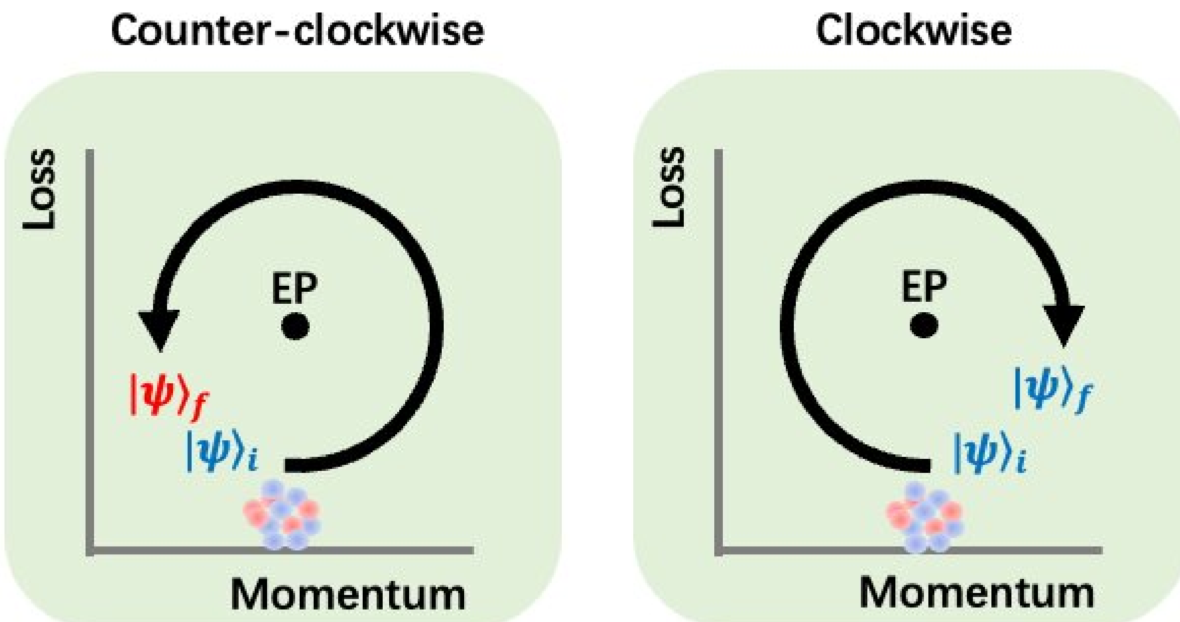
Researchers find new way of gaining quantum control from loss

January 24 2022



A new study finds that quantum state evolution is direction dependent in the parameter space of dissipative spin-orbit coupled system. Credit: Dong Liu

Researchers at the Hong Kong University of Science and Technology (HKUST) have demonstrated a new way to control the quantum state through the loss of particles—a process that is usually avoided in the quantum device, offering a new way towards the realization of unprecedented quantum states.

Manipulating a quantum system requires a subtle control of quantum state with zero imperfect operations, otherwise the useful information encoded in the quantum states is scrambled. One of the most common detrimental processes is the loss of particles that consist of the system. This issue has long been seen as an enemy of quantum control and was avoided through the isolation of the system. But now, researchers at the HKUST have discovered a way that could gain quantum control from loss in an atomic quantum system.

The finding was published recently in *Nature Physics*.

Prof. Gyu-Boong Jo, lead researcher of the study and Hari Harilela Associate Professor of Physics at HKUST, said the result demonstrated loss as a potential knob for the quantum control.

"The textbook taught us that in quantum mechanics, the system of interest will not suffer from a loss of particles as it is well isolated from the environment," said Prof. Jo. "However, an open system—ranging from classical to quantum ones, is ubiquitous. Such open systems, effectively described by non-Hermitian physics, exhibit various counter-intuitive phenomena that cannot be observed in the Hermitian system."

The idea of non-Hermitian physics with loss has been actively examined in classical systems, but such counter-intuitive phenomena were only recently realized and observed in genuine quantum systems. In the study, HKUST researchers adjusted the systems' parameters such that they sweep out a closed loop around a special point—also known as an exceptional point occurring in the non-Hermitian system. It was discovered that the direction of the loop (i.e. whether it goes clockwise or anti-clockwise) determines the final quantum state.

Jensen Li, Professor of Physics at HKUST and the other leader of the team, said, "This chiral behavior of a directional quantum state transferring around an exceptional point can be an important ingredient in quantum control. We are at the starting point in controlling non-Hermitian quantum systems."

Another implication of the findings is how two seemingly unrelated mechanisms: non-Hermitian physics (induced by loss) and spin-orbit coupling, interplay. Spin-orbit coupling (SOC) is an essential mechanism behind intriguing quantum phenomena such as topological insulator, which behaves as an insulator in its interior but whose surface flow electrons act like a conductor.

Despite the major advances in non-Hermitian physics, an SOC mechanism is only widely studied in Hermitian systems, much less is known experimentally on the major role played by the loss in spin-orbit-coupled quantum systems. The better understanding of such non-Hermitian SOC is of paramount importance to the development of novel materials, but it remains elusive in the area of condensed matter physics.

In this work however, researchers realized for the first time a dissipative spin-orbit-coupled system for ultracold atoms, fully characterizing its quantum state and demonstrating chiral quantum control in the context of non-Hermitian physics. This finding sets the stage for future exploration of spin-orbit coupling physics in the non-Hermitian regime, and highlights the remarkable capabilities of non-Hermitian quantum systems to realize, characterize, and harness two fundamental mechanisms, namely loss and SOC, providing a new approach for precisely simulating such competing mechanisms in a highly controllable quantum simulator with ultracold atoms.

More information: Jensen Li, Chiral control of quantum states in non-Hermitian spin–orbit-coupled fermions, *Nature Physics* (2022). DOI: 10.1038/s41567-021-01491-x.
www.nature.com/articles/s41567-021-01491-x

Provided by Hong Kong University of Science and Technology