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Persistent valley currents and topological transport in gapped graphene

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The anomalous Hall effect (AHE), arising due to Berry curvature in materials with broken inversion symmetry, results in topological currents flowing in system bulk transversely to the applied electric field. We will discuss recent work on AHE in materials with several valleys, such as e.g. graphene and transition metal dichalcogenide monolayers, where these currents have been observed [Mak et al., Science 344, 1489 (2014); Gorbachev et al., Science 346, 448 (2014)]. Interestingly, these materials do not fit the paradigm of topological materials with Chern bands and associated topologically protected edge modes dominating (quantized) Hall conductivity. Here, in contrast, gapless edge states may be absent since they are not enforced by topology or symmetry. Further, even when present, these states are not protected against backscattering due to roughness on the atomic scale. Naively, this would lead one to conclude that topological currents cease to exist. If true, this would imply that the key manifestations, such as the valley Hall conductivity and orbital magnetization, vanish in the gapped state. We will argue that the opposite is true: the absence of conducting edge modes does not present an obstacle since valley currents can be transmitted by the bulk states in the filled Fermi sea beneath the gap. This leads to an interesting behavior: rather than being vanishingly small, valley currents reach maximum value in the gapped state. Such undergap currents can also occur as persistent currents in the thermodynamic ground state and dominate orbital magnetization in valley-polarized gapped systems. We will conclude with discussing requirements for dissipationless valley transport and argue that they can be met under realistic conditions.

[1]based on the work done in collaboration with Yuri Lensky, Polnop Samutpraphoot and Justin Song