The role of the effective solid angle in the determination of the electron yield of metastable projectile Auger states

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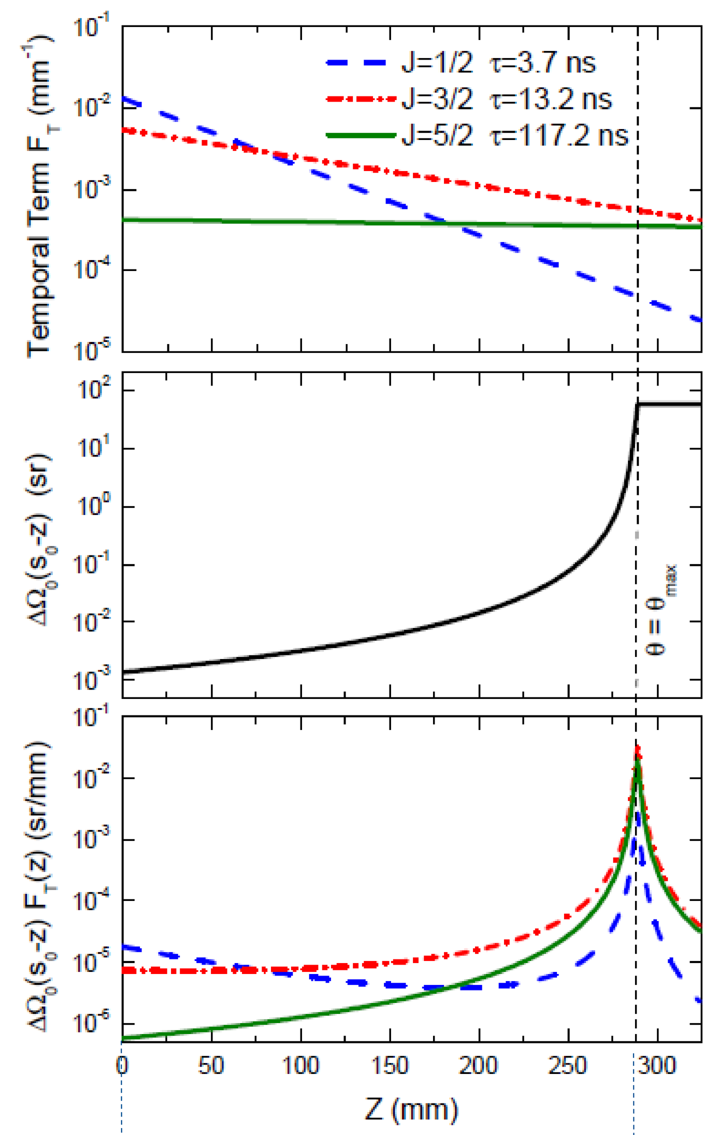
Abstract

The 1s2s2p ^4P metastable state life time τ formed by single electron capture (EC) in MeV/u He-like-ion - atom collisions is long (10^{-6}-10^{-9}s). In electron measurements, where the spectrometer lies in the direct path of the ion, electrons are measured at 0° to the beam and metastable projectile states Auger decay all along its path towards the spectrometer. Thus, the overall detection solid angle varies with the electron emission position and the determination of the Auger electron yields is not straightforward. Here, the SIMION electron optics software is used to treat the problem in an effective Monte Carlo simulation that includes τ obtained using the MCDF method. The experimental setup involving a hemispherical deflector analyzer with injection lens and PSD was accurately modeled. Random electron distributions in electron energy and emission angles were used to simulate the metastable Auger decay along the beam path, while the number of electrons was recorded. A systematic study based on the above procedure allowed for the accurate determination of the solid angle correction factor for the ^4P decay in excellent agreement with measured electron line shapes of both metastable and prompt Auger projectile states formed by EC in collisions of 25 MeV F^{7+} with H_2 [1] and 12 MeV C^{4+} with Ne. These results are important in the accurate evaluation of the $^4P/^2P$ ratio of Auger electron yields [2], whose observed non-statistical production by EC into He-like ions awaits further resolution [3].

Theoretical calculations of Auger rates W_A, X-ray rates W_X and lifetimes of the 1s2s2p ^4P_J states (J = 1/2,3/2,5/2) for atomic numbers 3 to 10. Numbers in parentheses stand for powers of 10.

