Alterelectrics: The Electric Counterpart of Altermagnets

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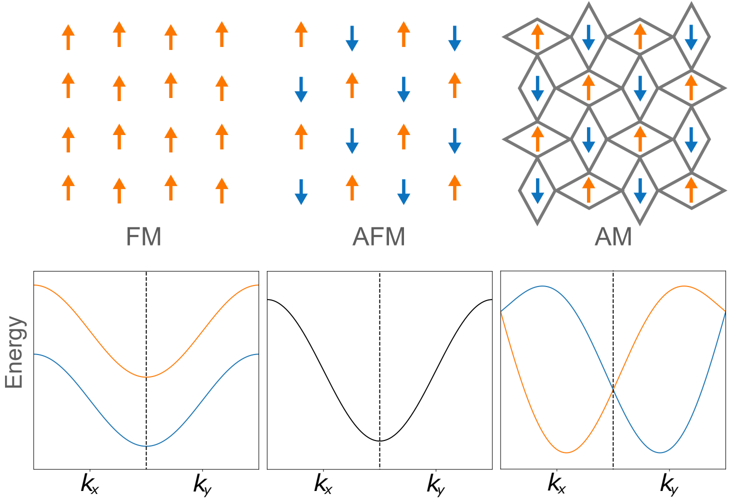
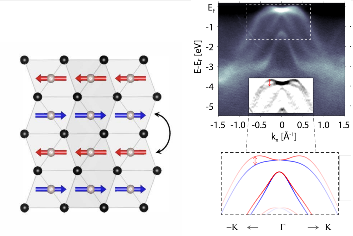
Altermagnets



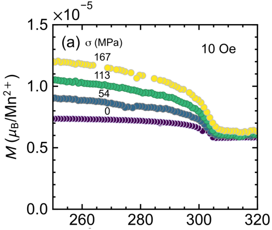
L Šmejkal, J Sinova, and T Jungwirth, PRX 12, 031042 (2022)

Altermagnetic materials

- AHE in MnTe, J.D. Wascher (1969)
- Spin Hall effect
- Piezomagnetic effect



J. Krempasky et al., Nature 626, 517–522 (2024)

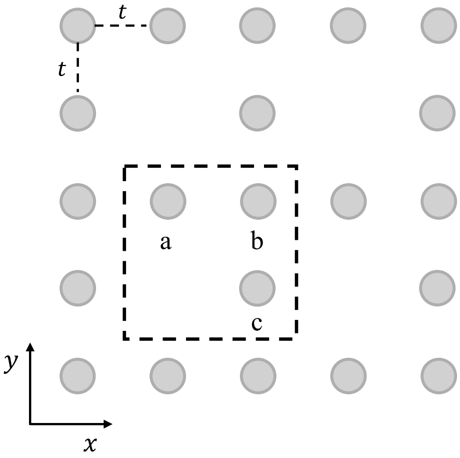


T. Aoyama and K. Ohgushi, Phys. Rev. Materials 8, L041402 (2024)

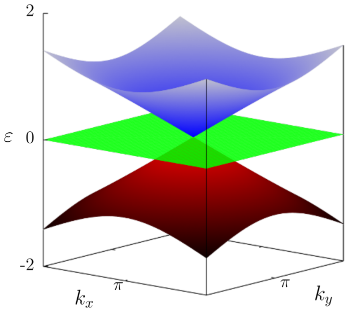
Alterelectrics?

- Ferroelectric and antiferroelectric materials are well known
- Is it possible to generalize altermagnets to electric polarization?
- What symmetries are required?
- Electric transport
- Pieozelectricity

