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Effect of polarization and absorption on differential cross sections and angular correlation parameters for electron excitation of helium

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The effects of local polarization and absorption potentials on differential cross sections and angular correlation parameters are studied within the distorted-wave approximation for electron excitation of the $2\,^1P$ state of helium. For examining the effect of local polarization, we have compared a recent numerical self-consistent adiabatic polarization potential for helium with the commonly used hydrogenic adiabatic polarization potential. Different radial regions for the polarization potential were studied to determine their contribution to the overall effect of polarization. Calculations are also presented which show the effects of different strengths for a local absorption potential.

INTRODUCTION

Recently there has been considerable effort directed toward obtaining an equivalent local, central potential to approximate nonlocal potentials which arise in the perturbation expansions of the scattering amplitude. These local approximations to the optical potential have been reasonably successful in describing elastic electron-atom scattering at high energies. Physical effects, such as atomic polarization caused by the incident electron, exchange distortion of the incident electron, and absorption of the incident electron into other channels of excitation are approximated by the equivalent central potential. Exchange distortion is a first-order, nonlocal effect and can be described by a real potential. Polarization and absorption arise from the real and imaginary parts of the second-order optical potential.

There have been many papers presented which describe the construction of various polarization, exchange, and absorption potentials[1-9] for elastic scattering. The majority of this work has dealt with the representation of the first-order exchange potential. Riley and Truhlar[4] and Bransden *et al.*[5] have presented studies which show that local approximations for the exchange potential can provide fairly accurate phase shifts at intermediate energies when compared to the exact solution of the static-exchange equations for electron scattering. Vanderpoorten and Winters[10] have done a similar study of polarization and absorption potentials, based on comparisons of partial-wave amplitudes.

The results of these elastic scattering studies have direct relevance for inelastic scattering in the distorted wave (DW) approximation since in the DW approximation, the inelastic event is viewed as a transition between two elastic scattering states. In two previous papers, Madison[11,12] has presented DW calculations of differential cross sections and the angular correlation parameters, λ and χ, for excitation of the $2\,^1P$ state of helium. In that work, several different DW calculations were examined. For each type of calculation, results were presented for both a static distorting potential and an optical potential which included exchange, polarization, and absorption distorting potentials. It was found that the additional optical potential terms produced a small effect in all the calculations except at the lowest incident-electron energies (~40 eV). Furthermore, there was no clear evidence that the small effect produced by the optical terms even improved agreement with experimental data.

In those calculations, only an elementary form of the optical model was used since the stated purpose was to examine the general magnitude and overall effect of the optical potential. The potentials which were used were the exchange potential of Furness and McCarthy[1] which has been shown to be good for elastic scattering calculations, a form of the polarization potential of Temkin and Lamkin[9] which was originally derived for H, and the absorption potential of McCarthy *et al.*[7] It can be argued that these last two potentials are perhaps not highly accurate for scattering from He. While these latter two elementary potentials produced small effects on the angular correlation results, it is possible that more accurate potentials may have a significant effect on the results. The sensitivity of the results on the form of the optical potential should be investigated. The purpose of this work is to examine the sensitivity of the angular correlation results to the polarization and absorption potentials. Such a study is necessary to determine whether the conclusions of Madison[11,12] are of a general nature or model potential dependent.

For examining the effect of the polarization potential, we have compared results of the Temkin and Lamkin[9] potential with a recent accurate adiabatic polarization potential.[13] This latter potential gives an upper bound for the effect of polarization. For the imaginary absorption potential, we have used the same form as the previous work but have investigated various strengths for this potential. We have not investigated different exchange potentials since the form we have used was shown by Bransden *et al.*[5] to be good for elastic scattering and the distorted waves are elastic scattering wave functions. Baluja and McDowell,[14] however, have reported calculations similar to these in which they have solved the static-exchange equation and found up to 50% change due to exchange at 80 eV. For the same parameters, our calculations with the local exchange potential show only a 10% effect.