	$^4P_{1/2}$			$^4P_{3/2}$			$^4P_{5/2}$		
Z	$W_A(s^{-1})$	$W_X(s^{-1})$	$\tau(ns)$	$W_A(s^{-1})$	$W_X(s^{-1})$	$\tau(ns)$	$W_A(s^{-1})$	$W_X(s^{-1})$	$\tau(ns)$
3	8.93[6]	2.43[2]	112.04	4.81[6]	7.37[2]	207.66	1.56[5]	1.38[1]	6396.90
4	4.98[7]	1.19[4]	20.08	2.51[7]	3.32[4]	39.82	9.40[5]	3.52[2]	1062.98
5	1.51[8]	1.78[5]	6.62	6.85[7]	4.79[5]	14.49	3.23[6]	3.35[3]	308.89
6	3.39[8]	1.45[6]	2.94	1.37[8]	3.83[5]	7.10	8.22[6]	1.91[4]	121.36
7	6.43[8]	8.11[6]	1.54	2.23[8]	2.12[7]	4.10	1.76[7]	7.95[4]	56.46
8	1.08[9]	3.49[7]	0.90	3.09[8]	9.06[7]	2.50	3.36[7]	2.66[5]	29.57
9	1.66[9]	1.24[8]	0.56	3.64[8]	3.21[8]	1.46	5.87[7]	7.56[5]	16.83
10	2.41[9]	3.80[8]	0.36	3.90[8]	9.85[8]	0.73	9.52[7]	1.91[6]	10.29

