previously reported two-step electron-capture mechanism. This result confirms the existence of the metastable state of Ar^-, which is probably the ^4S state, as predicted by theory.[2]

Using the same method for a Ne^0 beam, no Ne^- was detected, within the experimental background, for the single-electron-capture mechanism. Therefore the mean lifetime of a metastable Ne^- should be shorter than 10 nsec, or the cross section for its formation in single-electron capture is orders of magnitude smaller than the cross section for Ar^- formation in the similar process. This result is also in agreement with the experimental results of Bae *et al.*[1] and the calculation of Bunge *et al.*,[2] which predicted that a metastable bound state of Ne^- does not exist.

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