Elastic $e^{\pm}$-Ar scattering with the use of the model-potential method

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A model-potential method due to Khan *et al.* [Phys. Rev. A **29**, 3129 (1984)] is used to investigate elastic $e^{\pm}$-Ar scattering at low incident energy, up to 18 eV. The effect of short-range correlation has been included via an adjustable parameter. Same polarization potentials have been used for both the electron and positron cases, and scattering parameters are presented. The results are found to be in good agreement with the existing theoretical predictions and measured values.

I. INTRODUCTION

Recently, Khan *et al.*[1] investigated elastic $e^{\pm}$-He scattering using a model-potential method. Their model potential contains the static, polarization, and local-exchange potentials. Their local-exchange potential is a modified version of Hara's model based on a free-electron-gas approximation. They have used a semiempirical polarization potential in which the effects of short-range correlations are included via an adjustable parameter. The value of the parameter depends on the system considered. The suitability and validity of their model potential has been discussed by them. They have obtained very encouraging results for both the electrons and positrons. The present study is an extension of their method to investigate the elastic $e^{\pm}$-Ar scattering.

Much experimental work has been carried out recently to investigate $e^{\pm}$-Ar scattering. For the electrons total,[2–8] momentum-transfer,[9–11] and differential[12–16] cross sections have been obtained by different groups. Theoretical calculations using an R-matrix method[17] suitable for intermediate energies and a polarized-orbital method,[18] taking the contribution of various multipoles including exchange effects exactly into account, have also been performed. A polarized-orbital method using the local-exchange potential has also been carried out by Yau, McEachran, and Stauffer.[19,31]

Total cross sections for e^{+}-Ar scattering have been reported by several groups.[5,20–26] Theoretically, Schrader,[27] using a semiempirical polarization potential, obtained good agreement with experiment.[25,26] McEachran, Ryman, and Stauffer[28] have used the polarized-orbital method; their total cross sections favor the findings of Sinapius, Raith, and Wilson.[24] Montgomary and LaBahn[29] have also used the polarized-orbital method and their results agree well with those of Coleman *et al.*[25] and Kauppila, Stein, and Jesion[5] depending on the energy considered.

Considering these facts, and to find the suitability and validity of the model potential due to Khan *et al.*[1] for heavier atomic systems, we have applied their model to investigate the $e^{\pm}$-Ar scattering. This potential[1] is a sum of the static and polarization potentials for e^{+}-Ar and the sum of static, polarization, and exchange potentials for e^{-}-Ar.

II. RESULTS AND DISCUSSION

In the present calculations, we have used Clementi's[30] ground-state wave function for the argon atom. The phase shifts for different values of l are obtained by solving the appropriate differential equations.

The short-range correlation depends on the choice of r_c. We have taken the value of $r_c = 2.1$ (see Ref. 1) and our p-wave phase shift for e^{-}-Ar scattering at this energy is -0.1479 rad. The corresponding R-matrix result of Fon *et al.*[17] is -0.1480 rad and the experimental result of Williams[16] is -0.134 rad.

A. Electron-argon scattering

In Fig. 1 we compare our phase shifts with measured[12,15,16] and theoretical[17,19,31] values. Our s-wave phase shifts deviate from the experiment above 8.0 eV. Our higher-order phase shifts are in good agreement with both theory and experiment. Discrepancies in the s-wave phase shifts may be removed by tuning the exchange potential V_{ex}^{0}. This will not effect the higher-order phase shifts or the results for positrons.

Differential cross sections at 3, 5, and 15 eV have been plotted in Fig. 2. The theoretical predictions of Fon *et al.*[17] and McEachran and Stauffer[33] have been included in the same figure. The experimental findings of Srivastava *et al.*[15]

