fulfilled, and we reduced the probabilities by empirical factors gained from measurements of neon.[4]

CONCLUSIONS

By measuring relative abundances of multiply charged ions of krypton, produced by x-ray bombardment, we were able to demonstrate the existence of the double Auger process *3d-NNN* in which two electrons are ejected. Such a process has previously been observed in neon and argon for transitions to the outermost shells, but in the case of krypton an unusually large intensity of 0.3 relative to the single Auger process was obtained. It seems that the double Auger process competes strongly with the single Auger process when the outgoing electrons have small energies and originate from the outer atomic shell. We also could deduce from our data that the two Coster-Kronig transitions *3p-3d3d* and *3p-3dN* occur with about equal frequency. We showed further that the Stobbe-Hall theory poorly predicts partial absorption cross sections for *M* electrons in krypton even for photon energies as high as 1100 eV.

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Low-Energy e^--Ar Total Scattering Cross Sections: The Ramsauer-Townsend Effect*

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The Ramsauer technique has been used to measure absolute total e^--Ar scattering cross sections from 0.1 to 21.6 eV with an estimated probable error of $\pm 3\%$. A phase-shift analysis of the data (for the $l=0,1,2$ partial waves) has been made using "modified effective range" theory which yields a scattering length of $-1.65\ a_0$ and a minimum total cross section of 0.125 Å^2 at 0.285 eV.

INTRODUCTION

THE transparency of the heavy rare gases to low-energy electrons was discovered independently by Ramsauer[1] and Townsend and Bailey,[2] and is usually referred to as the Ramsauer-Townsend effect.[3] Holtsmark[4] was able to qualitatively explain the effect by empirically introducing an attractive long-range polarization potential with a variable small-distance cutoff parameter in connection with a Hartree field representation of the Ar atom. Thus the Ramsauer-Townsend effect can be explained (at least qualitatively) in terms of potential scattering. Alternatively this effect may be thought of as being a diffraction effect with the "size" of the target atom being determined by the polarizability of the system of the incoming electron plus the target atom.

O'Malley[5] has recently applied effective-range theory[6] to approximate determinations of electron–rare-gas scattering lengths from the data of Ramsauer and Kollath.[7] However, in the case of Ar, the cross section does not vary sufficiently[7] over the measured range of electron energies[5] to give a very sensitive determination of either the scattering length or the effective range of the polarization potential. The latter quantity would be of much value in the prediction of electron-atom scattering cross sections. Furthermore, the previous direct measurements in Ar which show a Ramsauer-Townsend minimum, of Ramsauer and Kollath,[7] Rusch,[8] and Normand,[9] disagree with each other by as much as a factor of 2.8 as to the cross section at the minimum and a factor of 2 as to the energy at the minimum.[10]

Therefore, it was decided to make precise direct measurements of the total electron–argon-atom scattering cross section to lower values of incident electron energy than were previously possible.

APPARATUS AND PROCEDURE

The apparatus and procedure are the same as those described previously for Ramsauer-type measurements

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[10] The other direct measurements, those of C. Ramsauer, Ann. Physik **66**, 555 (1923); E. Brüche, *ibid.* **84**, 280 (1927) and R. B. Brode, Phys. Rev. **25**, 636 (1925) did not extend to low enough values of electron energy to observe the increase in cross section with decreasing energy.

in He,[11] with the following exception: The last slit (S_3) in the 180° momentum selector (shown in Fig. 1 in Ref. 11) is now ungrounded. This allows S_3 to have a small voltage (usually negative) on it with respect to ground in order to focus the electron beam into the collector. This change in the apparatus has allowed the measurement of cross sections to lower electron energies than previously possible since the signal to noise ratio is increased, essentially by increasing the signal. The voltage on S_3 was zero for electron energies >0.5 eV.