CALCULATIONAL PROCEDURES

Details of the distorted-wave treatment for complex optical potentials can be found in Madison.[11] Further discussion of complex optical potentials can be found in Vanderpoorten and Winters.[15] Formulas for the differential cross section (DCS), the ratio of the $m=0$ cross section to the cross section summed over magnetic sublevels (λ), and the difference between complex phases for the $m=0$ and $m=1$ sublevel amplitudes (χ) are given by Calhoun *et al.*[16]

In a distorted-wave treatment, the transition probability for direct scattering is related to the transition matrix

$$T_{ba} = \langle \bar{\phi}_b^{(-)} \psi_b | (V_b - U_b) | \phi_a^{(+)} \psi_a \rangle , \tag{1}$$

where $\psi_{a(b)}$ is the initial (final) atomic wave function, ϕ_a is the eigenfunction of the initial distorting potential U_a, $\bar{\phi}_b$ is the eigenfunction for the Hermitian conjugate of the final-state potential $U_b^{(+)}$, and $V_{a(b)}$ is the full interaction potential in the incident (exit) channel. The distorted waves are the solutions of

$$(\nabla^2 + k_i^2 - U_i)\phi_i = 0 \quad (i = a, b) , \tag{2}$$

where k_i^2 is the projectile energy. The full, non-Hermitian optical potential is given by

$$U_i = V_s + V_{\text{pol}} + V_{\text{ex}} + V_{\text{abs}} . \tag{3}$$

V_s will be referred to as the static potential and is the spherical average of the static interaction between the incident electron and the atom. V_{pol} is the polarization potential, V_{ex} is the exchange distortion potential, and V_{abs} is the imaginary absorption potential.

For these calculations, we use the static atomic potential and wave functions designated as FC by Madison,[12] since they give the best agreement with the experimental data. These wave functions and potentials were obtained using the Hartree-Fock code of Froese-Fischer[17] for a helium atom in the $1s\,2p\ 2\,{}^1P$ configuration with the $1s$ wave function frozen in the $1s^2\,1\,{}^1S$ ground state. We shall designate the static potential which results from these wave functions as V_{fc}. Madison[12] found that the use of V_{fc} in calculating distorted waves in both the incident and exit channels gave the closest agreement with experiment for all parameters considered. The merit of using the same potential in each channel has been discussed several times in the literature (see, for example, Fano and Inokuti[18]). Thus for both the incident and exit channels we use $V_s = V_{\text{fc}}$. Similarly, the ground-state charge distribution is used to obtain V_{ex} and V_{abs} in both channels. Madison[11] noted a weak dependence of V_{ex} on the atomic charge distribution, while McCarthy *et al.*[7] noted a similar behavior for V_{abs}. Since the adiabatic V_{pol} which we will be using[13] was also obtained for the ground-state He atom, the optical potential is the same in both channels. Thus for Eq. (2)

$$U_a = U_b \equiv U .$$

A. Polarization

For studying the polarization potential, the optical potential was taken to be

$$U = V_{\text{fc}} + V_{\text{pol}} . \tag{4}$$

The polarization potential used in the previous work was the adiabatic polarization potential given by Temkin and Lamkin[9]:

$$V_p^a = -\frac{9[1 - (1 + 2y + 2y^2 + \frac{4}{3}y^3 + \frac{2}{3}y^4 + \frac{4}{27}y^5)\exp(-2y)]}{(2y^4)} , \tag{5}$$

where $y = 1.3414r$, consistent with a static dipole polarizability of 1.39 a_0^3 for He. This polarization was assumed to be adequate since it has the correct asymptotic behavior where the polarization potential dominates the optical potential. However, it will be shown below that the asymptotic behavior is of essentially no consequence, while the behavior in and near the atom is most important. In this close region, the polarization given by Eq. (5) cannot be expected to be accurate for helium.

For comparison to the analytic polarization potential of Eq. (5) we have also used a recent adiabatic polarization potential of Eades *et al.*[13] for He. This calculation uses a self-consistent-field approach to calculate the potential of the ground state of the helium atom in the presence of a single stationary external electron. The adiabatic polarization potential for a fixed position of the external electron is obtained by subtracting the static potential from the polarized potential. The evolution of this potential as a function of the position of the fixed external electron yields the adiabatic polarization potential for helium. In the actual dynamical problem, however, the atomic wave functions will not have time to completely adjust to the presence of the external electron. Consequently, it is likely that this completely adiabatic potential will not accurately represent the potential seen by the electron in the scattering problem. However, this potential does represent an upper limit for the effect of polarization and, consequently, the results presented here will represent an upper bound for the effects of the polarization potential on the calculations.