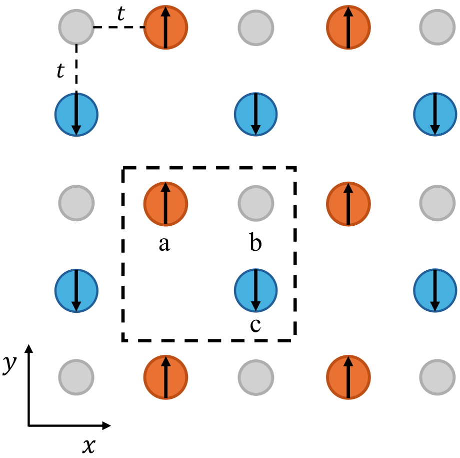
Lieb lattice



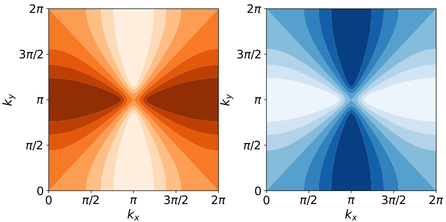
$$H(\mathbf{k}) = \begin{pmatrix} 0 & 2t\cos k_x a & 0 \\ 2t\cos k_x a & 0 & 2t\cos k_y a \\ 0 & 2t\cos k_y a & 0 \end{pmatrix}$$



Lieb lattice altermagnet



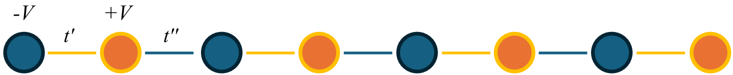
$$H_\sigma(\mathbf{k}) = \begin{pmatrix} -\sigma J_s S & 2t\cos k_x a & 0 \\ 2t\cos k_x a & 0 & 2t\cos k_y a \\ 0 & 2t\cos k_y a & \sigma J_s S \end{pmatrix}$$



B. Brekke, A. Brataas, and A. Sudbø, PRB 108, 224421 (2023)

Rice-Mele model

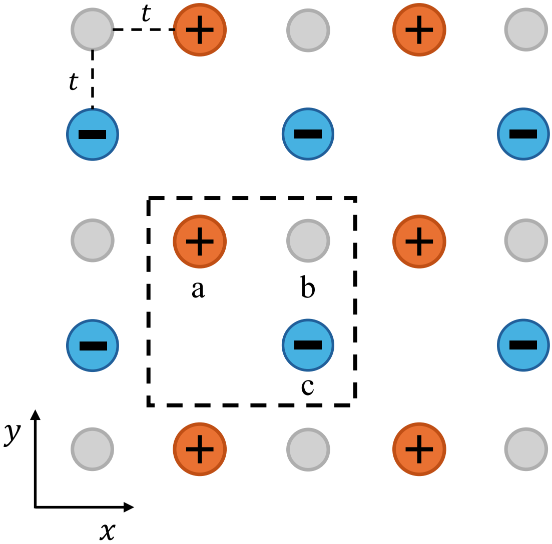
- 1D chain with staggered hopping and onsite potential



