Sub-Cycle Field Driven Dynamical Berry Phase in Solids

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In quantum mechanics, a wavepacket acquires a geometric phase, known as the Berry phase, as it evolves along a closed trajectory in parameter space. In condensed matter systems, the Berry phase underlies a broad range of phenomena, including the anomalous Hall effect, orbital magnetism, and electric polarization.

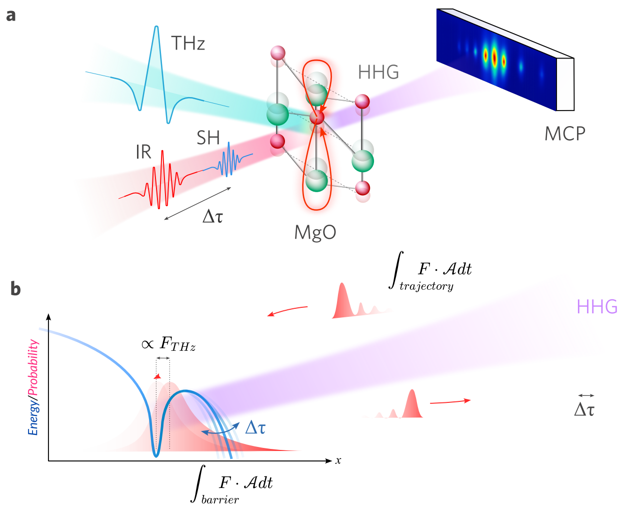

Figure 1: Field-induced Berry phase

However, in centrosymmetric materials possessing time-reversal (TR) symmetry, its manifestation is suppressed and effectively vanishes. When a system is driven by a strong terahertz (THz) field, it can be coherently driven far from equilibrium, transiently reshaping its symmetry on sub-picosecond timescales. This capability opens new avenues for quantum control with potential applications in information processing and sensing. Here, we experimentally demonstrate that a strong THz field can transiently break inversion symmetry in MgO, inducing a dynamical complex Berry phase, thereby manipulating the topological properties of the material. Applying high-harmonic generation (HHG) spectroscopy, we directly resolve the Berry phase, accessing both its real and imaginary components. The first is associated with coherent intraband dynamics while the second with quantum tunneling through a potential barrier. This observation enables the reconstruction of the time-dependent evolution of the Berry phase within the cycle of the THz field. The coherent manipulation of solids with strong fields, combined with attosecond-resolved HHG spectroscopy, represents a fundamental step toward unveiling and controlling geometric quantum phenomena in condensed matter systems.