In Fig. 1, the analytical polarization potential of Eq. (5) and the present numerical polarization potential (both multiplied by r) are presented out to an atomic radius of $7a_0$. (The actual calculation extends to $144a_0$.) It is interesting to note that the two potentials are very similar beyond about $3a_0$. Closer examination of the potentials reveals that the numerical potential is about a constant 5% lower than the analytic in this region.

B. Absorption

The absorption potential has received the least attention in the literature. For our study of absorption, we use the full optical potential of Eq. (3). Included in the potential is the modified polarization potential of Temkin and Lamkin [Eq. (5)] and the exchange potential of Furness and McCarthy[1] and Vanderpoorten[3]:

$$V_{\mathrm{ex}} = \{(k^2 - U) - [(k^2 - U)^2 + 8(\beta_{1s}/r)^2]^{1/2}\}/2 \,. \qquad (6)$$

Here β_{1s} is r times the radial atomic wave function for the ground state. This form has been shown to be one of the best local approximations for the exchange potential in this energy region.

The imaginary absorption potential used here is that of McCarthy *et al.*[7]:

$$V_{\mathrm{abs}} = 15.01579\times 10^4\, W\beta_{1s}/(k^2 - U)^2 \,, \qquad (7)$$

where W is an energy-dependent parameter. The method of calculating W is essentially the same as that used in the previous work, except that an additional strength factor, C, has been included:

$$W = C(0.068\, k^2 - 0.099)\times 10^{-4} \,. \qquad (8)$$

The original expression for W, obtained from Fig. 1 of McCarthy *et al.*,[7] was obtained by normalizing the theoretical nonelastic-reaction cross section to the experimental values for He at energies from 40 to 200 eV. This normalization would not hold for $C \neq 1$, but the scale factor provides the option of determining the possible physical effects for a potential of this form.

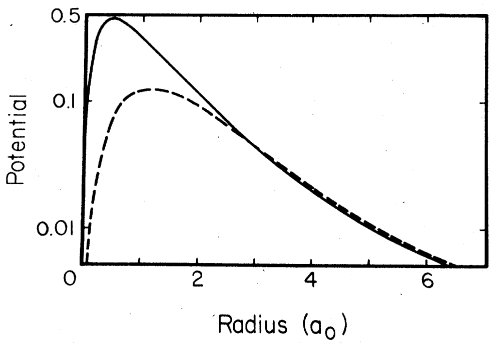

FIG. 1. The r multiplied adiabatic polarization potentials for helium out to a radial distance of $7a_0$ in units of a_0Ry. The curves are as follows: --- hydrogenic polarization potential, (V_p^a) of Temkin and Lamkin (Ref. 9), and —— numerical polarization potential (V_p^n) of Eades *et al.* (Ref. 13).

RESULTS

A. Polarization

Figures 2–4 show the results of using the two polarization potentials on λ, χ, and the DCS, respectively, at 40 eV (part a) and 80 eV (part b). We have included the recent large-angle measurements of Hollywood *et al.*,[26] which are in significant disagreement with the measurements of Sutcliffe *et al.*[27] and Steph and Golden.[28] Slevin *et al.*[29] have recently reported measurements in agreement with Hollywood *et al.* Our calculations are in much better agreement with the data of Sutcliffe *et al.* and Steph and Golden. In each figure, results are presented for a static potential $U = V_{\mathrm{fc}}$ only, for a static plus analytic polarization potential $V_{\mathrm{pol}} = V_p^a$ of Eq. (5), and for a static plus numerical adiabatic polarization potential V_p^n of Eades *et al.*[13] We have omitted the calculation using V_p^a at 80 eV since it is only slightly different from the corresponding static calculation. Calculations with V_p^n show a substantially larger effect than was previously found using the analytic counterpart.

