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

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## Abstract

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. Single differential cross sections for the production of the three-electron $C^{3+}$ $1s2s^2\ ^2S$, $1s2s2p\ ^{4,2}P$, $1s2p^2\ ^2D$ 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 $C^{4+}(1s2s\ ^3S)$ metastable fraction.

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].

$$C^{4+}(1s^2,\ 1s2s\ ^3S) + He \rightarrow C^{3+}(1s2s2l\ ^{2,4}L) + He^+$$

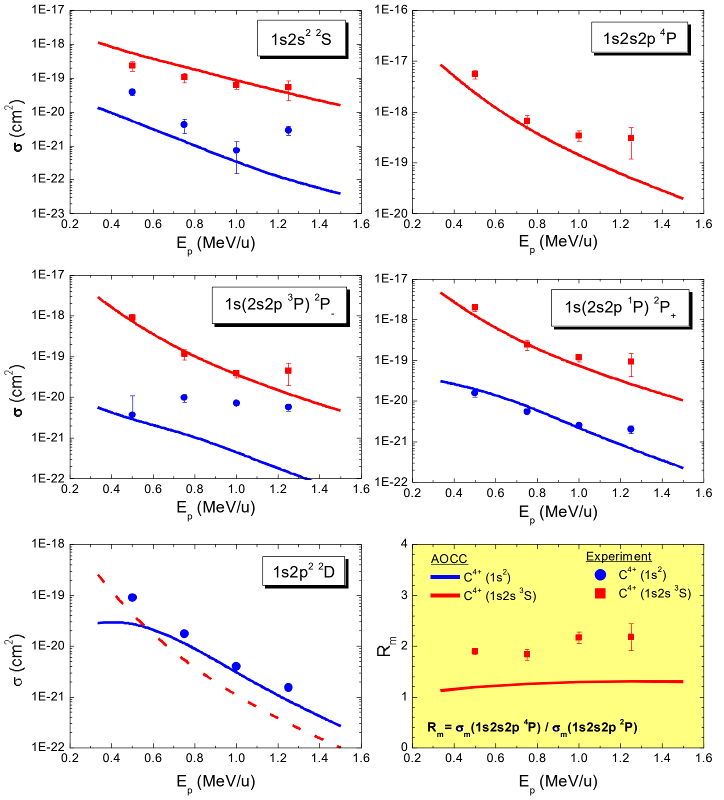

**Fig. 2.** Comparison of AOCC 3-electron calculations to experimental data obtained with zero-degree Auger projectile spectroscopy. AOCC calculations involve two projectile electrons and one target electron. The experimental SDCS data of Fig. 1 were multiplied with 4π to obtain the total cross sections. The graph in yellow background is the ratio $R_m = \sigma_m(^4P)/\sigma_m(^2P)$ that is examined in order to identify cascading contribution effects to the $^4P$.

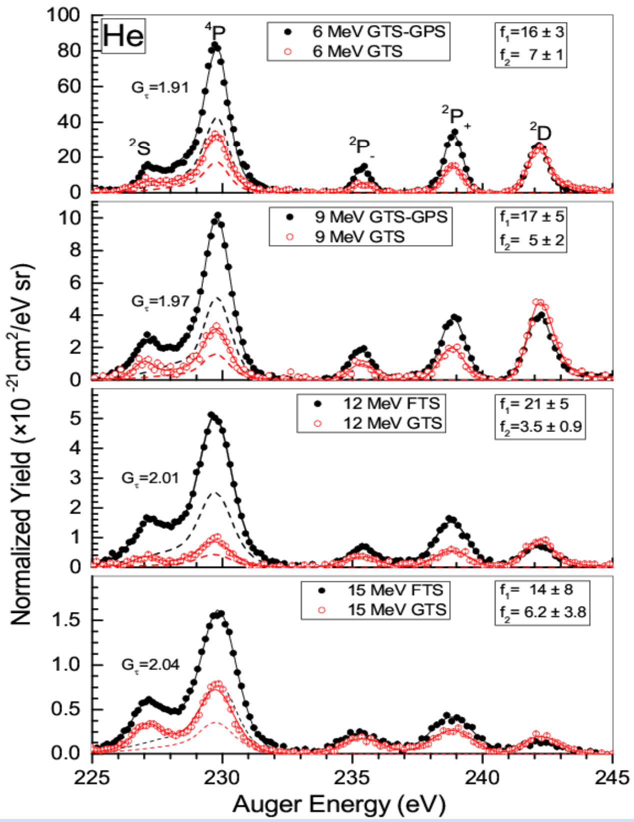

**Fig. 1.** Zero-degree $C^{3+}$ Auger line spectra for $C^{4+}(1s^2,\ 1s2s\ ^3S)$ collisions with He. Two spectra are shown for each collision energy with different metastable (1s2s $^3S$) beam fraction ($f_1>f_2$) content, (in %) as judged by the corresponding $^4P$ yields. These spectra are used within the method described in [3] to separate the contributions of the ground $C^{4+}(1s^2)$. and metastable $C^{4+}(1s2s\ ^3S)$ parts to the formation of the 1s2lnl' $^{2,4}L$ states.

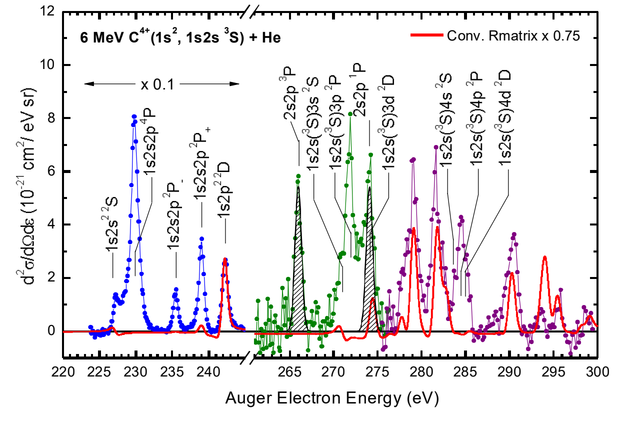

**Fig. 3.** Measured spectrum covering the whole KLn (n≥2) range. R-matrix calculations [9] convoluted with the spectrometer function account for the contributions from the $C^{4+}(1s^2)$. Capture to the $C^{4+}(1s2s\ ^3S)$ lead to the populations of 1s2snl $^{2,4}L$, of which only the $^2L$ strongly autoionize and can be seen in the spectrum, while the $^4L$ cascade down to the 1s2s2p $^4P$ state.

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