Revisiting the valley (and orbital) Hall effect

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Abstract

We discover that the conservation of the valley density in multi-valley insulators is broken in an unexpected way by the electric field that drives the valley Hall effect in the first place. This implies that time-reversal-invariant fully-gapped insulators, in which no bulk or edge state crosses the Fermi level, can support a valley Hall current in the bulk and yet show no valley density accumulation at the edges. If the system is not fully gapped then valley density accumulation at the edges is possible. The accumulation has no contribution from undergap states and can be expressed as a Fermi surface average. We also discover that a net valley density polarization is dynamically generated for certain edge terminations. We draw general conclusions which apply to other phenomena, such as the orbital Hall effect.

Figures

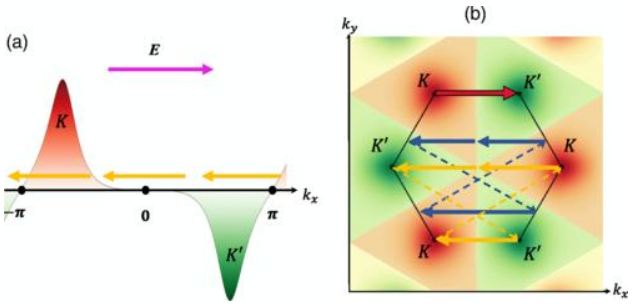

Figure 1: The cyclic flow of electrons (yellow arrows) in the one-dimensional Brillouin zone of a ribbon subject to electric field E (pink arrow). The valley charge changes sign whenever the electron crosses the boundaries between the red and green regions. Each electron performs half the cycle as a "left-valley electron" and half as a "right-valley electron." Also shown are the Berry curvature hot spots with a positive (negative) value near K (K'). Because of opposite Berry curvatures in the two valleys, the result is a steady valley Hall current. However, in a fully gapped insulator, at the end of the cycle each electron returns to its initial state, thus no valley redistribution occurs. Panel (b): Two examples (blue and yellow arrows) of a similar flow in the two-dimensional Brillouin zone of the infinite system.

References

[1] Alexander Kazantsev, Amelia Mills, Eoin O'Neill, Hao Sun, Giovanni Vignale, and Alessandro Principi, Phys. Rev. Lett. 132, 106301 (2024).
[2] Hao Sun, Alexander Kazantsev, Alessandro Principi, and Giovanni Vignale, Phys. Rev. B 111, 075432 (2025)