Symmetric-Resonance Charge Transfer in Ar from 0.1–20 eV Using Merging Beams*

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(Received 23 December 1966)

The absolute cross section for $Ar^+ + Ar \rightarrow Ar + Ar^+$ at an interaction energy W of 0.3 eV has been measured using a previously described merging-beams technique. A modification of this method has also been employed to measure relative cross sections for the same process in a range of W from 0.1 to 20 eV. The results are in agreement with the theoretical prediction of Rapp and Francis.

We have previously described[1] a merging-beams technique (this technique or the paper in which it appeared will hereafter be referred to as I) that was used to measure the absolute cross section Q for symmetric-resonance charge transfer in Ar (i.e., $Ar^+ + Ar \rightarrow Ar + Ar^+$) at an interaction energy W of 100 eV. Using this technique, we have now measured an absolute Q for the same process at $W=0.3$ eV.[2] In addition, we have obtained relative cross-section measurements in a range of W from 0.1 to 20 eV employing a modified technique (hereafter referred to as II). In this paper, these low-energy measurements are described and the results are compared with theoretical predictions.

The basic distinction between the techniques is that for I there is an energy difference ΔE between the two primary beams all along their paths, whereas for II it exists only along the desired interaction region. Outside this region, the primary beams in II have the same energy E_0. ΔE in II is obtained by raising the potential of the interaction region. The primary ion beam is thereby decelerated to $E_0 - \Delta E$ at the entrace to the interaction region and accelerated to E_0 at the exit. A schematic of the apparatus for achieving this is shown in Fig. 1. This device replaces the collimating and interaction regions used in I and is one of two modifications of the apparatus. Argon ions produced by the desired process in the interaction region of II are accelerated at its exit to an energy $E_0 + \Delta E$.

Belyaev, Brezhnev, and Erastov[3] used a similar scheme to measure an absolute Q for $H^+ + H \rightarrow H + H^+$ at $W=15.9$ eV. The use of such a device was also suggested in I. It is used in the present experiment for measuring charge-transfer cross sections at lower W's than have been reached by other direct methods.

Use of II eliminates undesired signals and neutral noise (i.e., the output from the electron multiplier with only the neutral beam present) generated outside the interaction region. Consequently, the detector assembly need no longer be translated along the axis of the interaction region to obtain legitimate signals. This permits the removal of the aperture and sweep plates (see I) in front of the multiplier, resulting in an increased signal-to-noise ratio. This is the second modification of the apparatus used in I. The mobility of the detector assembly is still required for II in order to measure profiles of each primary beam. The multiplier is not used in profile measurements.

E_0 was fixed at 3000 eV. The potential of the interaction region was raised to that ΔE appropriate for the desired W, while that of the retarding grid was set at $(\Delta E + 2985)$ V. From the total output of the lock-in amplifier we subtracted neutral noise and an anomalous output that was dependent on the presence of both beams when ΔE was zero (see below). The net result S is proportional to a relative Q. Each cross-section measurement at W was accompanied by a measurement at 1 eV. From these measurements and Eq. (8) of I we computed the square root of the ratio of the cross section at W, Q_W, to the cross section at 1 eV, Q_1. These ratios, $(Q_W/Q_1)^{1/2}$, are shown in Fig. 2(a). The ratio of overlap integrals is equal to the ratio of the products of the respective primary-beam currents since it was experimentally determined that, in the energy range of interest and in the interaction region at ΔE, (1) all primary-ion-beam shapes were identical (within experimental error), (2) all neutral-beam shapes were identical, and (3) the position of the primary neutral beam with respect to the primary ion beam was always the same.

The effect of neglecting the anomalous signal on $(Q_W/Q_1)^{1/2}$ would be about 1%, except at $W=0.1$ eV, where it would be about 5%. There is evidence that it arises primarily in front of the interaction region; its cause is unknown.

There are end corrections to the interaction region because some argon ions were formed between grids 1 and 2 and between 3 and 4 that could arrive at the multiplier. These corrections are largest at $W=0.1$ eV, but even here their total effect will reduce the values of the points in Fig. 2(a) by less than 3%.

Other errors can be introduced by residual transverse velocity components of the beams in the interaction region, which can cause uncertainties in the interaction energy and measured cross section. An upper bound on

* Work supported by the Advanced Research Projects Agency (Project Defender) through the U. S. Office of Naval Research.
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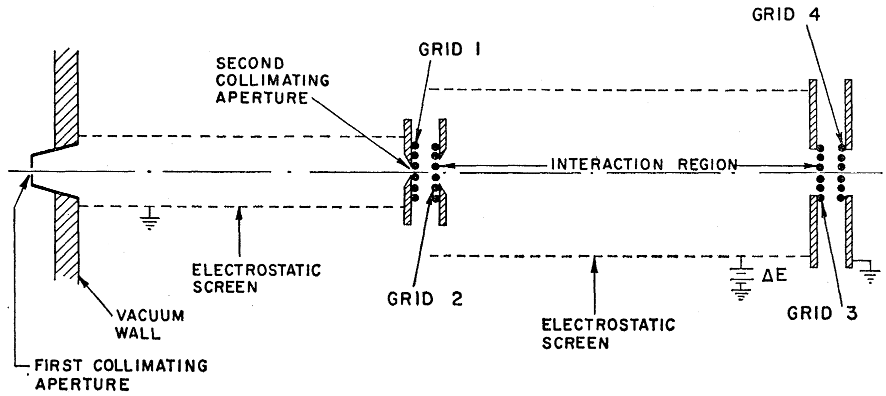

