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LOW ENERGY IONIZATION OF ARGON ATOMS BY ARGON ATOMS*

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Studies of ionization cross sections for neutral heavy-particle collisions may provide information on both excitation and ionization processes.[1,2] In this letter we report the total cross section for production of electrons, σ_-, by collisions between neutral argon atoms. Marked structure observed at low energies suggests a series of competing processes, which could be excitation of metastable states in either the atom or ion, or possibly both. An alternative explanation could be that of energy resonances in the production of autoionizing states.

The method employs the use of a neutral argon beam formed by symmetric charge transfer. The measurements were carried out over the laboratory energy range of 30 eV (just below the ionization threshold for electron production in ground-state argon atom collisions) to 2900 eV.

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*Supported by NASA Grant NsG-392.

[1] N. G. Utterback and G. H. Miller, Phys. Rev. 124, 1477(1961).

[2] N. G. Utterback, Phys. Rev. Letters 12, 295(1964).

An electron-impact ion source was used to produce the ions which were then electrostatically accelerated and focused.[3] The ionizing electron energy was 20 eV, although no effect on the ionization cross-sections was observable up to 45 eV. The ions produced were the $^2P_{3/2}$ and $^2P_{\frac{1}{2}}$ states, separated by 0.17 eV. Mass analysis of the Ar^+ beam showed a purity greater than 99%.

Neutral beam intensities of the order of 5×10^9 $\sec^{-1}$ were obtained in the charge transfer cell. Because of the magnitude of the 10/01 charge transfer cross sections,[4] the neutral beam was probably composed mostly of ground-state argon atoms. Similarly, impurities were partially eliminated because of their smaller charge transfer cross sections in argon. The neutral beam intensity was determined as previously[3] from the slow ion current arising in the charge transfer cell, corrected for scattered ions.

A parallel-plate ionization chamber was used in the measurement of the electron current arising from ionization. The chamber is equipped with a grid for suppressing secondary electrons, and was employed in the same manner as described in Ref. 1. The electron current was read from a Cary vibrating-reed electrometer. Secondary electrons arising from the grid were shown to be of minor significance in the measurement, except very near threshold. (See Ref. 5). The ionization current was determined by extrapolating pressure saturation curves to the zero-intercept. Complete voltage saturation was achieved with the grid at -1500 volts.

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[3] N. G. Utterback and G. H. Miller, Rev. Sci. Instr. 32, 1101(1961).

[4] R. C. Amme and H. C. Hayden, J. Chem. Phys. 42, 2011(1965).

Cross sections were obtained using the equation:

$$\sigma_{-} = \frac{ki}{PB} \quad (\mathrm{cm}^2) \quad ,$$

in which i is the electron (negative) current to the collector, P is the target gas pressure and B is the neutral beam intensity. The constant k depends upon the collector length (10 cm.) and is equal numerically to 3.05×10^{-14} if the pressure P is expressed in units of 10^{-4} torr, with B and i in the same current units. The cross section σ_{-} is the sum of the target particle ionization cross section and the stripping, or reionization, cross section, which for this case are both equal to $\sigma_{-}/2$.

The observed cross sections up to 1000 eV (lab) are plotted in Fig. 1 as a function of one-half the beam energy less the ionization potential of 15.8 eV. The abscissa thus corresponds to the excess energy available in the center-of-mass system over that required for single-electron production.

Ionization measurements[5] to 1000 eV for He on He and He on N_2 were found to extrapolate smoothly to the higher energy results of Solov'ev, Il'in, Oparin and Fedorenko. However, the present results did not seem to align with those of Afrosimov and these authors.[6] To investigate the intermediate energy region, the measurements were performed at energies up to 2900 eV. These energies overlap the

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[5] H. C. Hayden and N. G. Utterback, Phys. Rev. 135, A1575(1964).

[6] V. V. Afrosimov, R. N. Il'in, V. A. Oparin, E. S. Solov'ev and N. V. Fedorenko, Soviet Phys. JETP 14, 747(1962).

older work of Berry[7] and approach those of Sluyters, de Haas and Kistemaker.[8] A comparison is made in Fig. 2 with the measurements of Rostagni[9] and with Rosen's calculation from time dependent perturbation theory.[10] A reduction of our cross sections by about 30% to 50% would be required to fit them onto the results of Sluyters, et al. Even so, it appears that additional broad structure, with possibly a minimum near 8 keV lab, would be required. This trend is suggested in their data. The distance of closest approach for 8 keV head-on collisions is on the order of 1 a.u., at which a number of M-shell potential crossings become possible.[11]

As a check on our neutral beam intensity, secondary electron emission coefficients (γ^+ and γ^o respectively) were measured for both the Ar^+ and neutral Ar beams incident on a gold surface. The energy was varied from 250 to 2500 eV. Although the surface was not microscopically clean, one expects that at high energies the two species should eject electrons with nearly the same efficiencies. This assumption was made, per se, by Sluyters, et al. in obtaining their ionization cross sections. As in Ref. 3, it was found that the γ^+ measurement showed a marked dependence upon the time after the ion beam was allowed to strike the surface. At high energies,

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[7] H. W. Berry, Phys. Rev. 61, 63(1942). For a discussion of some earlier measurements see H. Massey and E. Burhop, "Electronic and Ionic Impact Phenomena" (Oxford Univ. Press, London, 1952) p. 532.