The general effect of V_p^a on the λ parameter was to raise and narrow the small-angle minimum slightly. The calculation with V_p^n shows a similar behavior but with a more significant change in the large-angle region, especially at 40 eV. The overall effect of polarization on λ remains small,

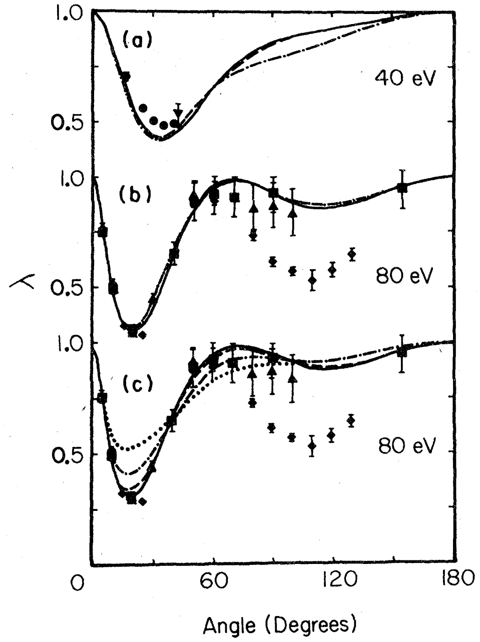

FIG. 2. Angular correlation parameter λ for electron-impact excitation of the $2\,^1P$ state of helium. (a) and (b) present comparisons of the effect of different polarization potentials for 40-eV incident electrons (a) and 80-eV incident electrons (b). The theoretical curves for the polarization calculations are as follows: —— static atomic potential only, --- static plus hydrogenic polarization potential V_p^a (omitted at 80 eV for clarity), and —·— static plus numerical polarization potential V_p^n. (c) presents comparisons of different strengths for the absorption potential. The theoretical curves are as follows: —— $C=0$ (no absorption), --- $C=4$, —·— $C=16$, and ······ $C=32$. At 40 eV, the experimental values are those of ● Eminyan *et al.* (Ref. 19) and ▼ Tan *et al.* (Ref. 20). The experimental values at 80 eV are those of ■ Sutcliffe *et al.* (Ref. 27), ▲ Steph and Golden (Ref. 28), and ◆ Hollywood *et al.* (Ref. 26).

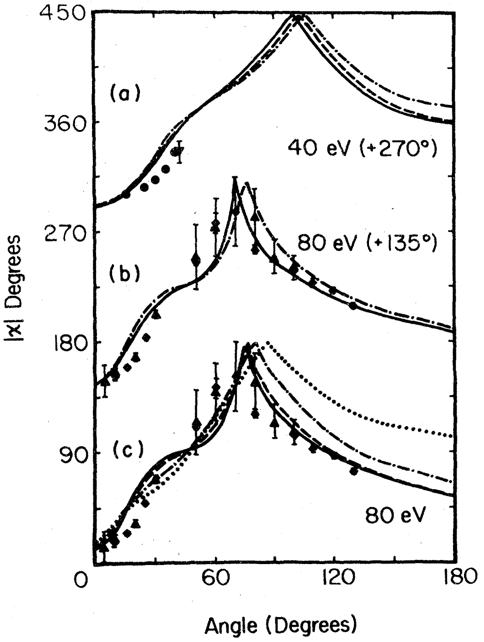

FIG. 3. Angular correlation parameter χ for electron impact excitation of the $2\,^1P$ state of helium. The legend is the same as Fig. 2.

however. Agreement with experiment has not been significantly improved or worsened in regions where experimental data are available.

In general, it can be seen that polarization has a somewhat larger effect on the χ parameter than the λ parameter, especially at intermediate angles. It is interesting to note that as energy increases, the effect of the polarization potential on χ decreases rapidly for large angles, but rather slowly for intermediate angles ($45° < \theta < 100°$). Again, the two polarization calculations have similar effects on the results for the χ parameter with V_p^n producing somewhat larger changes. In almost every instance, the calculation with V_p^a lies between the numerical adiabatic polarization calculation and the static calculation, usually much closer to the latter. In general, the additional polarization potential terms tend to worsen the agreement with experimental data for χ.

For the DCS, the polarization potential increases the theoretical values at large angles and slightly decreases the small-angle values, with the numerical adiabatic polarization having a significantly larger effect than the analytical polarization potential. Similar to the results for the χ parameter, the change is toward a worse agreement with the experimental data.