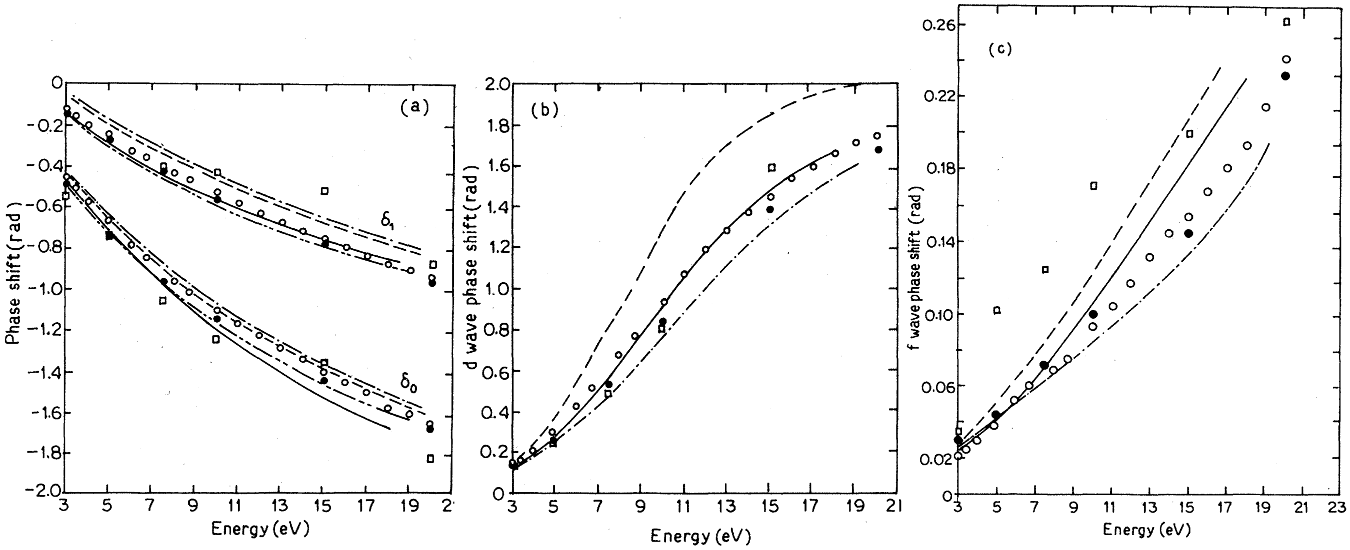

FIG. 1. Phase shifts for e^--Ar elastic scattering: ●, Andrick and Bitsch (Ref. 12); ○, Williams (Ref. 16); □, Srivastava *et al.* (Ref. 15); ----, Fon *et al.* (Ref. 17); — — —, Yau *et al.* (Ref. 31), — · — ·, Yau *et al.* (Ref. 19), ——, present calculations.

and Andrick and Bitsch[12] are also shown. Our results at these three incident energies are in excellent agreement with both experiment and theory. The formation of double minima at all the energies considered has also been noticed in our case. At all energies studied we have noticed a backward peak. The sharp forward peak becomes more prominent as the incident energy increases. The positions of the two minima become closer with increasing energy. The positions of the two dips predicted by the present method are very close to those of Srivastava *et al.*[15] This may be due to the fact that our d-wave phase shifts, which are mainly responsible for the two dips, are in close agreement [Fig. 1(b)] with the measured values.

The momentum-transfer and total cross sections are plotted in Figs. 3 and 4. Our total cross sections are in close agreement with those of Andrick and Bitsch (as quoted by McEachran and Stauffer[18]) and Wagenaar and de Heer.[8] The present results deviate from those of Srivastava *et al.*[15] and the R-matrix results of Fon *et al.*[17] above the incident energy 7.0 eV. However, the present results are better than McEachran and Stauffer[18] when comparisons are made with Fon *et al.*[17] The experimental results of different groups

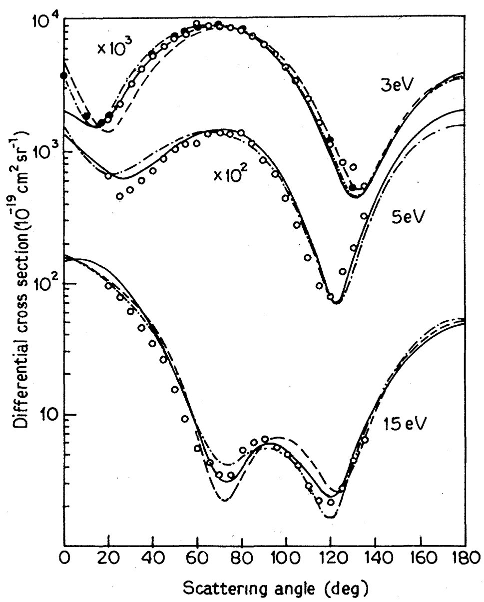

FIG. 2. Differential cross section for e^--Ar scattering (10^{-19} cm^{2}sr^{-1}) at 3, 5, and 15 eV: Expt.: ○, Srivastava *et al.* (Ref. 15); ●, Andrick (Ref. 32); Theory: — · — ·, Fon *et al.* (Ref. 17); — — —, McEachran and Stauffer (Ref. 33); ——, present calculations.

