A Quasi Four-Body FWL Treatment of Single Charge Transfer in Energetic Proton-Helium Collisions

Z. Safarzade*[1], R. Fathi†[2], Shojaei Akbarabadi†[3], M.J. Brunger‡[4], M.A. Bolorizadeh†[5]

*Department of Physics and Photonics, Graduate University of Advanced Technology, Kerman, Iran.

†Faculty of Physics, Shahid Bahonar University of Kerman, Kerman, Iran.

‡School of Chemical and Physical Sciences, Flinders University, S.A., Australia.

Synopsis: We rewrite the FWL terms in proton-helium collisions by considering a fully quantum mechanical model to find the charge transfer amplitudes. Then the charge transfer cross sections are calculated.

In a three-body treatment of single charge transfer in proton-helium collisions, only a one active electron model is assumed to apply in a fully quantum mechanical FWL formalism. In a four-body treatment of proton-helium collisions, as defined by Sloan [1], four particles are taken into account to find the FWL terms. Hence, here both electrons of helium are active. By taking into account that the target electrons are fermions of spin ½, and substituting the electronic cloud identity for double electrons in atomic helium, we have developed a method to calculate the charge transfer cross section in the collision of protons and helium atoms.

We have made use of the FWL formalism and the expansion of the scattering process defined by Sloan, to investigate the single electron transfer in the collision of protons by helium. Hence, the prior form of the FWL transition operators for single charge transfer up to second order is:

$$\begin{aligned} U_{\beta\alpha}^{-} = V_{PC} + T_{Pe_T,PC} + T_{Te_P,PC} + T_{e_Pe_T,PC} + T_{PT,PC} \\ + T_{Pe_T,PT} + T_{Te_P,PT} + T_{e_Pe_T,PT} + T_{PT,PT} \end{aligned} \quad (1)$$

where P, T, C, e_P and e_T refer to the projectile, the target's nucleus, the target's electronic cloud, the electron transferred to the projectile and the electron that remained with the target, respectively. The pure potential, the two-body transition matrix and the four-body transition matrix in a proton-electron cloud interaction, respectively, are assumed to comply with the Pauli Exclusion principle by: $V_{PC} = 0.5(V_{Pe_P} + V_{Pe_T})$, $t_{PC} = 0.5(t_{Pe_P} + t_{Pe_T})$ and also $T_{j,PC} = 0.5(T_{j,Pe_P} + T_{j,Pe_T})$. Electron indistinguishability also introduces a singlet (1) and a triplet (3) wave function into the final channel. Hence the quasi four-body FWL transition amplitude is $A_{FWL}^{Q} = \langle \psi_f | U_{\beta\alpha}^{-} | \psi_i \rangle$.

In analogy to a three-body treatment of the charge transfer reaction, where the transferred electron is the result of the interaction of the incoming projectile with the nucleus, here in a four-body treatment the projectile captures an electron as the result of it interacting with the other bound electron. Note however, while in the three-body treatment, there is only one second order term leading to the Thomas peak, there are four terms in the four-body formalism.

The amplitude terms up to the second order are added up separately for the singlet and triplet states. The final angular dependence of the electron transfer cross sections are:

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{d\sigma^{(1)}}{d\Omega} + \frac{3}{4}\frac{d\sigma^{(3)}}{d\Omega} = \frac{\nu_i \nu_f}{4(2\pi)^2}\frac{K_f}{K_i}\left(\left|A^{(1)}\right|^2 + 3\left|A^{(3)}\right|^2\right) \quad (3)$$

and plotted in figure (1) where the Thomas peak is clearly visible. The quantities K_i (K_f) and ν_i (ν_f) are the initial (final) momentum and mass ratios, respectively.

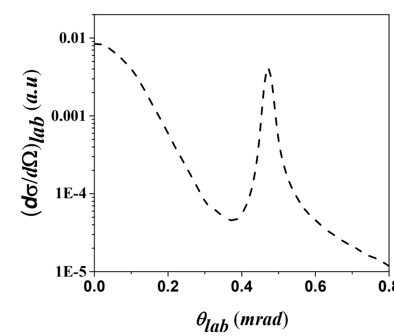

Figure (1): Angular dependence of electron transfer cross sections for proton-helium collision at 7.42 MeV.

References:

[1] Sloan JH, 1972 *Phys. Rev. C* **6**, 6

[1] Email: zsafarzade@yahoo.com
[2] Email: rfathi@uk.ac.ir
[3] Email: fshojaei@uk.ac.ir
[4] Email: Michael.brunger@flinders.edu.au
[5] Email: mabolori@uk.ac.ir