EXPERIMENTAL RESULTS

The total cross section was determined at various values of electron energy between 0.1 and 21.6 eV using the procedure previously described,[11] with the modification described above. The resulting values of total cross section are plotted versus electron energy in Fig. 1 for three different samples of argon[12] and two different pressure gauges. Also shown on the plot are the previous measurements of Brüche[13] and Normand.[9] The present results are within about 5% of those of Brüche[13] for the higher electron energies and within about 10% of those of Normand.[9] The low-energy results are shown on Fig. 2 together with the previous direct measurements of Ramsauer and Kollath[7] and Normand[9] as well as the recent indirect measurements of the momentum-transfer cross section of Frost and Phelps.[14] The present measurements yield a deeper and sharper Ramsauer-Townsend minimum than that observed by either Ramsauer and Kollath[7] or Normand.[9] The present results do not lie significantly deeper at the minimum than those of Frost and Phelps.[14] However, the minimum presently obtained is significantly sharper than that obtained by Frost and Phelps.[14] The line going through the present data was obtained as the best fit to the data using "modified effective-range" theory.[5] This is discussed in the next section.

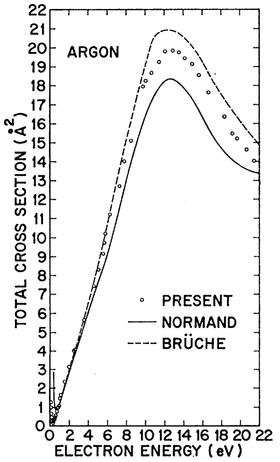

FIG. 1. Total e^--Ar scattering cross sections versus electron energy 0–22 eV.

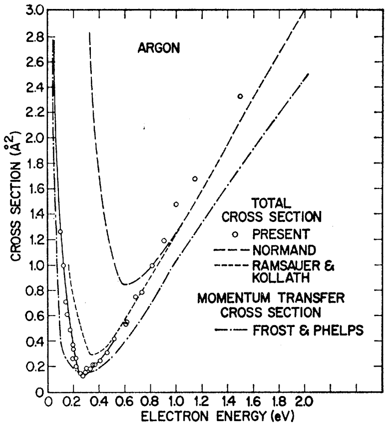

FIG. 2. e^--Ar scattering cross sections versus electron energy 0–2 eV.

DATA ANALYSIS

The data obtained in the present experiment were analyzed using the effective-range formulas given by O'Malley[5] for the ($L=0$, 1, 2) phase shifts. The total scattering cross section is given by

$$\sigma_t(\text{Å}^2)=3.517\sum_{L=0}^{2}(2L+1)\frac{\sin^2(\eta_L)}{k^2}\,, \tag{1}$$

where $k^2=(2m/\hbar^2)E$, and $E(\text{eV})=13.6(ka_0)^2$, with a_0 the electron radius of the first Bohr orbit in Å, and E the electron energy in eV.

$$\tan\eta_0/k=-A-0.2840\alpha\sqrt{E}-0.04902A\alpha E\ln E+BE\,, \tag{2}$$

$$\tan\eta_1/k=0.05679\alpha\sqrt{E}-0.07353A_1E\,, \tag{3}$$

$$\tan\eta_2/k=0.00811\alpha\sqrt{E}\,, \tag{4}$$

where A is the scattering length in units of a_0, α is the atomic electric polarizability in units of a_0^3, and A_1 is measured in units of a_0^3. In Eqs. (2)–(4), $\tan\eta_L$ were replaced by $\sin\eta_L$ and the parameters A, B, and A_1 were determined by using Eq. (1) to find the best fit to the experimental data for $0.1\leqslant E\leqslant 0.5$.[15]

The values of the parameters obtained by the best fit to the data as given by Eq. (1) are given in Table I.

TABLE I. Values of the parameters for the modified effective-range formula.

α	A	B	A_1
$11.0a_0^3$	$-1.647a_0$	$1.108a_0^3$	$11.60a_0^3$

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[11] D. E. Golden and H. W. Bandel, Phys. Rev. **138**, A14 (1965).

[12] The argon used in this work was Airco assayed reagent-grade gas in 1.1-liter Pyrex flasks. The analysis supplied by the manufacturer showed an impurity of 3.5 ppm N_2 by volume.

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[15] The best fit to the data was obtained by varying the parameters A, B, and A_1 in Eq. (1) and minimizing the sum of the squares of the percentage differences between measured and calculated values of σ_t.