Bulk Pumping in 2D Topological Phases and Controlled Parity Switch of Persistent Currents

Michele Filippone, Charles-Edouard Bardyn, and Thierry Giamarchi

Department of Quantum Matter Physics, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland

Laughlin’s argument for the quantization of the Hall conductance in two-dimensional quantum Hall systems provides a rich paradigm to identify robust physical effects in topological phases. It relies on a notion of topological pump controlled by a magnetic flux that threads the system without penetrating its bulk – an Aharonov-Bohm flux. Here we explore analogous pumping effects induced by transverse flux quanta $\delta \chi$ inserted, instead, through the bulk of 2D topological phases. We show that variations $\delta \chi$ control the analog of a topological pump, accompanied by distinct yet similarly robust physical effects as Laughlin’s pump. We exemplify these phenomena in two standard classes of topological phases: quantum Hall systems and topological superconductors – integer and fractional variants thereof. We show that pumping effects induced by $\delta \chi$ typically exhibit a $4\pi l$ periodicity in these phases, where $e/l$ is the charge of underlying quasiparticle excitations. Our considerations lead to the prediction of interesting effects in mesoscopic systems: for instance, we consider the behavior of persistent currents for a fixed number of noninteracting fermions in a periodic quantum ladder threaded by Aharonov-Bohm and transverse magnetic fluxes $\Phi$ and $\chi$. We show that the coupling between ladder legs provides a way to effectively change the ground-state fermion-number parity, by varying $\chi$. Specifically, we demonstrate that varying $\chi$ by $2\pi$ (one flux quantum) leads to an apparent fermion-number parity switch. We find that persistent currents exhibit a robust $4\pi$ periodicity as a function of $\chi$. The parity-switching and the $4\pi$ periodicity effects are robust with respect to temperature and disorder, and we outline potential physical realizations using Corbino disk geometries in solid state systems, quantum ladders with cold atomic gases and, for bosonic analogs of the effects, photonic lattices.