From Fig. 1 it was seen that the two polarization potentials were about the same for radii greater than $3a_0$. The fact that the two potentials have effects of different magnitude over various angular ranges of the parameters indicates a varying sensitivity to small radii for different angular regions and scattering parameters. This observation prompted a study of the radial dependence of the effect of the polarization potential. We have made several calculations with V_p^n at 40 eV to help elucidate the dependence on various radial regions. In these calculations, it was found that setting the polarization potential equal to zero for radii greater than $6a_0$ produced the same results as those calculations using the complete polarization potential with the correct asymptotic form (three-significant-figure agreement). Further, it was found that 70 to 80% of the total effect of the polarization potential can be attributed to the radial region inside $2a_0$. As far as the very small radii are concerned, it was found that radii less

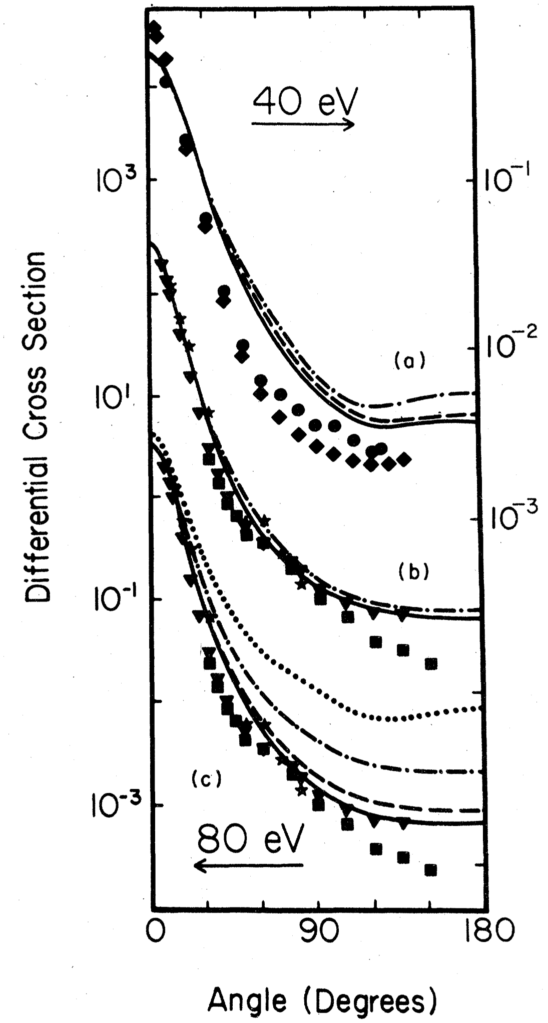

FIG. 4. Differential cross sections for electron impact excitation of the $2\,^1P$ state of helium in units of a_0^2/Sr. The theoretical curves are the same as Fig. 2 with (b) multiplied by a factor of 100. The experimental values at 40 eV are those of ● Hall *et al.* (Ref. 21 at 39.2 eV) and ◆ Truhlar *et al.* (Ref. 22 at 40.1 eV). At 80 eV, the experimental values are those of ■ Opal and Beaty (approximated from the figures of Ref. 23 at 82 eV), ★ Truhlar *et al.* (approximated from the figures of Ref. 24 at 81.63 eV), and ▼ Chutjian and Srivastava (Ref. 25).

than $0.05a_0$ affect the results inconsequentially. This last observation is expected since the polarization potential is becoming small relative to V_{fc}. If these radii are compared with the atomic size, it is seen that the only significant contributions from the polarization potential result from inside the atom since the 1*s* charge cloud peaks near $0.7a_0$ and becomes very small near $5a_0$. Examination of the relative magnitude of V_{fc} and V_p^n shows that in spite of the fact that V_p^n peaks at $0.48a_0$, it continues to increase in size relative to V_{fc} until $0.67a_0$, where V_p^n is approximately 20% of V_{fc}. It then decreases to about 4% of V_{fc} at $5a_0$ before increasing as V_{fc} approaches zero.

From these observations, we conclude that the asymptotic behavior of the polarization potential is of little importance in the calculation of these parameters. The important region of the polarization appears to be confined to radii less than $6a_0$, with the majority of the effect coming inside $2a_0$. These results show that the common practice of artificially zeroing the polarization potential inside the atom while carefully requiring the correct asymptotic behavior will negate a majority of the polarization effect.

