



Missouri University of Science and Technology
Scholars' Mine

Physics Faculty Research & Creative Works

Physics

01 Jan 2012

Effect of Projectile Coherence on Atomic Fragmentation Processes

Michael Schulz

Missouri University of Science and Technology, schulz@mst.edu

Kisra N. Egodapitiya

Sachin D. Sharma

Aaron C. Laforge

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/phys_facwork/1530

Follow this and additional works at: https://scholarsmine.mst.edu/phys_facwork

 Part of the [Physics Commons](#)

Recommended Citation

M. Schulz et al., "Effect of Projectile Coherence on Atomic Fragmentation Processes," *Journal of Physics: Conference Series*, vol. 388, no. PART 10, Institute of Physics - IOP Publishing, Jan 2012.
The definitive version is available at <https://doi.org/10.1088/1742-6596/388/10/102027>

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in Physics Faculty Research & Creative Works by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Effect of Projectile Coherence on Atomic Fragmentation Processes

M. Schulz¹, K. Egodapitiya¹, S. Sharma¹, A.C. Laforge^{1,2}, R. Moshhammer², A. Hasan³, D.H. Madison¹

¹Missouri S&T Rolla, USA ²MPI-K, Germany ³UAE University, UAE

Synopsis We demonstrate that the projectile coherence can have a major impact on atomic fragmentation processes. This has been overlooked for decades in formal scattering theory and may explain puzzling discrepancies between theoretical and experimental fully differential cross sections for single ionization.

Several years ago a surprising symmetry breaking, strictly demanded by first-order theories, was reported in measured fully differential cross sections (FDCS) for single ionization by ion impact even for very small perturbation parameters η (projectile charge to speed ratio) [1]. Until today, the data could not even qualitatively be reproduced by any fully quantum-mechanical calculation. In contrast, treating the projectile – target nucleus interaction classically resulted in good agreement with the data [2]. This raises the question whether the fully quantum-mechanical calculations share a fundamental problem which has been overlooked so far. One feature which all of these calculations have in common is that they assume a completely delocalized projectile wave, i.e. a coherent projectile beam. This is a very unrealistic assumption for fast ion impact since there the projectile wave packet always has a width which is negligible compared to the size of the target atom. Here, we report experimental data which demonstrate that cross sections for atomic fragmentation processes can sensitively depend on the projectile coherence.

We measured the fully momentum-analyzed scattered projectiles in coincidence with the recoiling target ions for ionization in 75 keV p + H₂ collisions. From the data we extracted double differential cross sections (DDCS) for a fixed projectile energy loss of $\epsilon = 30$ eV as a function of scattering angle θ . The width of the projectile wave packet (i.e. the transverse coherence length Δr) is proportional to $L\lambda/a$, where L is the distance between the collimating slit and the target region, a is the slit width, and λ the DeBroglie wave length of the projectile. The experiment was performed for $L_1=50$ cm and $L_2=6.5$ cm, which for $a=0.15$ mm corresponds to $\Delta r \approx 2$ a.u. and 0.3 a.u., respectively [3].

In the DDCS for L_1 we observe a pronounced interference structure, which is completely absent for L_2 . The interference is due to indistinguishable diffraction of the projectile wave from the two atomic centers in the molecule [4]. However, it can only occur if the projectile wave packet is wide enough to illuminate both atomic centers simultaneously, i.e. if $\Delta r > D$ (inter-nuclear separation). This

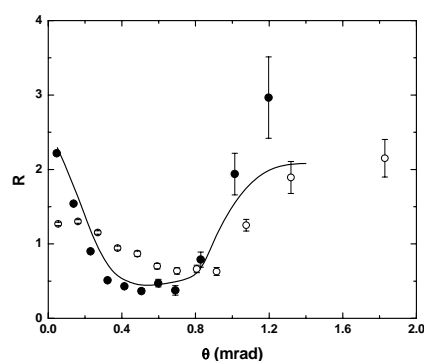


Figure 1. Cross section ratio for large to small slit distance for ionization (closed symbols) and capture (open symbols). Curve: theory for ionization

explains why the interference is absent for L_2 since there $\Delta r < D$.

The closed symbols in Fig. 1 show the ratio R between the DDCS for L_1 and L_2 , which assuming that at L_2 the projectile beam is incoherent to a good approximation represents the interference term. The solid curve shows a calculation of the DDCS assuming a coherent beam normalized to twice the DDCS for atomic hydrogen. Except for large θ this calculation qualitatively reproduces the data.

The finding that the interference structure disappears for an incoherent projectile beam was recently confirmed by equivalent data for capture in p + H₂ collisions (open symbols in Fig. 1). We thus have to conclude that it is crucially important to properly account for the projectile coherence length in theoretical calculations. For atomic targets the unrealistic assumption of a coherent beam probably results in artificial path interference between two impact parameters leading to the same scattering angle. This could quite possibly explain the theoretical difficulties in reproducing measured FDCS for single ionization by fast ion impact [1].

References

- [1] M. Schulz et al., Nature **422**, 48 (2003)
- [2] M. Schulz et al., Phys. Rev. **A76**, 032712 (2007)
- [3] K. Egodapitiya et al., submitted to PRL (2011)
- [4] J.S. Alexander et al., Phys. Rev. **A78**, 060701 (2008)