Single ionization of helium by 730-eV electrons

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We present fully differential measurements of 730-eV electron-impact single ionization of the ground state of helium with 205- or 100-eV outgoing electrons. Internormalized data are obtained for coplanar geometries with the fast electron detected at $\theta_A=6°$, 9°, and 12°. The data are compared, where possible, with the corresponding data of Catoire *et al.* [J. Phys. B **39**, 2827 (2006)] and the convergent close-coupling theory. An improved agreement is found between the present measurements and the theory.

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The theoretical treatment of single ionization of helium has advanced significantly in the last decade. Following the extension of the convergent close-coupling (CCC) method to these processes [1,2] we expect mostly quantitative agreement with experiment for any kinematics or geometrical orientation of the electrons. For this reason, we were somewhat surprised at some minor, but clearly evident, discrepancies between the CCC calculation of Bray *et al.* [3] and the measurements of Catoire *et al.* [4] for single ionization of helium by 730-eV electrons leading to outgoing electron energies of $E_B=205$ eV and $E_A=500$ eV. Given that the experimental and theoretical interest has largely moved on to more complicated excitation processes involving both of the target electrons, it is important that any discrepancies for the simpler one-electron processes are understood.

In order to resolve the above-mentioned discrepancy we have undertaken new measurements of the case studied by Catoire *et al.* [4], who presented uninternormalized data for the fast electron at $\theta_A=3°$, 6°, and 9°. Whereas we are not able to study the smallest angle considered, we have obtained internormalized data for the $\theta_A=6°$, 9°, and 12° geometries. In addition, we give similar data for the case of $E_B=100$ eV. As was argued by Bray *et al.* [3], the CCC calculations for a given incident energy need to reproduce all possible measurements (involving one-electron transitions) irrespective of the ejected electron energy or geometrical orientation of the outgoing electrons. Hence, the new data allow for a more stringent test of the original CCC calculation.

A brief description of the apparatus used in these measurements follows; further details may be found in Ref. [5]. The measurements were performed in an electron-electron coincidence spectrometer, using the coplanar asymmetric kinematics. The coincidence spectrometer comprises two hemispherical electron energy analyzers mounted on independently rotatable turntables; one analyzer is equipped with a channel electron multiplier and the other with a position-sensitive detector for electron detection at the exit of the analyzer. The scattered and ejected electrons emitted into the same plane as the incident electron beam are detected and energy analyzed by these analyzers (coplanar geometry). In the asymmetric kinematics the faster (scattered) electron is detected at a fixed forward angle while the slower (ejected) electron is detected as a function of angle in the scattering plane. The incident electron beam is produced by a custom-built electron gun, employing a tungsten filament, grid element, and a five-element electrostatic lens. The incident beam crosses at right angles the target gas beam, which is produced by effusive emission from a stainless steel capillary. Coincidence fast timing electronics are used to detect time-correlated electron pairs, and signals from the four corners of a resistive anode provide position (and hence energy) information from the position-sensitive detector [6]. The measured cross sections are on a relative scale; in order to measure absolute cross sections, one must accurately determine quantities such as the target gas density and the abso-

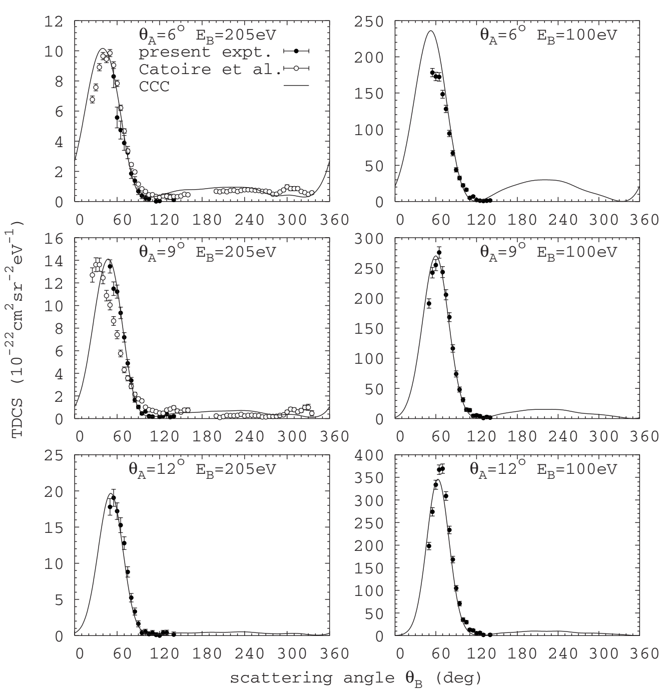

FIG. 1. Coplanar triply differential cross sections (TDCSs) for 729.6-eV *e*-He ionization with $E_B=205$ eV (left column) and $E_B=100$ eV (right column) outgoing electrons. The relative uninternormalized measurements due to Catoire *et al.* [4] have been normalized to the CCC theory individually at each angle of the fast electron. The present internormalized data set for each E_B have been normalized to the CCC theory by a single constant.

lute transmission efficiencies of the analyzers, which are difficult to determine in coincidence experiments. Internormalization of the different data sets at different scattering angles is achieved in a separate experiment in which the ejected electron energy analyzer is positioned at a fixed angle, the scattered electron energy analyzer is alternately positioned at two scattering angles (for example, 12° and 9°), and the cross-section ratio is measured. During the measurement the gas pressure and incident current are carefully monitored for stability. The statistical errors in the ratio determination range from 5% (for the 12° : 9° ratio) to 8% (for the 12° : 6° ratio).

The new and previous measurements are given in Fig. 1 together with the theoretical results. The CCC results presented are from almost the same calculation described previously [3], but with additional angular target-space momentum. Briefly, owing to the high incident energy and the large difference in the energies of the outgoing electrons, exchange was not included. Single ionization is associated with excitation of the positive-energy pseudostates. These are singlet frozen-core states that have the inner electron described by the He^+ 1s orbital and the outer electron by a linear combination of Laguerre functions obtained by diagonalizing the helium Hamiltonian [1]. The earlier calculation had target space $l_{max} \leqslant 5$. However, here we present results for $l_{max} \leqslant 7$. These are barely distinguishable from those presented earlier for the $E_B = 205$ eV case, but add just a few percent to the peaks for $E_B = 100$ eV.

From the figure we see that for $E_B = 205$ eV and $\theta_A = 9°$ the CCC theory predicts the binary peak around 20° further than observed by Catoire *et al.* [4]. However, the new measurements are in much better agreement with the CCC predictions. Extending them to the higher angle of $\theta_A = 12°$ maintains good agreement between the present measurements and the CCC theory. Turning to the case of $E_B = 100$ eV, we generally find quite good agreement between the experimental and CCC results, though with a hint that the positions of the peaks are slightly shifted by a few degrees.

In conclusion, we believe that the discrepancy identified earlier [3] does not reflect a substantial disagreement between experiment and theory, but is more of a reflection on the difficulty involved in performing measurements of this type. Additionally, we have presented more data that may be used as test cases for further experiments and theories.

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