B. Absorption

Figures 2(c)–4(c) show our results for λ, χ, and the DCS at 80-eV incident-electron energy as the strength of the absorption potential is varied. The curves shown are calculations for C equal to 0 (no absorption), 4, 16, and 32. As pointed out by Madison,[11] the original calculation ($C=1$) produced very little change for all energies and therefore we omit that calculation for clarity. Calculations using values of C between 0 and 1 produce little or no change, as might be expected from the previous results. As C is further increased, we find that the calculation is relatively insensitive until a value of about 4 has been reached. As C is increased past 4, however, fairly uniform changes are observed.

Examination of the figures shows that previous to the addition of the absorption term, both the λ and χ calculations contained essentially all of the structure shown by the experimental data. By increasing the strength of the absorption potential, much of this structure begins to disappear and agreement with experiment deteriorates significantly. The general effect on λ is to raise and broaden the small angle minimum. For χ, absorption appears to have a larger effect, especially at large angles. The calculated values are raised substantially at large angles and are also raised slightly at small angles, moving the calculation away from the experimental data in both regions.

For the DCS, the absorption potential raises the calculated values at all angles but the effect is much greater at large angles. The magnitude of this effect is large enough that for $C=32$, a large-angle minimum develops that is not present for lesser strengths. This behavior obviously worsens the agreement with experiment.

These observations indicate that if absorption does represent a significant effect in the scattering calculation, the form of the absorption potential given by Eq. (7) is not suitable for a DW calculation of this type. Probably the best overall agreement with the experimental data is still the static FC calculation of Madison.[12] These values are tabulated in Tables I–III for reference purposes.

CONCLUSION

We have examined different forms for the polarization and absorption potentials in an effort to determine the overall effect of the second-order optical model in inelastic scattering. We have found no evidence which would indicate that including these potentials in a DW calculation improves agreement between experiment and theory for the λ and χ parameters or the DCS.

For the polarization calculations, we have used an accurate adiabatic polarization potential which represents the maximum effect for polarization on the calculations. We have found that this numerical polarization potential, like the analytic hydrogenic potential which had been used previously, did not tend to improve agreement with experiment except, perhaps, at the small-angle minimum in λ. The numerical potential (V_p^n), however, does give a much larger effect than the analytical potential (V_p^a). If the actual nonadiabatic polarization potential is close to V_p^n, these results indicate that polarization could have a significant effect on the results for this kind of calculation. In addition, we have found that the form of the polarization potential for the radial region in and near the atom ($0\text{–}6a_0$) is most important and that requiring the correct asymptotic behavior is of negligible importance to the scattering process. The importance of the polarization potential at small radii indicates that the practice of zeroing the polarization inside the atom will negate a large part of the effect of polarization.

We have also examined various strengths for the absorption potential of Eq. (7). We have found that as the strength of the absorption potential is increased, agreement with experiment becomes increasingly worse. This observation indicates that if absorption does make a significant contribution to the scattering process, the localized approximation used here is not an appropriate representation.

In the present study we have not been able to achieve total agreement with experimental data and it appears unlikely that agreement will be obtained by including optical potential terms in a

TABLE I. Angular correlation parameter λ for the electron excitation of the $2\,^1P$ state of helium calculated in the DW approximation using the FC wave functions and potential and omitting optical effects.