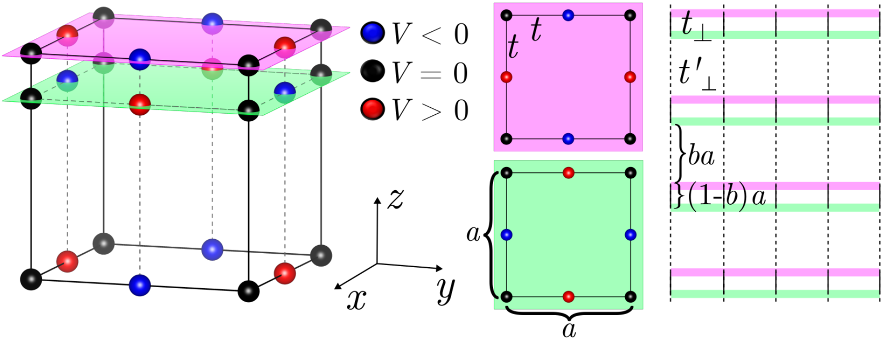
- Edge states
- Polarization

J. K. Asbóth, L. Oroszlány, A. Pályi, *A Short Course on Topological Insulators*

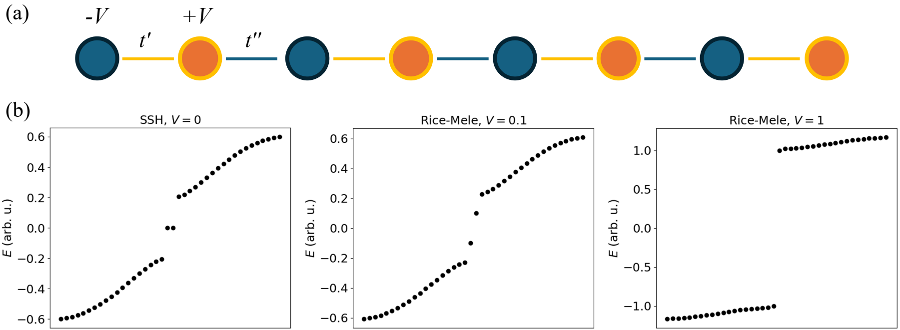
Lieb lattice alterelectric



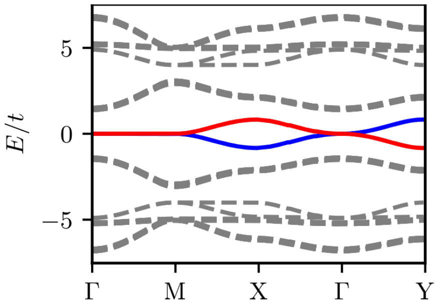
Lieb lattice alterelectric

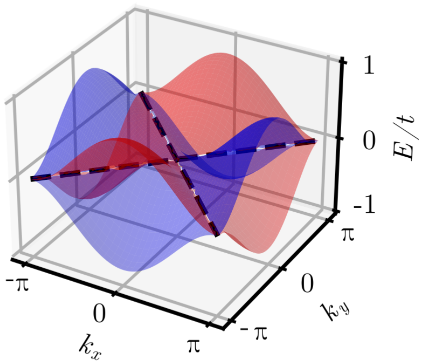


Edge states in the RM model

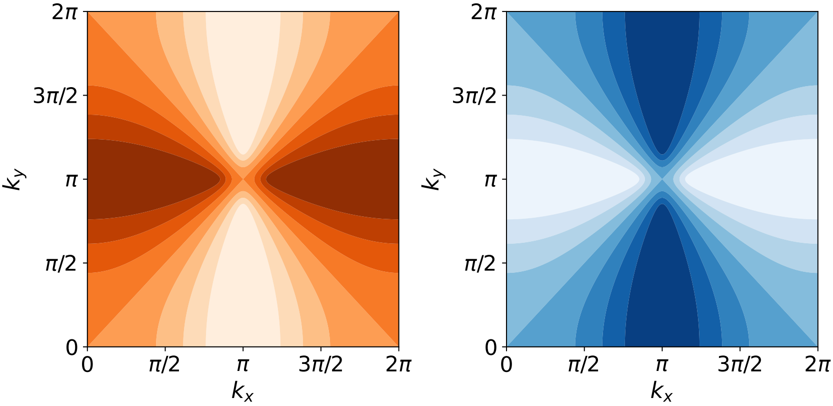


Hyperbolic surface states

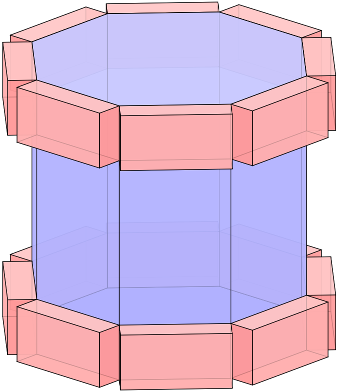


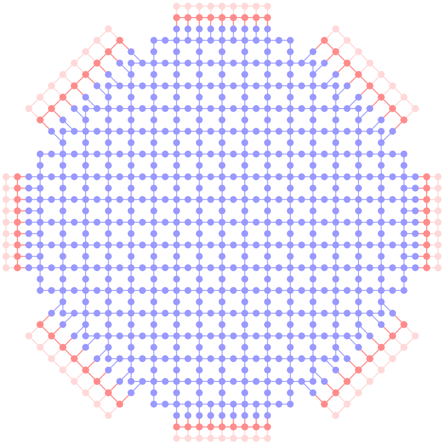


Hyperbolic surface states



Transport setup

