In tunneling physics, a decades-old paradox is resolved

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As if the concept of quantum tunneling—where atoms pass through barriers—isn't confusing enough, one of the vexing questions within that area of physics is why particles seem to travel faster than the speed of light when passing through a barrier, but not when they travel through empty space.

Also puzzling is why the time spent by the particle in the barrier does not seem to increase as the barrier is made longer and longer.

This paradox has stirred debate in the physics community since 1932, but Herbert Winful, a professor at the University of Michigan's College of Engineering, believes he's put an end to these questions. Winful says his theoretical results show that what's being calculated and measured isn't the time it takes the particle to go from A to B (passing through a barrier in between) "but the time it takes to empty the barrier of energy already stored in the barrier." The technical term for this time is the "group delay."

Winful worked out his theory mathematically, using photonic band gap structures. Such structures filter, or "tune" out, certain wavelengths of light and let certain others pass through. He then calculated the delay for electromagnetic waves that made it through the band gap and found that the result was exactly equal to the time it takes energy to escape from the barrier through both ends of the barrier.

Here is how group delay works in quantum tunneling: imagine two tour buses, one with 100 passengers and the other with 10 passengers. The buses are heading toward the same restaurant across town. They arrive together, but the bus with 10 people empties more quickly so those diners get to eat first. If you define the arrival time as the average time at which a passenger arrives at the dinner table, then this time is shorter for the bus with fewer passengers. This also explains why the so-called group delay is the same no matter the distance traveled.

In quantum tunneling most of the particles (people on the bus) bounce off the barrier and only a tiny fraction makes it through. The presence of the barrier reduces the amount of energy that can be stored compared to the amount stored in a barrier-free region. The delay time measured is directly proportional to the stored energy and is the time it takes to release this stored energy.

The time doesn't change when the barrier is widened because the barrier has a certain energy storage capacity, which does not increase with length, just as the bus has a fixed capacity regardless of the distance traveled, Winful said.

Winful presented his results in an invited paper July 25 at the Slow and Fast Light Conference in Washington, DC.

"This is an important question from a fundamental physics viewpoint, but it's also important because it can tell you the ultimate speed tunneling devices can operate," said Winful. "My result is actually in a way is a bit of a downer, because it shows that we can't do that (travel faster than light)." But, he said, it's comforting to know that Einstein was right. Einstein's theory of relativity tells us that nothing can travel faster than light, about 186,171 miles per second.

Quantum tunneling is used in scanning tunneling microscopes, which make observations at the atomic scale possible, and certain electronic devices, such as tunneling diodes and Josephson junctions.

Source: University of Michigan