Angle (deg) \ Energy (eV)	40	60	80	100	150	200
0	1.000	1.000	1.000	1.000	1.000	1.000
5	0.948	0.863	0.761	0.660	0.454	0.318
10	0.822	0.622	0.470	0.365	0.224	0.161
15	0.679	0.456	0.337	0.272	0.198	0.167
20	0.559	0.376	0.306	0.275	0.247	0.245
25	0.476	0.360	0.336	0.335	0.364	0.406
30	0.432	0.390	0.413	0.447	0.539	0.627
35	0.422	0.457	0.524	0.590	0.726	0.811
40	0.441	0.548	0.651	0.736	0.868	0.925
45	0.483	0.647	0.767	0.851	0.950	0.966
50	0.540	0.738	0.860	0.931	0.986	0.971
55	0.600	0.815	0.925	0.976	0.991	0.955
60	0.658	0.873	0.965	0.996	0.978	0.926
65	0.710	0.915	0.985	0.998	0.953	0.887
70	0.753	0.942	0.990	0.987	0.922	0.857
80	0.819	0.961	0.968	0.941	0.857	0.789
90	0.862	0.948	0.925	0.888	0.806	0.746
100	0.888	0.922	0.885	0.849	0.782	0.739
110	0.906	0.901	0.864	0.835	0.784	0.759
120	0.922	0.895	0.865	0.844	0.808	0.795
130	0.938	0.907	0.884	0.870	0.848	0.838
140	0.956	0.930	0.913	0.904	0.894	0.885
150	0.973	0.956	0.946	0.941	0.937	0.932
160	0.988	0.979	0.975	0.973	0.970	0.970
170	0.997	0.994	0.994	0.994	0.991	0.994

TABLE II. Angular correlation parameter $|\chi|$ (in degrees) for the electron impact excitation of the 2^1P state of helium calculated in the DW approximation using the FC wave functions and potential and omitting optical effects. (Number in parentheses is power of ten by which value should be multiplied.)

Scattering angle (deg) \ Energy (eV)	40	60	80	100	150	200
0	2.07 (1)	1.45 (1)	1.14 (1)	9.29	6.30	4.78
5	2.18 (1)	1.69 (1)	1.48 (1)	1.39 (1)	1.38 (1)	1.49 (1)
10	2.51 (1)	2.36 (1)	2.44 (1)	2.61 (1)	3.10 (1)	3.45 (1)
15	3.06 (1)	3.36 (1)	3.79 (1)	4.16 (1)	4.76 (1)	5.11 (1)
20	3.81 (1)	4.59 (1)	5.19 (1)	5.57 (1)	6.05 (1)	6.20 (1)
25	4.75 (1)	5.88 (1)	6.45 (1)	6.72 (1)	6.89 (1)	6.76 (1)
30	5.83 (1)	7.06 (1)	7.47 (1)	7.55 (1)	7.23 (1)	6.63 (1)
35	6.96 (1)	8.08 (1)	8.21 (1)	8.05 (1)	7.19 (1)	5.94 (1)
40	8.05 (1)	8.88 (1)	8.75 (1)	8.34 (1)	6.69 (1)	4.35 (1)
45	9.03 (1)	9.52 (1)	9.15 (1)	8.47 (1)	5.69 (1)	1.58 (1)
50	9.88 (1)	1.01 (2)	9.55 (1)	8.63 (1)	3.05 (1)	2.66 (1)
55	1.06 (2)	1.07 (2)	1.01 (2)	9.01 (1)	2.87 (1)	5.24 (1)
60	1.13 (2)	1.14 (2)	1.12 (2)	1.06 (2)	6.53 (1)	6.48 (1)
65	1.19 (2)	1.23 (2)	1.35 (2)	1.39 (2)	7.62 (1)	7.12 (1)
70	1.25 (2)	1.36 (2)	1.76 (2)	1.13 (2)	8.11 (1)	7.37 (1)
80	1.41 (2)	1.75 (2)	1.30 (2)	1.02 (2)	8.10 (1)	7.30 (1)
90	1.59 (2)	1.48 (2)	1.11 (2)	9.47 (1)	7.65 (1)	6.79 (1)
100	1.79 (2)	1.25 (2)	9.96 (1)	8.67 (1)	7.05 (1)	6.17 (1)
110	1.57 (2)	1.09 (2)	8.96 (1)	7.87 (1)	6.44 (1)	5.63 (1)
120	1.38 (2)	9.69 (1)	8.08 (1)	7.14 (1)	5.87 (1)	5.16 (1)
130	1.22 (2)	8.73 (1)	7.35 (1)	6.52 (1)	5.34 (1)	4.70 (1)
140	1.10 (2)	8.00 (1)	6.76 (1)	6.01 (1)	4.92 (1)	4.30 (1)
150	1.01 (2)	7.47 (1)	6.32 (1)	5.63 (1)	4.64 (1)	4.06 (1)
160	9.55 (1)	7.07 (1)	6.04 (1)	5.38 (1)	4.44 (1)	3.84 (1)
170	9.18 (1)	6.79 (1)	5.95 (1)	5.32 (1)	4.34 (1)	3.74 (1)

TABLE III. Differential cross sections (a_0^2/Sr) for electron impact excitation of the 2^1P state of helium calculated in the DW approximation using the FC wave functions and potential and omitting optical effects. (Number in parentheses is power of ten by which value should be multiplied.)

