Multi-Electron Processes In MeV/u Mixed-State C^{4+} ($1s^2$, $1s2s\ ^3S$) + He Collisions: Comparison Of AOCC Calculations And Experiments

E.P. Benis[1], A. Dubois[2], J.W. Gao[2, 3], A. Laoutaris[4, 5], I. Madesis[4, 5] and T.J.M. Zouros[4, 5]

[1]Dept. of Physics, Univ. of Ioannina, GR 45110 Ioannina, Greece
[2]Sorbonne Université, CNRS, Laboratoire de Chimie Physique–Matière et Rayonnement, Paris, France
[3]Institute of Applied Physics and Computational Mathematics, 100088 Beijing, China
[4]Dept. of Physics, Univ. of Crete, Voutes Campus, GR 70013 Heraklion, Greece
[5]Tandem Accelerator Laboratory, INPP, NCSR Demokritos, GR 15310 Ag. Paraskevi, Greece

Complex three-electron Atomic Orbital Coupled Channel (AOCC) calculations using the semi-classical close-coupling approach [1] have been performed and compared to state-selective zero-degree Auger projectile spectroscopy measurements [2] for 4-18 MeV $C^{4+}(1s^2,1s2s\ ^3S)$ mixed-state ions in collisions with He. Assumptions used in the interpretation and analysis of theoretical and experimental results are examined, including comparisons to other existing independent calculations using one-electron models.

Single differential cross sections for the production of the three-electron C^{3+} $1s2s^2\ ^2S$, $1s2s2p\ ^{4,2}P$, $1s2p^2\ ^2P$ states and the two-electron C^{4+} $2s2p\ ^{3,1}P$ states from either the $1s^2$ ground or $1s2s\ ^3S$ metastable beam component are determined using a new experimental technique [3] that can be applied in a two-measurement approach using different amounts of metastable fraction. Thus, the following processes are investigated:

$$
\begin{aligned}
C^{4+}(1s2s\ ^3S) + He &\rightarrow C^{4+}(2s2p\ ^3P) && + He && \text{[Excitation]}\\
&\rightarrow C^{3+}(1s2s^2\ ^2S,\ 1s2s2p\ ^4P,\ ^2P_{\pm}) && + He^{+} && \text{[Transfer]}\\
&\rightarrow C^{3+}(1s2p^2\ ^2D) && + He^{+} && \text{[Transfer-Excitation]}\\
C^{4+}(1s^2\ ^1S) + He &\rightarrow C^{4+}(2s2p\ ^1P) && + He && \text{[Double Excitation]}\\
&\rightarrow C^{3+}(1s2s^2\ ^2S,\ 1s2s2p\ ^2P_{\pm},\ 1s2p^2\ ^2D) && + He^{+} && \text{[Transfer-Excitation]}
\end{aligned}
$$

One of the existing more severe disagreements is the ratio of cross sections $R_m = \sigma_m(1s2s2p\ ^4P)/\sigma_m(1s2s2p\ ^2P)$ produced by direct transfer to the $1s2s\ ^3S$ metastable (m) component [4-6], expected to be 2 according to spin statistics [7]. However, previous measurements [4,5], as well as theoretical calculations including cascade feeding (expected to have a significant role in selectively enhancing the $1s2s2p\ ^4P$ population [4-6]) have found much larger numbers, in disagreement with the most recent results of $R_m \simeq 2$ [8].

For the selected processes, aside of the experimental difficulties, there are also tremendous theoretical challenges since some of these involve four open shells and high spin (up to quartet) atomic states, within a singlet/triplet total spin of the collision system (we neglect spin-orbit effects). Thus, one needs to take into account both the dynamic and static electron correlations and describe coherently the spectrum of the various spin states of C^{3+} and C^{4+}. This is a work in progress and results to date will be presented.

[1] J. W. Gao, Y. Wu, N. Sisourat, J.G. Wang and A. Dubois, Phys. Rev. A **96**, 052703 (2017).
[2] I. Madesis, A. Dimitriou, A. Lagoyannis, M. Axiotis, T. Mertzimekis, M. Andrianis, S. Harissopulos, E.P. Benis, B. Sulik and T. J.M. Zouros, J. Phys. Conf. Ser. **583**, 012014 (2015).
[3] E.P. Benis and T.J.M. Zouros, J. Phys. B **49**, 235202 (2016).
[4] T. J.M. Zouros, B. Sulik, L. Gulyas, K. Tökési, Phys. Rev. A **77**, 050701R (2008).
[5] D. Strohschein, D. Röhrbein, T. Kirchner, S. Fritzsche, J. Baran and J. A. Tanis, Phys. Rev. A **77**, 022706 (2008).
[6] D. Röhrbein, T. Kirchner, and S. Fritzsche, Phys. Rev. A **81**, 042701 (2010).
[7] E.P. Benis, T. J.M. Zouros, T.W. Gorczyca, A.D. González, P. Richard, Phys. Rev. A**73**, 029901E (2006).
[8] E.P. Benis, I. Madesis, A. Laoutaris, T. J. M. Zouros, HCI 2018 (this conference), invited progress report.