FIG. 1. Schematic of deceleration-acceleration apparatus for merging-beams system. The collimating apertures are 2.5 mm in diameter. Each grid consists of a set of parallel 0.013-mm tungsten wires spaced eight per mm and thus has a geometrical transparency of 90%. The wires of grids 1 and 2 are mutually perpendicular, as are those of 3 and 4. The distance between grids 1 and 2 and between 3 and 4 is 1.27 cm. The grid geometry was chosen to achieve a compromise between maximum transmission, minimum electric-field penetration, and uniformity of electric fields. Grids 2 and 3 are electrically connected together. The distance between the first and second collimating apertures and the length of the interaction region are each 20.3 cm. Grids 3 and 4 and the electrostatic screen are attached to the movable detector assembly (see I) and can be translated in all directions.

$\bar{W}$, the energy of interaction averaged over all possible angles of intersection of the beams and over all points in the interaction region, can be calculated from Eq. (7) of I. A lower bound on the average measured cross section $Q_{\bar{W}}$ can be calculated by substituting $\bar{W}$ for W in Eq. (8) of I. The uncertainties in the interaction energy and the cross section are considerably less than these calculations would indicate, since it can be shown that Eq. (7) grossly overestimates $\bar{W}$. The uncertainties are negligible at all W's of interest except, perhaps, at 0.1 eV. Here the upper bound on $\bar{W}$ is 0.13 eV and $(Q_{\bar{W}}/Q_{\bar{W}=1\text{ eV}})^{1/2}$ is about 95% of the uncorrected ratio. Since the uncertainties are less than these values indicate, the corrections at 0.1 eV will have little effect on the experimental curve.

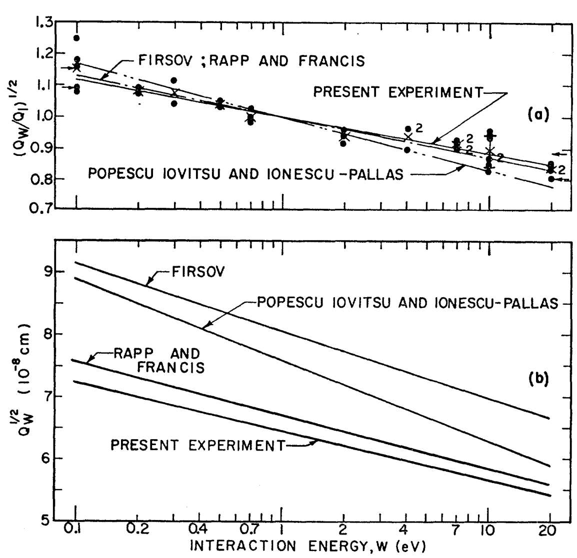

FIG. 2. (a) $(Q_W/Q_1)^{1/2}$ versus W for symmetric-resonance charge transfer in Ar. Three theoretical results are included. The slopes of the Firsov (Ref. 4) and of the Rapp and Francis (Ref. 5) lines are almost equal. Each dot represents a value obtained for a single measurement; a dot accompanied by a number 2 means that two measurements resulted in the same quantity. The error bar is the standard deviation for measurements at 10 eV and is about ±6%. Crosses indicate arithmetic averages of dots. The experimental line is made to pass through $(Q_W/Q_1)^{1/2}=1$ at 1 eV. Its slope was obtained from the crosses (properly weighted) by the method of least squares. The standard deviation of this slope confines the extremities of an experimental line to the space between the arrows. (b) Square root of the absolute cross section for symmetric-resonance charge transfer in Ar. The experimental results were obtained from the experimental line in (a) and an absolute-cross-section measurement of 47.1 Å^2 at 0.3 eV.

From Fig. 2(a) it is noted that a straight line appears to fit the crosses. The extremities of the Firsov[4] (F) and the Rapp and Francis[5] (RF) lines fall well within the limits of the extremities of the experimental line. The end points of the Popesecu Iovitsu and Ionescu-Pallas[6] (PI) line fall outside these limits.

Absolute Q measurements at 0.3 eV were made using both I and II. The results were compatible and gave an average Q of 47.1 Å^2 with an estimated total error of +25% and −21%. This value of Q was used to obtain the experimental line in Fig. 2(b). The RF line is in agreement with the experimental results; the F and PI lines are not. It can be shown that our cross section at $W=100$ eV, obtained in I, is compatible with our results in Fig. 2.

The authors thank Dr. P. K. Rol for helpful discussions.

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