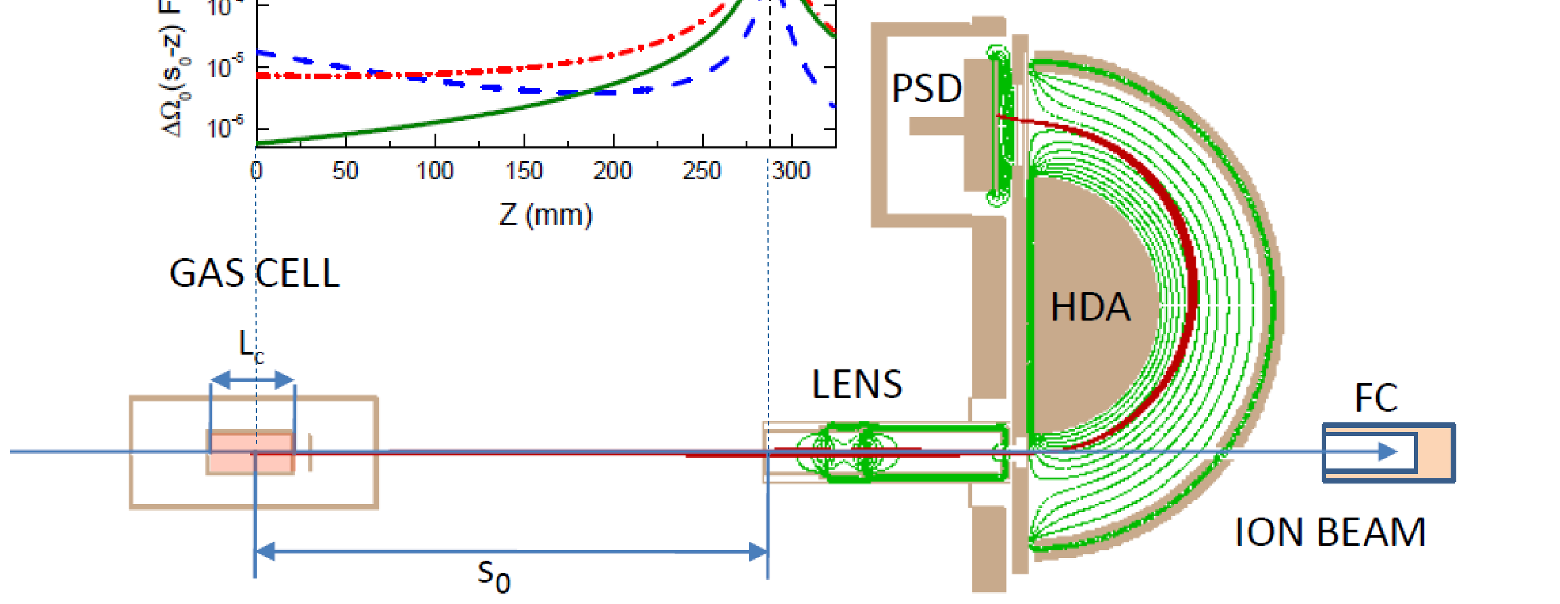


$$dN_{\tau_J} = dN_0^J \left(\frac{e^{-z/V_p\tau_J}}{V_p\tau_J}\right) dz$$

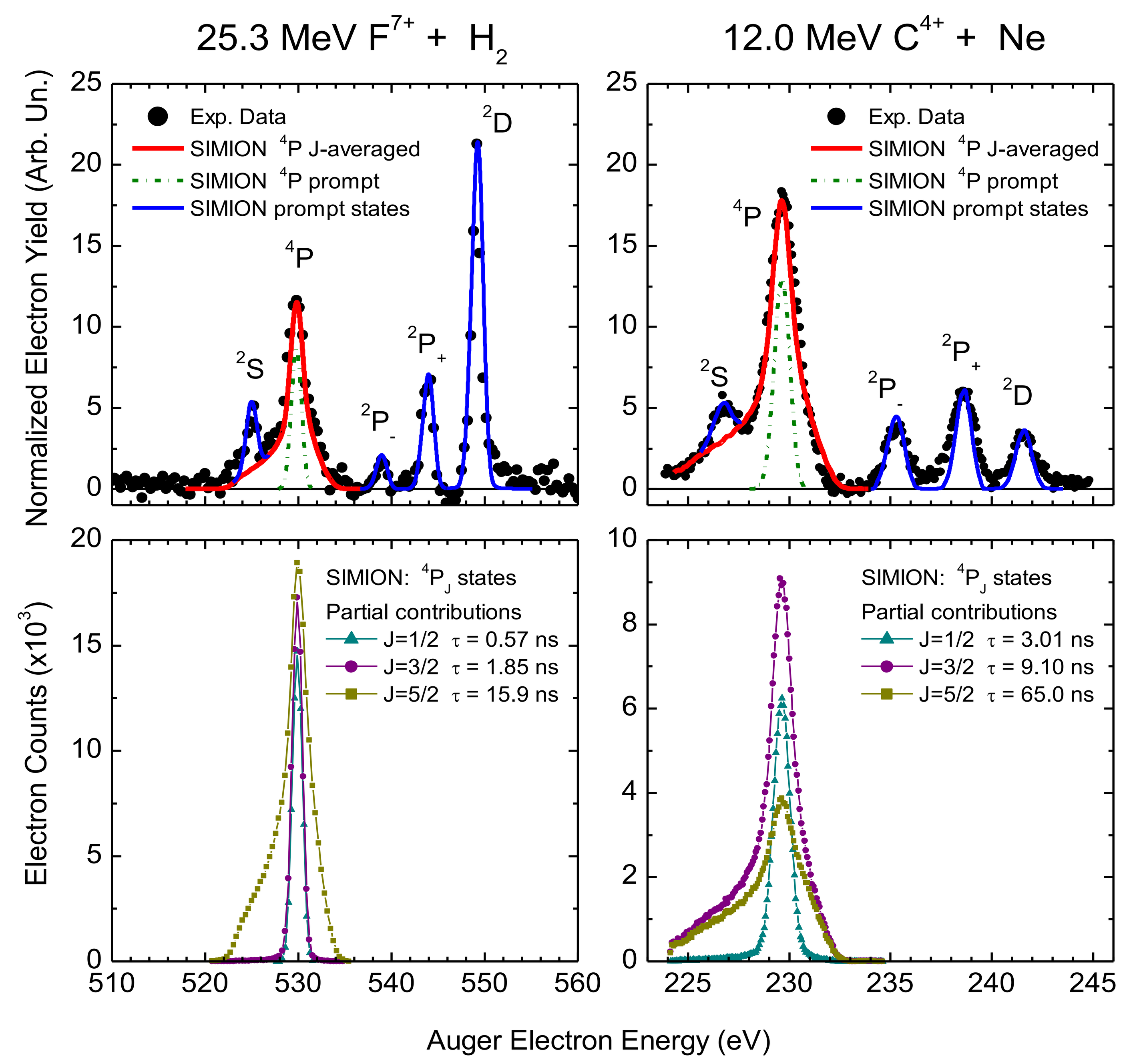
$$\Delta\Omega_0(s) = 2\pi(1-\cos\theta) = 2\pi\left(1-\frac{s}{\sqrt{r^2+s^2}}\right)$$

