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Linear and nonlinear responses in topological semimetals

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Topological phases that are insulating in the bulk often have quantized electromagnetic responses, such as the quantum Hall effect or axion electrodynamics. Gapless phases with topological features, such as Dirac and Weyl semimetals in 3D, can also have interesting electromagnetic responses, although one might not expect them to be quantized. We first discuss linear response and the possibility of a chiral magnetic effect in Weyl semimetals; instead we find a "gyrotropic magnetic effect" (GME) determined at low frequency by the magnetic moments on the Fermi surface of Bloch electrons. The GME should be observable in optical rotation on mirror-free Weyl semimetals. At higher order in electromagnetic fields, many possible effects occur, which are studied both semiclassically and via a fully quantum Floquet approach. Nonlinear optical properties, specifically photocurrents and second-harmonic generation, are discussed in detail. The circular photogalvanic effect (CPGE) is a piece of the photocurrent that was previously argued to have a Berry-phase origin; we confirm this in a fully quantum calculation and then show that for certain Weyl semimetals the CPGE injection current is actually quantized with no material-specific parameters.