Scattering angle (deg) \ Energy (eV)	40	60	80	100	150	200
0	5.95 (−1)	1.81	3.18	4.67	8.62	1.25 (1)
5	5.51 (−1)	1.49	2.29	2.84	3.30	3.11
10	4.47 (−1)	9.38 (−1)	1.12	1.12	8.67 (−1)	6.24 (−1)
15	3.30 (−1)	5.28 (−1)	5.11 (−1)	4.32 (−1)	2.51 (−1)	1.46 (−1)
20	2.30 (−1)	2.86 (−1)	2.32 (−1)	1.72 (−1)	7.78 (−2)	3.79 (−2)
25	1.56 (−1)	1.55 (−1)	1.08 (−1)	7.16 (−2)	2.66 (−2)	1.14 (−2)
30	1.04 (−1)	8.61 (−2)	5.34 (−2)	3.24 (−2)	1.06 (−2)	4.39 (−3)
35	7.07 (−2)	5.01 (−2)	2.84 (−2)	1.63 (−2)	5.18 (−3)	2.16 (−3)
40	4.91 (−2)	3.09 (−2)	1.66 (−2)	9.37 (−3)	2.97 (−3)	1.28 (−3)
45	3.52 (−2)	2.04 (−2)	1.06 (−2)	5.94 (−3)	1.94 (−3)	8.54 (−4)
50	2.63 (−2)	1.43 (−2)	7.30 (−3)	4.09 (−3)	1.36 (−3)	6.08 (−4)
55	2.02 (−2)	1.05 (−2)	5.31 (−3)	2.98 (−3)	1.00 (−3)	4.52 (−4)
60	1.61 (−2)	7.98 (−3)	4.00 (−3)	2.25 (−3)	7.73 (−4)	3.51 (−4)
65	1.30 (−2)	6.22 (−3)	3.12 (−3)	1.77 (−3)	6.07 (−4)	2.80 (−4)
70	1.07 (−2)	4.98 (−3)	2.49 (−3)	1.42 (−3)	4.96 (−4)	2.28 (−4)
80	7.61 (−3)	3.38 (−3)	1.71 (−3)	9.84 (−4)	3.50 (−4)	1.63 (−4)
90	5.68 (−3)	2.48 (−3)	1.27 (−3)	7.41 (−4)	2.68 (−4)	1.27 (−4)
100	4.53 (−3)	1.97 (−3)	1.02 (−3)	5.98 (−4)	2.19 (−4)	1.05 (−4)
110	3.91 (−3)	1.68 (−3)	8.74 (−4)	5.11 (−4)	1.87 (−4)	8.92 (−5)
120	3.62 (−3)	1.52 (−3)	7.85 (−4)	4.56 (−4)	1.66 (−4)	7.78 (−5)
130	3.53 (−3)	1.43 (−3)	7.31 (−4)	4.21 (−4)	1.51 (−4)	6.97 (−5)
140	3.56 (−3)	1.39 (−3)	6.97 (−4)	3.97 (−4)	1.41 (−4)	6.48 (−5)
150	3.64 (−3)	1.37 (−3)	6.76 (−4)	3.82 (−4)	1.34 (−4)	6.22 (−5)
160	3.69 (−3)	1.36 (−3)	6.65 (−4)	3.73 (−4)	1.30 (−4)	6.05 (−5)
170	3.82 (−3)	1.34 (−3)	6.64 (−4)	3.70 (−4)	1.28 (−4)	5.85 (−5)

first-order calculation unless a different absorption potential would produce changes different from that which we have observed. While it may be possible to achieve agreement with some particular set of wave functions and potentials, we would conclude that the physical understanding of this process probably lies in the second-order amplitudes in the distorted-wave series.

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