[8] Th. J. M. Sluyters, E. DeHaas, and J. Kistemaker, Physica 25, 1376(1959).

[9] A. Rostagni, Nuovo Cimento II, 621(1934). A factor of 2 must be used to convert those results to the total cross section, σ_-.

[10] P. Rosen, Phys. Rev. 109, 351(1958). These results have been doubled also.

[11] U. Fano and W. Lichten, Phys. Rev. Letters 14, 627(1965).

the measured γ^+ dropped approximately 15% within the first fifteen seconds. This effect is attributed to the buildup of space charge near the surface, causing the return of secondaries. Our secondary emission coefficients are in good agreement above 350 eV using the maximum γ^+ and a 20% correction to the neutral beam intensity (see Ref. 3) to account for incomplete collection of slow charge-transferred ions. Errors in the cross sections from all uncertainties are estimated to be $\lesssim$ 20%.

As a further test of procedure, measurements of Ar-N_2 ionization cross sections (argon beam) have been compared at the same center-of-mass energies with N_2-Ar ionization cross sections (N_2 beam). The results are in good agreement at excess CM energies above 35 eV. At lower energies, the Ar-N_2 results appear consistently higher, which suggests that metastable argon atoms may arise during charge transfer. (Metastable helium atoms were found to arise in the same manner by Utterback,[2] with a concentration of less than 1%.) Hence the structure in the Ar-Ar ionization cross section at beam energies less than 100 eV may be attributable in part to a neutral metastable component. The high background current observed in the neighborhood of threshold tends to support this possibility.

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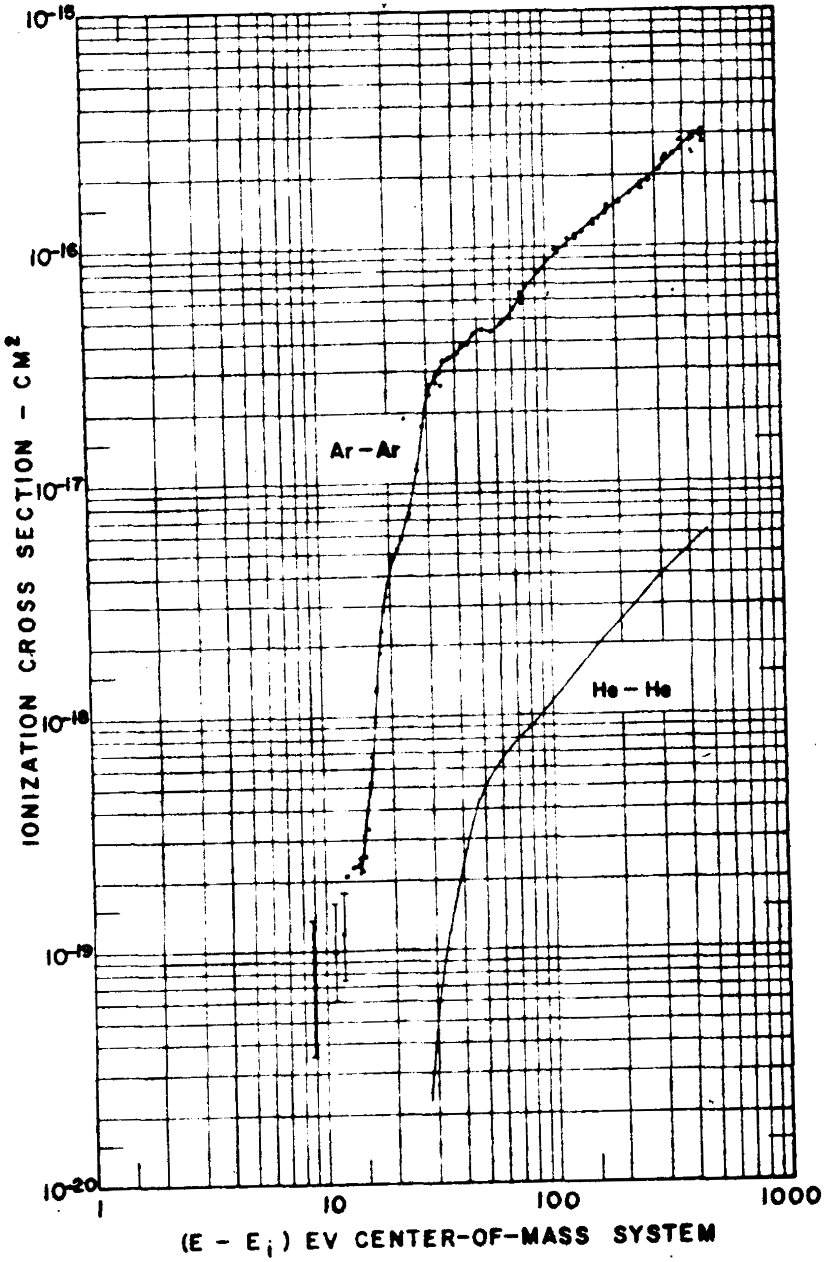

