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Do topological defects in quadrupole insulators host quantized fractional charges?

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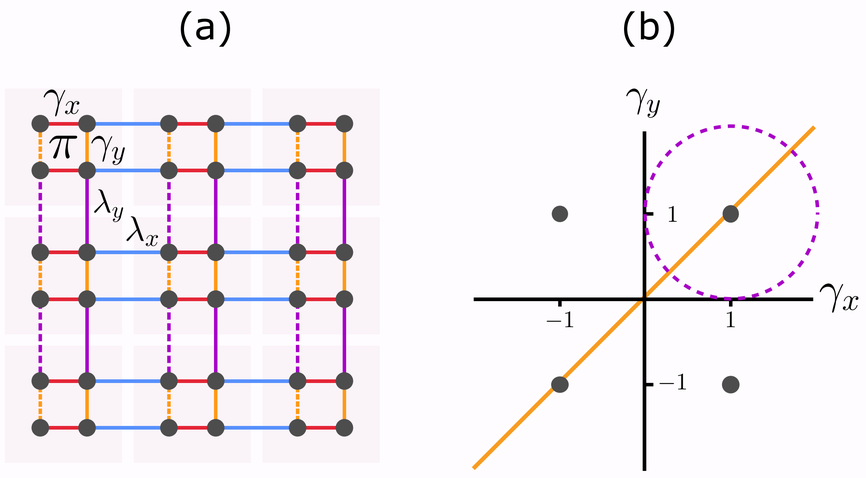
Topological defects in a double-mirror quadrupole insulator displace diverging charge

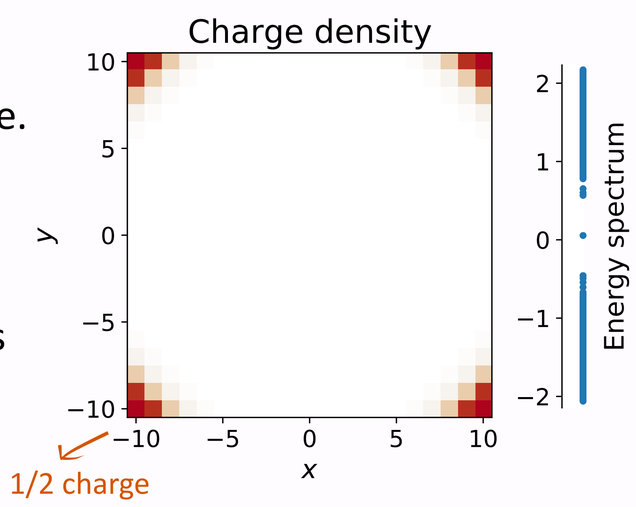
1

The BBH model, a quadrupole insulator



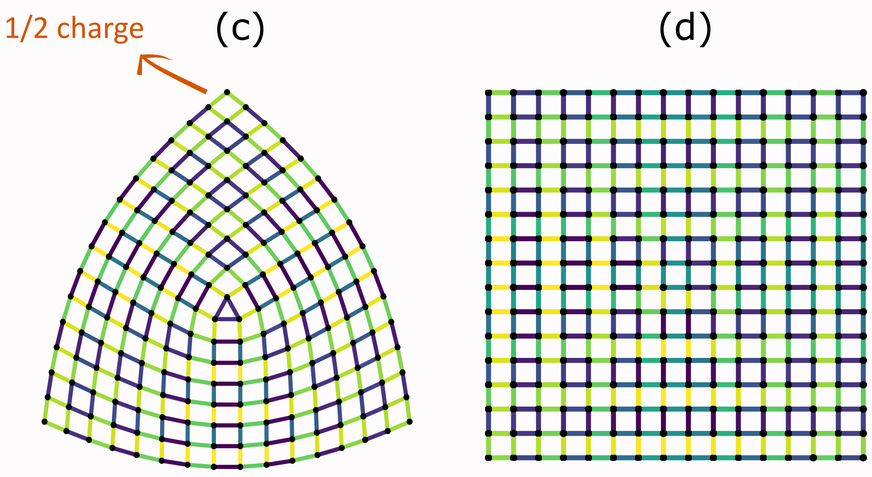
(a) BBH model. (b) Phase diagram with 4 bulk-gap closing points.

* Quantized 1/2 corner charges in topological phase.
* Disclinations were reported to host quantized fractional charges too.
* The phase diagram allows us to create a parametric defect.



2

Two defects with expected 1/2 charge



(c) Disclination. (d) Parametric defect.

* Triangle at the disclination has 3/2 electrons at half-filling.
* Parametric defect has a half-integer charge due to odd-sized cluster of unit cells.

Hypothesis: Local reflection symmetries of the BBH model protect defect charge quantization.

3

Removing sublattice symmetry

* Sublattice symmetry enforces charge quantization.
* We add next-nearest neighbor hoppings $\delta \neq 0$ to break sublattice symmetry.

