UC SANTA BARBARA

THE Current

February 28, 2022
Sonia Fernandez

Quantum Boomerang

Physicists at UC Santa Barbara have become the first to experimentally observe a quirky behavior of the quantum world: a “quantum boomerang” effect that occurs when particles in a disordered system are kicked out of their locations. Instead of landing elsewhere as one might expect, they turn around and come back to where they started and stop there.

“It’s really a fundamentally quantum mechanical effect,” said atomic physicist David Weld, whose lab produced the effect and documented it in a paper published in Physical Review X. “There’s no classical explanation for this phenomenon.”

The boomerang effect has its roots in a phenomenon that physicist Philip Anderson predicted roughly 60 years ago, a disorder-induced behavior called Anderson localization which inhibits transport of electrons. The disorder, according to the paper’s lead author Roshan Sajjad, can be the result of imperfections in a material’s atomic lattice, whether they be impurities, defects, misalignments or other disturbances.

“This type of disorder will keep them from basically dispersing anywhere,” Sajjad said. As a result, the electrons localize instead of zipping along the lattice, turning what would otherwise be a conducting material into an insulator. From this rather sticky quantum condition, the quantum boomerang effect was predicted a few years ago to arise.

Launching disordered electrons away from their localized position and following them to observe their behavior is extremely difficult if not currently impossible, but the Weld Lab had a few tricks up its sleeve. Using a gas of 100,000 ultracold lithium atoms suspended in a standing wave of light and “kicking” them, emulating a so-called quantum kicked rotor (“similar to a periodically kicked pendulum,” both Weld and Sajjad said), the researchers were able to create the lattice and the disorder, and observe the launch and return of the boomerang. They worked in momentum space, a method that evades some experimental difficulties without changing the underlying physics of the boomerang effect.

“In normal, position space, if you’re looking for the boomerang effect, you’d give your electron some finite velocity and then look for whether it came back to the same spot,” Sajjad explained. “Because we’re in momentum space, we start with a system that is at zero average momentum, and we look for some departure followed by a return to zero average momentum.”

Using their quantum kicked rotor they pulsed the lattice a few dozen times, noting an initial shift in average momentum. Over time and despite repeated kicks, however, average momentum returned to zero.

“It’s just a really very fundamentally different behavior,” Weld said. In a classical system, he explained, a rotor kicked in this way would respond by constantly absorbing energy from the kicks. “Take a quantum version of the same thing, and what you see is that it starts gaining energy at short times, but at some point it just stops and it never absorbs any more energy. It becomes what’s called a dynamically localized state.”

This behavior, he said, is due to the wave-like nature of quantum systems.

“That chunk of stuff that you’re pushing away is not only a particle, but it’s also a wave, and that’s a central concept of quantum mechanics,” Weld explained. “Because of that wave-like nature, it’s subject to interference, and that interference in this system turns out to stabilize a return and dwelling at the origin.” In their experiment, the researchers showed that periodic kicks exhibiting time-reversal symmetry would produce the boomerang effect, but randomly timed kicks would destroy both the symmetry and, as a result, the boomerang effect.

Up next for the Weld Lab: If individual boomerang effects are cool, how much more of a party would it be to have several interacting boomerang effects?

“There are a lot of theories and questions about what should happen — would interactions destroy the boomerang? Are there interesting many-body effects?” Sajjad said. “The other exciting thing is that we can actually use the system to study the boomerang in higher dimensions.”

Research on this project was also conducted by Jeremy L. Tanlimco, Hector Mas, Eber Nolasco-Martinez and Ethan Q. Simmons at UCSB; Tommaso Macrì at Universidade Federal do Rio Grande do Norte and Patrizia Vignolo at Université Côte d’Azur.

About UC Santa Barbara

The University of California, Santa Barbara is a leading research institution that also provides a comprehensive liberal arts learning experience. Our academic community of faculty, students, and staff is characterized by a culture of interdisciplinary collaboration that is responsive to the needs of our multicultural and global society. All of this takes place within a living and learning environment like no other, as we draw inspiration from the beauty and resources of our extraordinary location at the edge of the Pacific Ocean.