Search for hidden dynamical induced symmetry breaking in many-particle molecular fragmentation processes investigated by multi-fragment vector correlation imaging

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State-of-the-art multi-fragment imaging techniques like the COLTRIMS reaction microscope unveil the complete momentum pattern in low energy atomic and molecular many-particle fragmentation processes much like the bubble chamber in high energy particle physics. The excellent momentum resolution far below 1 $m_e a_0 E_h/\hbar$ (1 a.u.) and the high multi-fragment detection efficiency of the COLTRIMS technique reveal the dynamic correlation of bound many-particle systems as they are fragmented into the continuum. For the fragmentation process of carbon monoxide following carbon K-shell ionization using 306 eV photons (right and left circularly polarized) $h\nu + CO \Rightarrow e_{photo} + O^+ + C^+ + e_{K\text{-}Auger}$, the vector correlations between all fragments were measured in coincidence for each event. According to the common view of this process, the photoelectron and Auger electron emission probe different aspects of the time dependent fragmentation process, i.e. the "time evolution" of fragmentation. Based on measured vectors and vector combinations (e.g. vector products) of (1) the absorbed photon, (2) the emitted photoelectron and (3) ions, the Auger electron emission can be investigated with respect to axes and planes defined by these vector combinations for each event in order to explore dynamical symmetries in multi-particle systems. In the traditional vector correlation measurements (see Nobel Prize speeches 1986 of Dudley Herschbach, John C. Polanyi, and Yuan T. Lee) single particle detection measurements with aligned quantum objects were performed thus only symmetry properties of huge ensembles could be explored. Performing the here described multi-coincidence vector correlation measurements event by event dynamically induced symmetry breaking in single dynamically entangled processes can be revealed.

In our approach all momenta of the charged fragments are measured in coincidence and are stored for each interaction in an event list (k,l,m,n). This way of data storing ensures that the photo electron of event (k,l,m,n) is only correlated to fragments of the same event and never to any proceeding or subsequent events (k,l,m,n±i). Therefore one can calculate for each event the vector products and project the measured Auger distributions on axes or planes defined by these vector products. One example is the vector product $\boldsymbol{Z} = \boldsymbol{A}_{photon} \times \boldsymbol{p}_{ephoto}$. When mirroring the time from $t \Rightarrow -t$ this new vector $\boldsymbol{Z}$ does not change its direction. That means that $\boldsymbol{Z}$ is even under time reversal (T-even). On the other hand, under spatial inversion, $\boldsymbol{r} \Rightarrow -\boldsymbol{r}$, the vector $\boldsymbol{Z}$ is odd (P-odd). The Auger electron emission should show with respect to this $\boldsymbol{Z}$ direction a perfect symmetrical distribution, if time is reversible in the Auger process. Measuring the Auger electron distributions for ($\boldsymbol{A}_{photon}(t)$ and $\boldsymbol{p}_{ephoto}(t)$) as well as for ($\boldsymbol{A}_{photon}(-t)$ and $\boldsymbol{p}_{ephoto}(-t)$), i.e. for left and right polarized photons and photoelectrons emitted in opposite directions, respectively, one can test the time inversion symmetry. The then inversed Auger spectrum ($-t$) should be identical with the one of (t). In table 1, other interesting combinations of vector products and scalar products with different behavior under P- and T-reversal are presented (with $\boldsymbol{n}$ being the molecular vector pointing from the carbon nucleus to the oxygen nucleus).

Vector product	$t \Rightarrow -t$	$\boldsymbol{r} \Rightarrow -\boldsymbol{r}$
$\boldsymbol{Z} = \boldsymbol{A}_\gamma \times \boldsymbol{p}_{ephoto}$	$\boldsymbol{Z}(t) = +\boldsymbol{Z}(-t)$	$\boldsymbol{Z}(\boldsymbol{r}) = -\boldsymbol{Z}(-\boldsymbol{r})$
$\boldsymbol{Z'} = (\boldsymbol{A}_\gamma \times \boldsymbol{p}_{ephoto}) \times \boldsymbol{p}_{K\text{-}Auger}$	$\boldsymbol{Z'}(t) = -\boldsymbol{Z'}(-t)$	$\boldsymbol{Z'}(\boldsymbol{r}) = +\boldsymbol{Z'}(-\boldsymbol{r})$
$S = (\boldsymbol{A}_\gamma \times \boldsymbol{p}_{ephoto}) \cdot \boldsymbol{n}$	$S(t) = +S(-t)$	$S(\boldsymbol{r}) = +S(-\boldsymbol{r})$

Table 1: Vector products with respect to time and parity symmetries

Reference: F. Trinter, et al., Molecular Physics, Vol. 110, Nos. 15-16, 1863-1872 (2012)