Popular Summary

Time-reversal symmetry is the symmetric properties of physical laws when the flow of time is reversed. It has wide influence on condensed matter physics and thermodynamics, but little on quantum information science yet. As a potential application, controlling transport in quantum systems is found to be accessible by breaking time-reversal symmetry. Here, we develop an approach to direct this transport by controlled symmetry-breaking, and identified this phenomenon in a nuclear magnetic resonant (NMR) quantum simulator. We address it as “chiral quantum walks”.

Chiral quantum walks stems from the fact that breaking time-reversal symmetry is equivalent to introducing biased probability flow into a quantum system, which thus allows such quantum walks to tackle state transfer directly without biased initial states or couplings to an environment. Based on a complex network theory, we show that the symmetry-breaking can be controlled with just local operations paired with a natural time-symmetric Hamiltonian evolution, which has significant practical importance in the presence of limited control under current technologies. Furthermore, we specify necessary network topologies for implementing chiral quantum walks, and demonstrate it experimentally using a 3-qubit NMR simulator. Our experimental results exhibit near-perfect enhancement of transport probabilities achieved by breaking the time-reversal symmetry in the Hamiltonian using local gates only.

We expect our results provide a set of new tools for controlling transport in quantum systems, and can be applied to larger networks. The amount of enhancement in the transport is likely to be improved by designing the network topology or circuit structure too.