# Tunable $\varphi$-Josephson junction with a Quantum Anomalous Hall Insulator

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The Josephson effect is a fundamental phenomenon of superconductors. When two superconductors sandwich a material X, Josephson current $J$ flows as a function of the phase difference between two superconductors ($\theta$). The current-phase ($J$-$\theta$) relationship (CPR) reflects well the electronic properties of X. When X is an insulator, the CPR is sinusoidal $J = J_0 \sin\theta$ with a critical current $J_0$. Such junction is called 0-junction because the junction energy is minimum at the zero phase difference. In a 0-junction, Josephson current $J$ is absent at $\theta = 0$. The energy of junction some of time takes its minimum at $\varphi \neq n\pi$ ($n$ is any integer). The CPR in such $\varphi$-junction $J = J_0 \sin(\theta - \varphi)$ suggests that the Josephson current flows even at the zero phase difference. In the view of device application, a $\varphi$-junction can be used as a phase battery or a superconducting rectifier. The phase shift $\varphi$ is determined by characteristic electronic structures in X. So far, the realization of $\varphi$-junction has been discussed theoretically in various Josephson junctions with X being multilayered ferromagnets, quantum point contacts, quantum dots, nanowires and topologically non-trivial materials. In experiments, however, the realization of $\varphi$-junction has been reported only in a Josephson junction with a nanowire quantum dot. In the proposed $\varphi$-junctions, it is not easy to controle the phase shift $\varphi$ after fabricating Josephson junctions.

We theoretically study the Josephson current in a Josephson junction with a quantum anomalous hall insulator (QAHI) by using lattice Green function method. A QAHI is a topologically non-trivial material with chiral edge states protected by nonzero Chern number. When an in-plane external magnetic field is applied to the QAHI, the current-phase relationship becomes $J(\theta) \propto \sin(\theta - \varphi)$ [See also Fig. 1]. The phase shift $\varphi$ is proposal to the amplitude of Zeeman field, which implies the realization of a tunable $\varphi$-junction.

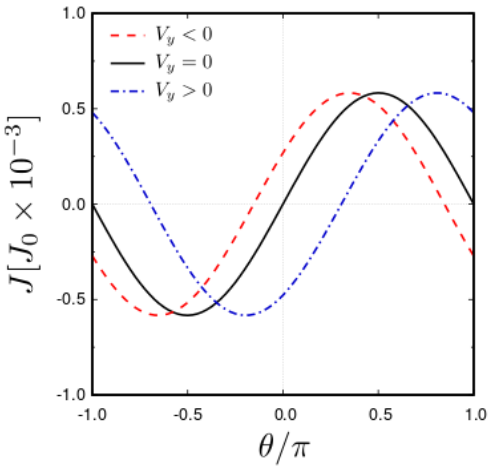


Fig. 1: Josephson current as a function of $\theta$

[1] K. Sakurai, S. Ikegaya, and Y. Asano, arXiv:1709.02338.