$$\overline{\Delta\Omega_0}(s_0, L_c) \equiv \left[\frac{1}{L_c}\int_{z'=0}^{L_c} dz'\,\Delta\Omega_0(L_c/2+s_0-z')\right]$$

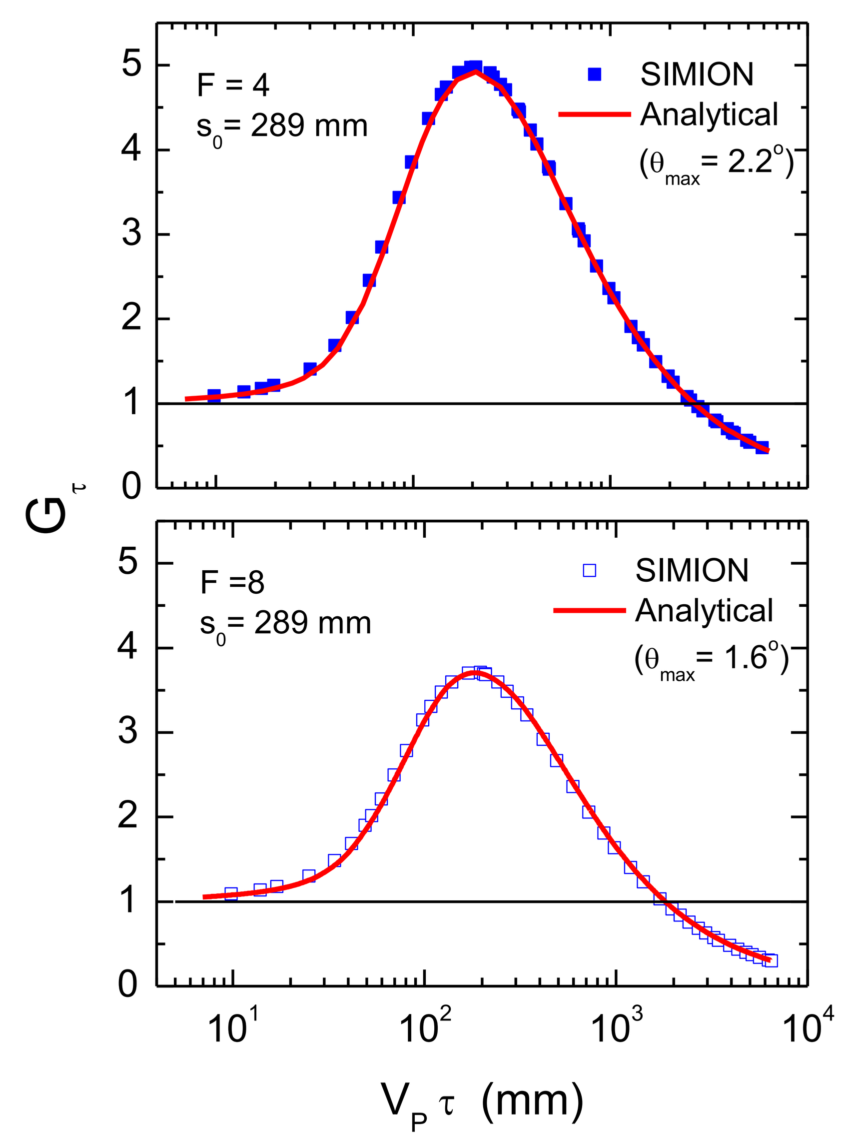
$$\overline{\Delta\Omega_J}(L, V_p\tau_J, L_c) \equiv \left[\frac{1}{L_c}\int_{z'=0}^{L_c} dz' \int_{z=0}^{L-z'} dz\, \frac{e^{-z/V_p\tau_J}}{V_p\tau_J}\,\Delta\Omega_0(L-z'-z)\right]$$



