Summary of “Quantum-limit Chern Topological Magnetism in $TbMn_6Sn_6$”

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Background

In Kagome materials with strong spin-orbit coupling and out-of-plane magnetization, spin-polarized Dirac fermions are theoretically possible, analogous to the Haldane model. However, ideal quantum materials are lacking, posing experimental challenges.

Key Findings / Evidence of Quantum-limit Chern Magnet

Spin-polarized Dirac cones with Landau Quantization

(1) Zero-field STM peak moves linearly with magnetic field (Zeeman effect):

$$\Delta E = \pm \tfrac{1}{2} g \mu_B B.$$

Indicates spin-polarized electronic states.

(2) STM dI/dV maps at high magnetic field show discrete Landau quantization, observing clear Dirac dispersion and characteristic E_n vs. B dependence.

(3) ARPES measurements confirm Dirac fermions in the Brillouin Zone.

Chern Gap

(1) *Landau fan:* High-bias STM measurements under varying magnetic fields show two parallel straight lines, revealing a Chern gap.

(2) *Landau-level fitting formula:*

$$E_n(B) = \pm \sqrt{\left(\frac{\Delta}{2}\right)^2 + 2e\hbar v_F^2 |n| B} - \frac{1}{2} g \mu_B B,$$

with fitted parameters:

$$\Delta = 34 \pm 2\,\text{meV}, \quad E_D = 130\,\text{meV}, \quad v_F = 4.2 \times 10^5\,\text{m/s}.$$

Bulk-boundary Correspondence and Dissipationless Edge States

- STM dI/dV mapping (Fig. 4a) clearly demonstrates localized in-gap edge states at step edges (interfaces between Kagome lattice layers).
- Edge states appear due to topological properties, as the bulk is insulating:

$$n_{\text{edge}} = C\,(\text{Chern number})$$

- Authors conducted an experiment, revealing dissipationless edge states by low QPI peaks (Fourier transforms) in Fig. 4b.

Quantum Limit

(1) **Low carrier concentration:** The Fermi level is very close to the Dirac point, leading to extremely low carrier density and symmetric electron-hole excitations [?].

(2) **Discrete and sparse Landau levels (Fig. 2b).**

Anomalous Hall Effect (AHE)

- AHE arises due to intrinsic Berry curvature:

$$\rho_{xy}^{\text{AHE}} = \alpha\rho_{xx} + \beta\rho_{xx}^2 + \gamma\rho_{xy}^2.$$

- Experimentally observed strong linear relationship between ρ_{xy}^{AHE} and ρ_{xx}^2, confirming intrinsic Berry curvature dominance.
- Verification of Chern gap via Berry curvature:

$$\sigma_{xy} = -\frac{e^2}{h}\frac{1}{N}\sum_n \int_{\text{BZ}} \frac{d^2k}{(2\pi)^2} f_n(\mathbf{k})\Omega_n(\mathbf{k}),$$

  Substituting $\Delta \approx 34\,\text{meV}$ and $E_D \approx 130\,\text{meV}$ gives theoretical $\sigma_{xy}^{\text{Berry}} = 0.13\,e^2/h$, matching experimentally measured $0.14\,e^2/h$, confirming Berry curvature origin.

Research Significance

- First experimental evidence of a "quantum-limited Chern topological magnet" [?].
- Establishes an experimental framework demonstrating bulk-boundary-Berry correspondence in topological magnets.

References

- Physical Review X **14**, 011047 (2024). `https://doi.org/10.1103/PhysRevX.14.011047`
- Yin, J.-X., Ma, W., Cochran, T. A., et al. (2020). Quantum-limit Chern topological magnetism in $TbMn_6Sn_6$. *Nature*, 583, 533–536.`https://doi.org/10.1038/s41586-020-2482-7`