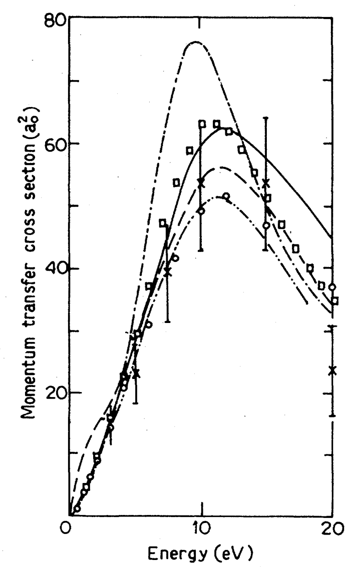

FIG. 3. Momentum transfer cross section for e^--Ar: □, Andrick and Bitsch (Ref. 12); ○, Frost and Phelps (Ref. 9); ⌶, Srivastava *et al.* (Ref. 15); — — —, — · — ·, McEachran *et al.* (Ref. 18); — · · —, Fon *et al.* (Ref. 17); ——, present calculations.

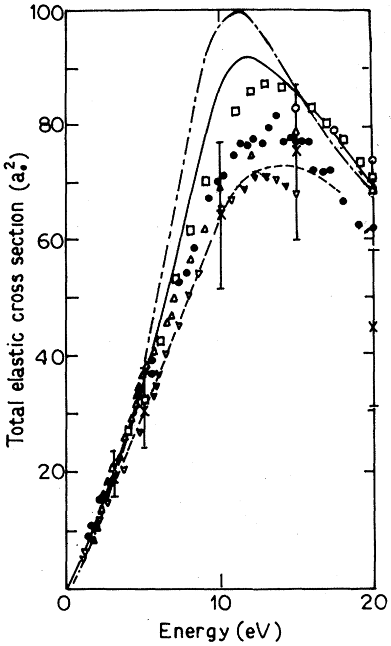

FIG. 4. Total cross section for e^--Ar elastic scattering: □, Andrick and Bitsch (Ref. 12); Δ, Charlton *et al.* (Ref. 2); ∇, Golden and Bandel (Ref. 3); ●, Kauppila *et al.* (Ref. 7); ⨯̄, Srivastava *et al.* (Ref. 15); –·–·, McEachran *et al.* (Ref. 18); ——, present calculations; — — —, Fon *et al.* (Ref. 17); ○, Wagenaar and de Heer (Ref. 8).

also differ by about 20%–25%. In the case of momentum-transfer cross sections similar features have also been noticed. Our results for momentum-transfer cross sections are in close agreement with Andrick and Bitsch[12] but deviate from those of Frost and Phelps.[9] The present results lie within the error bars of Srivastava *et al.*[15]

Thus, we notice that the model potential of Khan *et al.*[1] predicts reliable results for electron-noble gas atom scattering. This method is very simple and may be applied to heavier systems.

B. Positron-argon scattering

We have calculated the scattering of positrons by argon atoms using the same static and polarization potentials as in

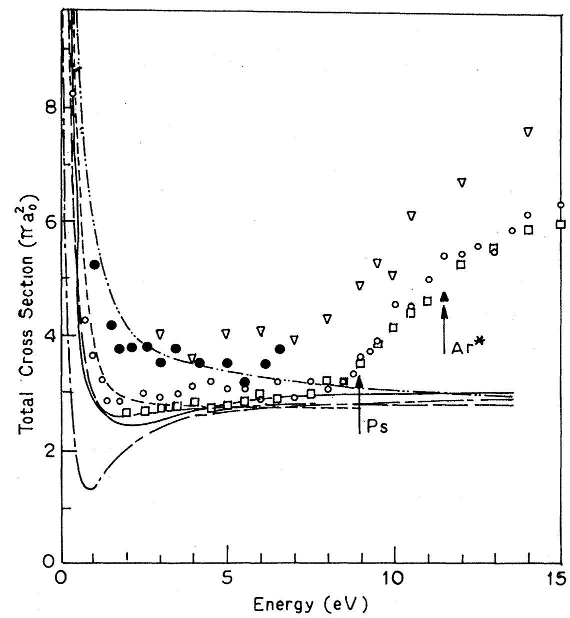

FIG. 5. Total cross section for e^+-Ar: ●, Sinapius *et al.* (Ref. 24); ○, Kauppila *et al.* (Ref. 5); □, Coleman *et al.* (Ref. 25); ∇, Coleman *et al.* (Ref. 23); –·–, Massey *et al.* (Ref. 34); — —, Montgomery and LaBahn (Ref. 29); — — —, Schrader (Ref. 27); –··–··–, McEachran *et al.* (Ref. 28); ——, present calculations.

the case of electron-argon scattering. Values of the s-, p-, d-, f-, and g-wave phase shifts are tabulated in Table I. The present s- and p-wave phase shifts differ appreciably from those of McEachran *et al.*,[28] who have employed a polarized-orbital method. In the present case, zero of the s-wave phase shift is obtained between 0.09 and 0.16 Ry, whereas they obtain the zero of s-wave phase shift between 0.16 and 0.2025 Ry. In other words, our polarization potential is less attractive than the corresponding potential of McEachran *et al.* In the absence of any elaborate calculations for this system, it is difficult to ascertain the reliability of the present phase shifts. However, the integrated elastic cross sections will give some measure of the accuracy of the present results. Our total elastic cross sections are shown in Fig. 5. Experimental results for the total cross sections of four groups[5,23–26] are also shown in the same figure. Theoretical predictions are also given.[27–29,34] The present results are in close agreement with those of the recent mea-

TABLE I. Phase shifts in radians for elastic scattering of positrons by argon atoms.