Sublattice symmetry condition

$$4 = 2\sum_{E_l<0}\sum_{\alpha=1}^{4}|\Psi_{\alpha l}^{ij}|^2 + \sum_{E_l=0}\sum_{\alpha=1}^{4}|\Psi_{\alpha l}^{ij}|^2$$

Defect charge is constrained to multiples of 1/2.

$$q_{\mathrm{tot}}(R) = \sum_{i,j=0}^{R/2}\Big(\rho_{ij} - 2\Big) = \frac{1}{2}\sum_{i,j=0}^{R/2}\sum_{E_l=0}\sum_{\alpha=1}^{4}|\Psi_{\alpha l}^{ij}|^2 = \frac{N_0}{2}$$

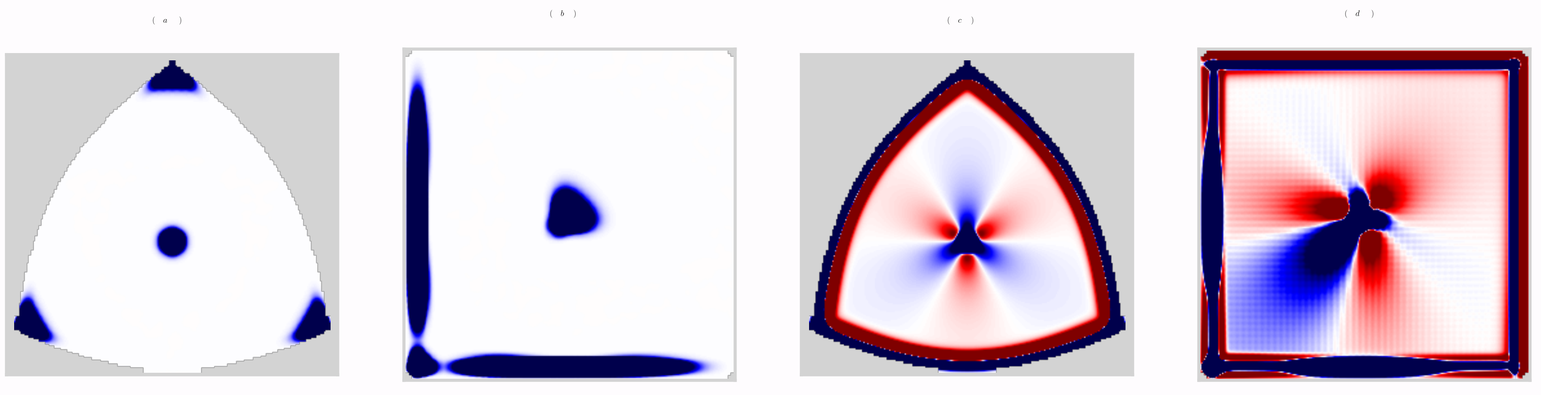
4

Result: Divergent defect charge in the absence of sublattice symmetry

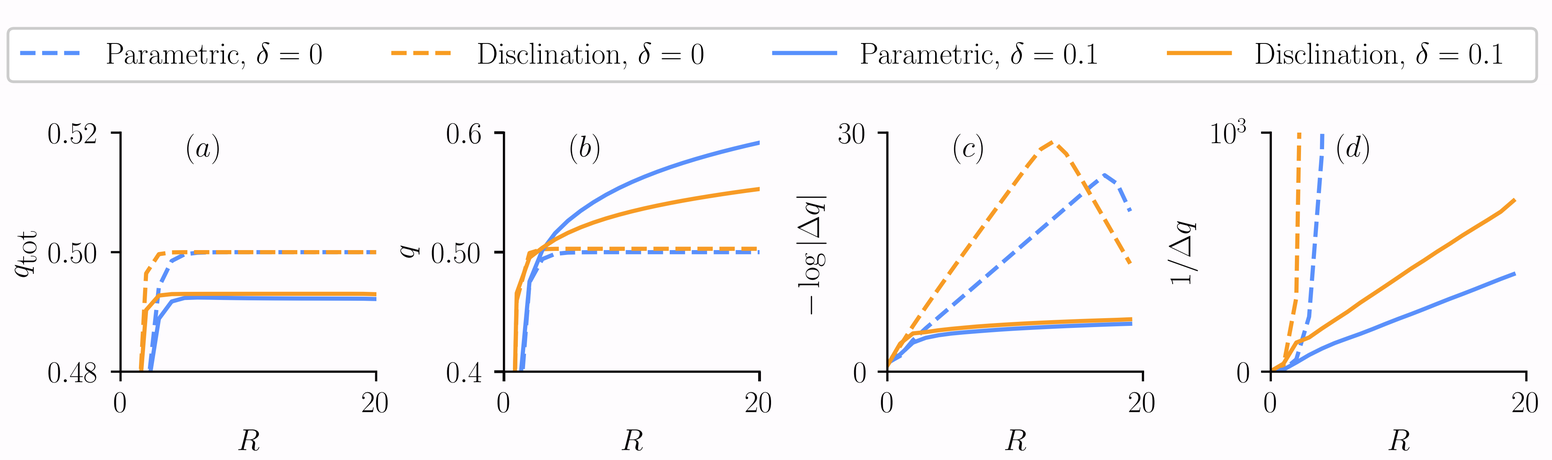
Breaking sublattice symmetry displaces positive and negative charges around the defect.

To study charge convergence, we introduce

$$q(R) = \sum_{i,j=0}^{R/2}\Big|\rho_{ij} - 2\Big|$$



Local charge density with (a-b) and without (c-d) sublattice symmetry.



(a) Total charge is 1/2 only with sublattice symmetry. (b) Defect charge diverges otherwise. (c) Defect charge converges exponentially with sublattice symmetry. (d) Without it, the charge density decays as $1/r^2$.

5

Defect charge is not quantized

* Local charge density decays as $1/r^2$.
* The origin of the previously reported charge quantization was sublattice symmetry.

[1] Benalcazar, W.A., Bernevig, B.A. and Hughes, T.L. Quantized electric multipole insulators. Science, 357 (2017).
[2] Peterson, C.W., Li, T., Jiang, W. et al. Trapped fractional charges at bulk defects in topological insulators. Nature 589, 376–380 (2021).
[3] Khalaf, E., Benalcazar, W.A., Hughes, Tl.L., Queiroz, R. Boundary-obstructed topological phases. Phys. Rev. Research 3, 013239 (2021).

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