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Manipulating Atomic Fragmentation Processes by Controlling the Projectile Coherence

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Several years ago a surprising breaking of a symmetry strictly demanded by first-order theories was reported in measured fully differential cross sections (FDCS) for single ionization by ion impact even for small perturbation parameters η (projectile charge to speed ratio) [1]. 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 de-localized projectile wave, i.e. a coherent projectile beam. This is an unrealistic assumption for fast ion impact since there the projectile wave packet usually has a width which is negligible compared to the size of the target atom. Here, we demonstrate that cross sections for atomic fragmentation processes can sensitively depend on the projectile coherence. We measured momentum-analyzed scattered projectiles in coincidence with the recoiling target ions for ionization in 75 keV p + H_2 collisions. From the data we extracted double differential cross sections (DDCS) for a projectile energy loss of $\varepsilon = 30$ 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 Lλ/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 absent for L_2. The interference is due to indistinguishable diffraction of the projectile wave from the two atomic centers in the molecule. 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 explains why the interference is absent for L_2 since there $\Delta r < D$. These findings we recently confirmed by equivalent data for capture in p + H_2 collisions. 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].

[1] M. Schulz et al., Nature 422**,** 48 (2003)
[2] M. Schulz et al., Phys. Rev. A76, 032712 (2007)
[3] K. Egodapitiya et al., PRL 106, 153202 (2011)