Controlling Quantum Optical Dynamics by Topological Phases and Parity-Time Symmetry

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The study of non-Hermitian systems with parity-time (PT) symmetry is a rapidly growing frontier in recent years. Experimentally, PT-symmetric systems have been realized in classical optics by realizing balanced gain and loss effects, which hold great promise for novel optical devices and networks. Here we report the first experimental realization of PT-symmetric quantum dynamics for single photons by temporally alternating photon losses in the quantum walk interferometers, and the observation of edge states originating from Floquet topological phases in the dissipative system.

Quantum walks are synthetic quantum systems whose dynamics are described by time-evolution operators, and provide potential applications for quantum computing and information. It is further interesting that the quantum walk possesses novel topological phases akin to those of Floquet topological phases, which are topological insulators driven by a time-periodic field.

Recently, we have theoretically studied PT symmetry of the time-evolution operator of quantum walks with balanced gain and loss[1] and the associated Floquet topological phases[2]. We have found the presence of combined parity and chiral symmetry and particle-hole symmetry, in addition to PT symmetry. The presence of these symmetries allows us to study Floquet topological phases in open quantum systems by using a generalized procedure for ordinal quantum walks belonging to class BDI. We have confirmed that the number of edge states originating from Floquet topological phases and topological numbers satisfy the bulk-edge correspondence, while a modification due to the imaginary energy is required.

Taking into account the above theoretical result, we experimentally study PT-symmetric quantum walks. To establish PT symmetric quantum walks, we implement an array of optical devices as shown in Fig.1. We observe edge states, in the form of localization in quantum walks, between regions with different bulk topological numbers and confirm the robustness of these edge states under small perturbations. Our results open a way to systematically control quantum optical dynamics by using topological phases and PT symmetry.

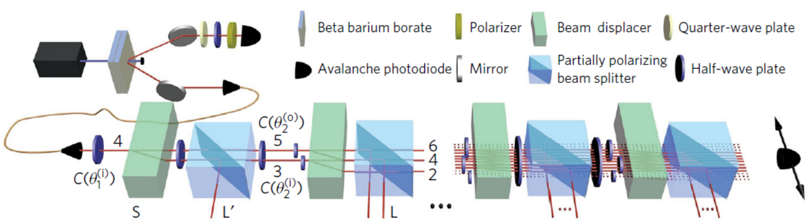

Figure 1: A experimental setup to observe edge states induced by topological phases in the dissipative PT symmetric optical system by using a pair of entangled photons.

[1] K. Mochizuki, D. Kim, and H. Obuse, Phys. Rev. A **93**, 062116 (2016).

[2] D. Kim, K. Mochizuki, N. Kawakami, and H. Obuse, arXiv:1609.09650.

[3] L. Xiao, X. Zhan, Z. H. Bian, K. K. Wang, X. Zhang, X. P. Wang, J. Li, K. Mochizuki, D. Kim, N. Kawakami, W. Yi, H. Obuse, B. C. Sanders, and P. Xue, Nature Physics (DOI:10.1038/nphys4204) (2017).