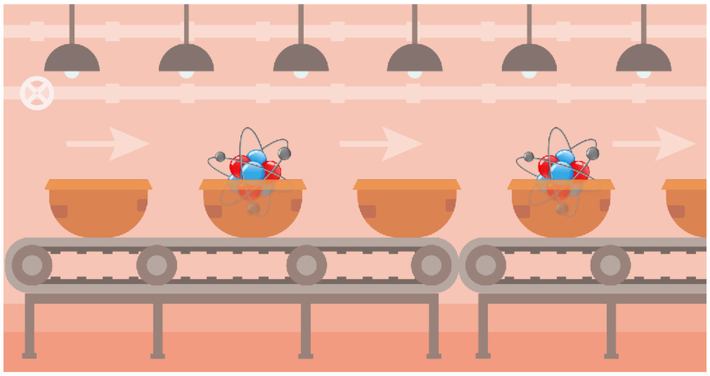
An Atom Pushed to Its Speed Limit

Researchers have transported an atom between two locations in the shortest possible time, an achievement that has implications for quantum technologies.

By **Katherine Wright**

Moving information from one place to another takes time, even in the quantum world. A team of researchers has now moved an atom in the shortest time possible, in a way that preserves the information that it contains [**1**]. Achieving the top overall speed turned out to require a series of accelerations and decelerations, not a constant cruise. The finding could lead to ways of optimizing speed and accuracy in future quantum technologies.

Disturbances from the environment degrade the performance of quantum computers, and carrying out the calculations as quickly as possible is one way to reduce such effects. But running calculations too quickly can also lead to information loss, so there is a “speed limit” on such systems.



Keep it movin’. Researchers used an atomic conveyor belt to find the top speed at which atoms can be moved without disturbing their quantum states.
Credit: A. Alberti/Univ. of Bonn

For simple, two-level quantum systems, such as an electron (which can be spin-up or spin-down), researchers have performed quantum operations at the theoretically predicted speed limits. However, some quantum technologies, such as atom interferometers, require a system to move among many quantum states. These systems should also have speed limits, but they have not been predicted or measured.

Andrea Alberti of the University of Bonn in Germany and his colleagues have now studied an example of such a speed limit. They measured the fastest speed at which an atom could be moved from one place to another, ending at the new location in the same state in which it began, despite transitioning to other states during the trip. Moving too rapidly can cause the atom to end up in a different state, which means that it loses information. Keeping the information safe while moving as fast as possible is a bit like transferring a bowl containing water from one location to another at the highest possible speed that avoids a spill.

For their experiments, the team used a so-called optical lattice trap, in which atoms sit in a row of potential energy valleys produced by a pair of overlapping, oppositely directed laser beams. They used a microwave field to cool the atoms to their lowest (ground) vibrational state. In this state, each atom is like a fluid sloshing back and forth in a bowl with the smallest possible amplitude; excited states correspond to larger-amplitude oscillations. The goal was to end in the ground state, even though the atoms transitioned to excited states along the way.

To transport the atoms, the team caused the valleys to move like a conveyor belt, with each valley moving as far as its nearest neighbor. They could vary the speed of the conveyor belt, and they used measurement techniques that allowed subnanometer tracking of the motion.

Alberti and his colleagues transported their atoms a distance of 0.5 micrometers using both constant-speed and variable-speed schemes. In each case, the researchers measured the fidelity, a parameter characterizing the similarity of the initial and final states. The protocol with the best fidelity involved a series of speedups and slowdowns. These speed "wiggles" canceled out the effects of transitions to excited states that occurred during the transport process, ensuring that the atoms ended in the ground state. This wiggling is analogous to physically wiggling a bowl containing water to counteract excessive sloshes as it is moved at high speed—tipping it forward a bit at the beginning of its journey and backward a bit at the end.

The researchers found that when the average speed over the trip was below about 17 millimeters per second, the fidelity was very good, but it dropped to much lower values for higher average speeds. The team developed a theory to explain this measured speed limit.

"The finding is a compelling demonstration of how fundamental properties of quantum dynamics change when one goes beyond the well-studied case of a two-level system," says Nora Tischler, a quantum physicist at Griffith University in Australia. "I am excited by this work," she adds. Daniel Burgarth of Macquarie University, also in Australia, is equally impressed. He hopes that the new method will be adapted by other groups to operate complex quantum systems at or near their speed limits.

Katherine Wright is a Senior Editor for ***Physics***.

REFERENCES

1. M. Lam *et al.*, "Demonstration of quantum brachistochrones between distant states of an atom," **Phys. Rev. X 11, 011035 (2021).**