Fig. 1. Total ionization cross section σ_- for Ar - Ar collisions as a function of excess CM energy. E_i is the ionization potential.

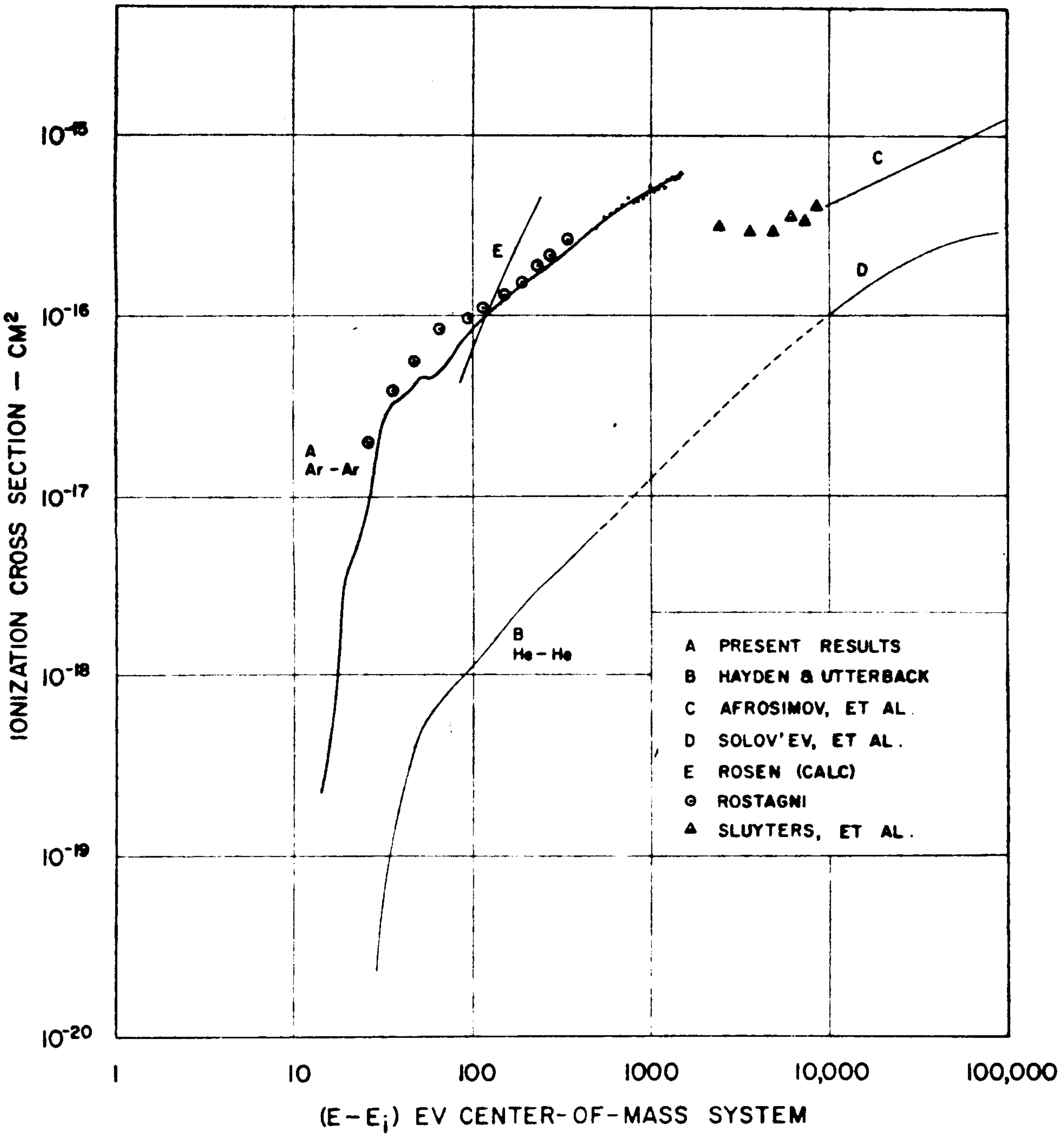

Fig. 2. Total ionization cross section up to 2900 eV lab energy compared with results of other investigators.