Colloidal topological insulators

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Quantum Hall fluids are incompressible and dissipationless fluids, in which electrons exhibit ballistic motion along quantum edge states. This type of transport arises from the topology of the band structure of the material, and it is thus topologically protected and very robust to perturbations. Topology, however, is not limited to the quantum world, as it enables to define properties in classical systems preserved under continuous deformation. This topological link between the classical and quantum worlds opens the door to the development of colloidal materials with transport properties analogous to those of quantum Hall fluids. Importantly, this will provide exquisite control over the transport of colloids as a function of their physicochemical properties, which will enable applications in microfluidics and soft robotics. Most of the topological mechanical designs operate in regimes where inertia drives the propagation of sound waves in the system. However, dissipation hinders the transport of colloidal systems, which need to be overcome by activity. Therefore, we propose the development of an active metamaterial that exhibits topologically protected transport properties upon external actuation.

Our design consists of active rotating particles suspended in a fluid and confined in an ordered array of fixed obstacles. External actuation of the particles makes them rotate in place, and the hydrodynamic coupling of the generated rotational flows with the array of obstacles makes them translate through the lattice. Depending on the angular velocity of the particles, which determine the appearance of nonlinear effects in the fluid, we find that particles translate along two closed steady-state trajectories. Then, time modulation of the angular velocity of the rotating particles, enables them to switch between these two closed states, thereby achieving ballistic transport through the lattice. Importantly, upon breaking the symmetry of the lattice, unidirectional transport in the absence of time modulation can be achieved in this system, which strikingly resemble the quantum Hall effect.

We will model and analyze this system by developing a master equation that describes the time evolution of the probability for the system, which will allow us to identify its different states. By properly identifying the currents of probability we will have access to the coarse-grained dynamics of this system providing crucial information about the transport properties of the system, aiding in the development of design rules to build this metamaterial. Moreover, the description of the system in terms of its Fokker-Planck equation will open the door to identify the topological invariants, providing a topological description thereof. We aim to draw parallels with solid-state systems and will examine the impact of thermal noise on the system's transport properties.