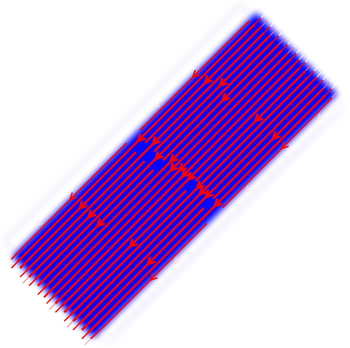




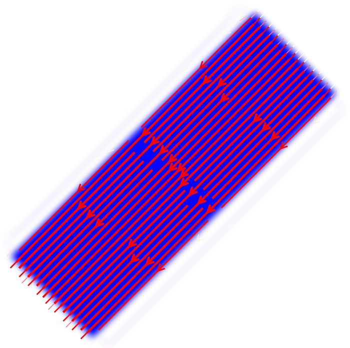
Surface current

E=0

Top



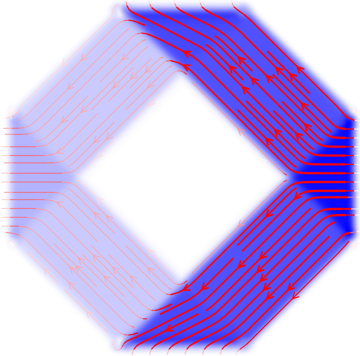
Bottom



Surface current

E=0

Top



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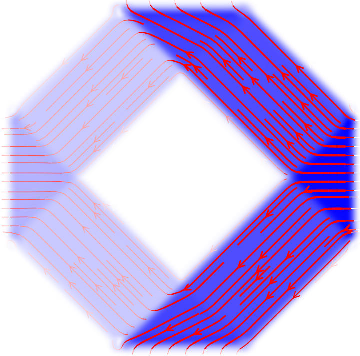
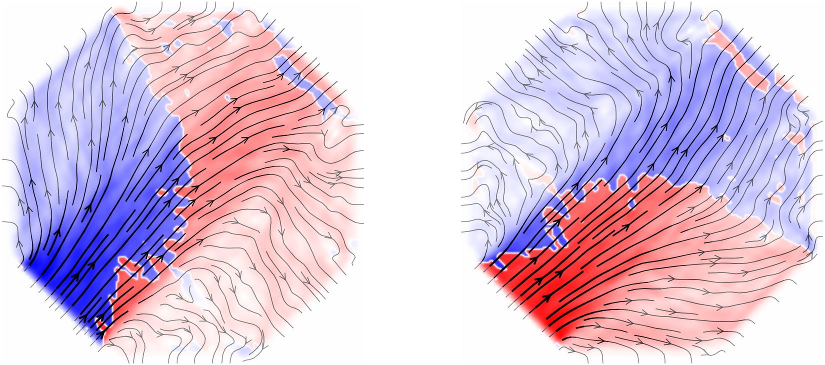


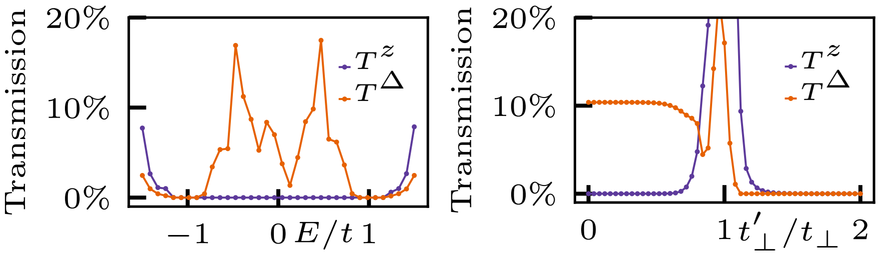
Surface current

E=0.2t

Top Bottom

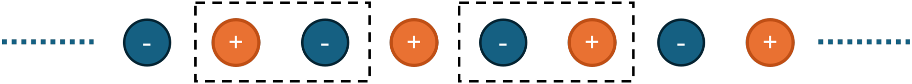


Transmission



- T^z: transmission from the top to the bottom surface.
- T^Δ: difference betweem the transmission through the top and bottom surfaces.

