Second-order Hall effect in insulators: the effect of interband Berry curvature dipole

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Noncentrosymmetric conducting materials have been shown both theoretically and practically to exhibit second-order Hall current even in the presence of time-reversal symmetry. Moreover, this nonlinear effect has been used to detect the Berry curvature of these materials via the relationship between the nonlinear response and the Berry dipole. [1,2] Here, we introduce the nonlinear Hall effect in a wide range of insulating systems. We first constructed the formalism from both the quantum perturbation theory and the semi-classical transport theory of insulators. To support our theory, we examined the oscillating second-order transverse electric current of various inversion-broken insulating materials as a response to applied linear polarized light. We performed real-time time-dependent density functional theory calculations for a CO molecule and topologically trivial (hexagonal boron nitride) and nontrivial (bismuthene) two-dimensional (2D) insulators. Irrespective of the dimension or topologic character, all samples exhibit second-order Hall current, which is found to be sensitive to the light polarization direction. Furthermore, the effect becomes visible when the light frequency exceeds one-half the bandgap energy; this effect is correlated with the interband Berry dipole of 2D systems in the sub-bandgap regime. This study suggests a new type of nonlinear Hall effect and provides methods to detect the Berry curvature, the band structure, and the symmetry properties of the insulators.

[1] I. Sodemann et al., Phys. Rev.Lett., **115**, 21 (2015)
[2] Q. Ma et al., Nature, **565**, 7739 337 (2019)