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# Symmetries and Symmetry-Breaking in High Harmonic Generation: Controlled Polarization and Ultrafast Spectroscopy

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The analysis of symmetries and their associated selection rules is extremely useful in all fields of science. The field of nonlinear optics is no exception. In the early days of nonlinear optics symmetries were used to derive whether particular nonlinear processes are allowed or forbidden according to the mediums point-group [1] . This approach (which is believed to be complete) is regularly taught in graduate classes and relies on reducing the nonlinear optical coefficient tensor to its minimal representation, where zeroed-out elements indicate a forbidden process (e.g. no second harmonic generation in centrosymmetric media) [1] . However, this derivation is based on a perturbative expansion that is inappropriate in extremely nonlinear processes such as high harmonic generation (HHG). Moreover, it fails to take into account the symmetries of the driving pump field (dynamical symmetries, DS), or the symmetries of the wave equations, which may manifest over several length scales (both on microscopic and macroscopic scales). While some selection rules were derived for HHG in the microscopic/macroscopic regimes, these were restricted to ad-hoc cases and a general theory has not been formulated. In particular, no theory has addressed combining these two regimes.

I will present a general, closed-form, group-theory based analysis for the role of dynamical symmetries (DS) in harmonic generation. This approach is used to derive novel symmetries and selection rules for any light-field interacting with any type of medium (gas, solid, or liquid). We experimentally explore several of these new DSs in harmonic generation for the first time, including a multi-scale macroscopic-microscopic DS, and an elliptical DS [24] , allowing polarization control over the emitted XUV radiation. I will also discuss the role of symmetry breaking in ultrafast spectroscopy. Specifically, I will focus on DS- breaking-based detection of chiral degrees of freedom [5,6] , leading to all-optical electric-dipole based chiral-signals, including preliminary experiments in chiral limonene liquid showing a huge chiral discrimination of 163%.

1. R. W. Boyd, Nonlinear Optics, 3rd ed. (2003). 2. O. Neufeld et al., Nat. Comm. 10, 405 (2019). 3. O. Neufeld et al., New J. Phys. 19, 23051 (2017). 4. O. Neufeld et al., Photonics 4, 31 (2017). 5. O. Neufeld and O. Cohen, arXiv1807.02630 (2018). 6. D. Ayuso et al., arXiv1809.01632 (2018).