K	E (eV)	δ_0	δ_1	δ_2	δ_3	δ_4
0.100	0.136	0.1932	0.0199	0.0021	0.0002	0.00002
0.300	1.224	0.0756	0.1253	0.0295	0.0097	0.0042
0.400	2.176	−0.0490	0.1656	0.0512	0.0175	0.0078
0.469	3.000	−0.1414	0.1787	0.0683	0.0242	0.0109
0.500	3.400	−0.1821	0.1804	0.0759	0.0290	0.0124
0.606	5.000	−0.3248	0.1679	0.1018	0.0401	0.0183
0.700	6.664	−0.4486	0.1371	0.1213	0.0524	0.0245
0.767	8.000	−0.5352	0.1062	0.1319	0.0617	0.0293
0.857	10.000	−0.6492	0.0556	0.1406	0.0742	0.0363
0.939	12.000	−0.7491	0.0035	0.1423	0.0851	0.0432
1.0501	15.000	−0.8792	−0.0737	0.1350	0.0980	0.0528
1.1502	18.000	−0.9915	−0.1474	0.1192	0.1071	0.0615

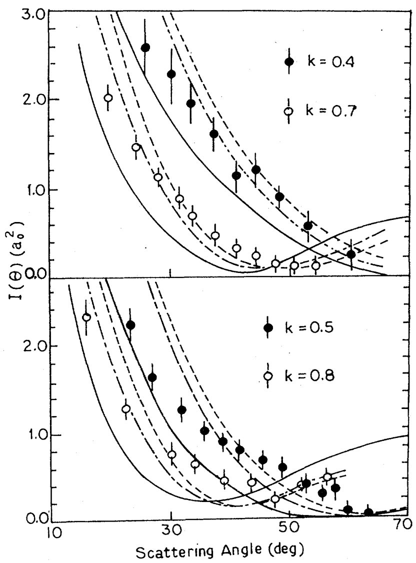

FIG. 6. Differential cross sections for e^+-Ar at different positron mean energies: — · — ·, Schrader (Ref. 27); — — —, McEachran *et al.* (Ref. 28); ——, present calculations. The error bars represent statistical standard deviation.

surement of Coleman and McNutt[26] up to the Ps-formation threshold and are also in fair agreement with those of the Detroit group.[5–7] However, the magnitudes of the total cross sections are higher than ours. The present results (Fig. 5) are in good agreement with those of Montgomery and LaBahn[29] and Schrader[27] up to the incident energy 8.0 eV, and at higher energies (above 10 eV) with those of McEachran *et al.*[28] Agreement between the experimental results of different groups is not satisfactory.

Differential cross sections are shown in Fig. 6 at $K = 0.4$, 0.5, 0.7, and 0.8. The present differential cross sections are in good qualitative agreement with the measured values of Coleman and McNutt.[26] There are some differences between our differential cross-section results with those of Schrader[27] and scaled down results of McEachran *et al.*[28] Minima in the differential cross sections have been predicted by the present method at all the energies considered. The minima in the differential cross sections have also been observed by Coleman and McMutt.[26] However, the position of the minimum is obtained at some different angle. We have also tabulated the differential cross sections at 3.0, 5.0, 10.0, and 15.0 eV (see Table II). Considering all these features, the present results for differential cross section are expected to be reliable.

TABLE II. Differential cross sections $d\sigma/d\theta$ (10^{-16} $cm^2 sr^{-1}$) for e^+-Ar scattering.

	Energy (eV)			
Angle θ (deg)	3.0	5.0	10.0	15.0
0	1.775	1.893	1.771	2.409
10	1.451	1.304	1.014	1.209
20	0.830	0.552	0.271	0.333
30	0.374	0.192	0.081	0.120
40	0.144	0.044	0.101	0.139
50	0.037	0.023	0.181	0.204
60	0.005	0.062	0.250	0.237
70	0.021	0.118	0.279	0.243
80	0.057	0.167	0.272	0.223
90	0.099	0.203	0.248	0.202
100	0.142	0.219	0.210	0.180
120	0.197	0.219	0.149	0.157
140	0.232	0.198	0.144	0.149
160	0.236	0.179	0.101	0.148
180	0.250	0.174	0.099	0.149

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