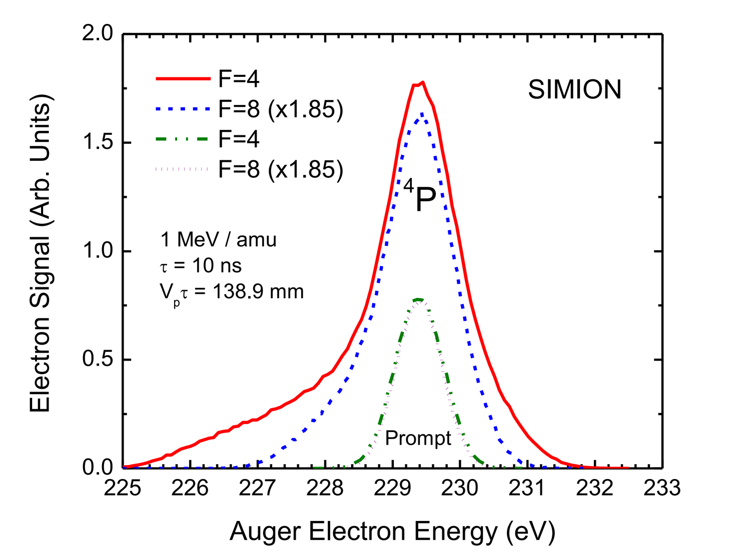
z-dependence along the ion trajectory for the probability decay density (top), the point source solid angle $\Delta\Omega_0(z)$ (middle) and their product (bottom) as calculated for the 1s2s2p ^4P_J states in the case of a 12.0 MeV C^{4+} ionic beam. At the very bottom drawn to scale is the experimental geometry showing the gas cell, the lens and the HDA.



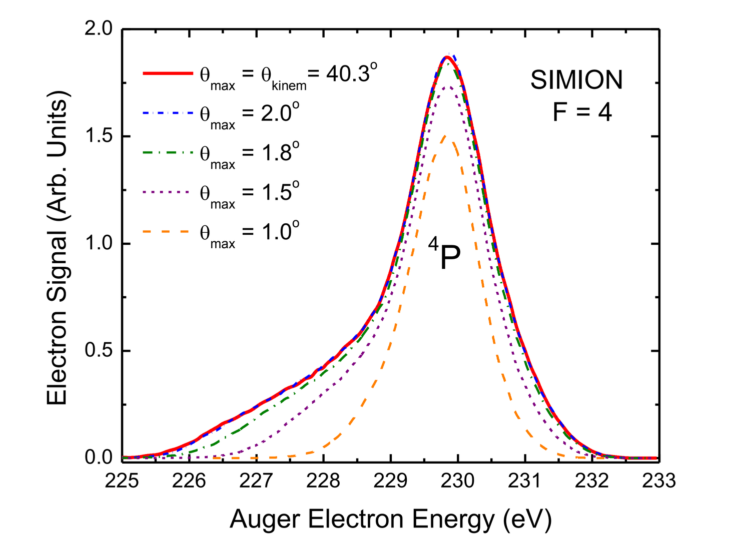
[Top] Presentation of SIMION Monte Carlo type calculations of the line shape of the Auger electron yields from metastable and prompt states in comparison to experimental data. [Bottom] Individual contributions of the J states to the ^4P state. [4]



The effective solid angle correction factor G as a function of the universal parameter $V_p\tau$, where V_p is the projectile velocity and τ the lifetime of the state. [Top] Case of gas deceleration factor F = 4. [Bottom] Case of gas deceleration factor F = 8. The solid lines represent analytical calculations terminated at maximum angles 2.2° for F = 4 and 1.6° for F = 8 in order to fit the SIMION results.



Detection efficiency for a prompt and a metastable state at deceleration conditions of F=4 and F=8.



Comparison of the 1s2s2p ^4P spectral distribution for various angles . The peak distribution is accurately reproduced considering angles having values of ≤ 2.0° in almost excellent agreement to the result from the analytical calculations.

References

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