Polarization



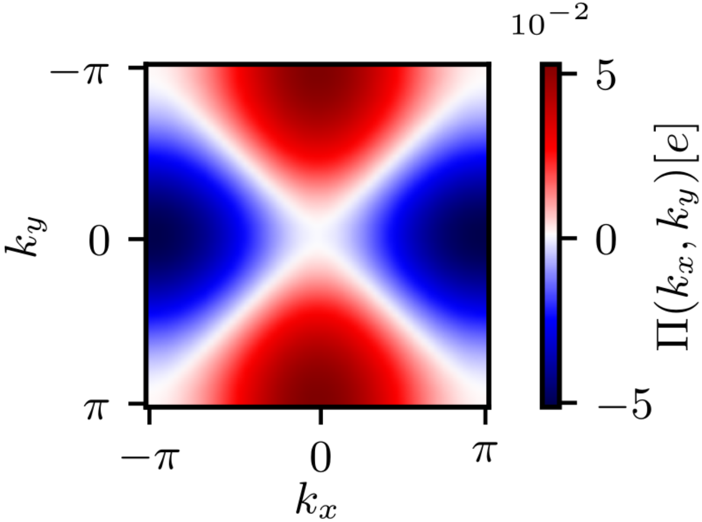
$$\mathbf{P} = \frac{-e}{(2\pi)^d} \sum_n^{\text{occ}} \int_{BZ} d^d k \langle u_{n\mathbf{k}} | i \nabla_{\mathbf{k}} u_{n\mathbf{k}} \rangle,$$

In 1D Berry phase

$$P = \frac{-e}{2\pi} \phi.$$

D. Vanderbilt, *Berry Phases in Electronic Structure Theory*

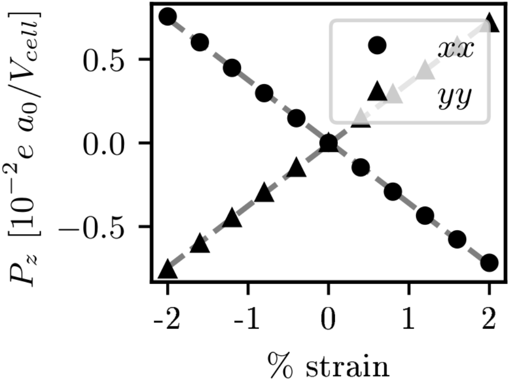
Polarization of the Lieb lattice alterelectric



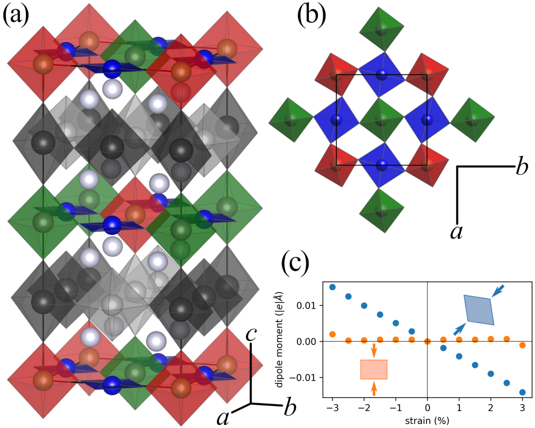
Piezoelectricity in the Lieb lattice alterelectric

$$P_i = d_{ijk}\varepsilon_{jk}$$

Rotoinversion symmetry $d_{311} = -d_{322}$

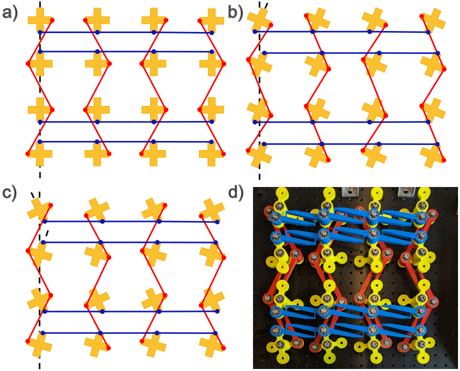


Material realization



Outlook

- Real materials
- Mechanical meta-materials
- Applications



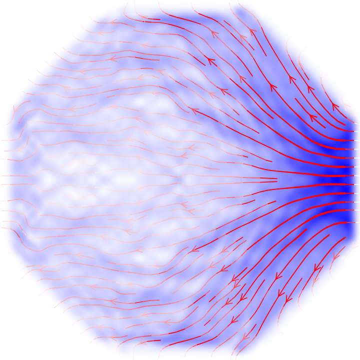
Summary and conclusions

- Rice-Mele chain can be used as building blocks for alterelectrics
- Surface states with hyperbolic dispersion
- Anisotropic surface electric transport
- Anisotropic piezoelectric effect analogous to the piezomagnetic effect in altermagnets

Surface current

E=0.4t

Top



Bottom