Search for the bridge to the quantum world

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Science fiction has nothing over quantum physics when it comes to presenting us with a labyrinthine world that can twist your mind into knots when you try to make sense of it.

A team of Arizona State University researchers, however, believe they've opened a door to a clearer view of how the common, everyday world we experience through our senses emerges from the ethereal quantum world.

Physicists call our familiar everyday environment the classical world. That's the world in which we and the things around us appear to have measurable characteristics such as mass, height, color, weight, texture and shape.

The quantum world is the world of the elemental building block of matter - atoms. Atoms are combinations of neutrons and protons and electrons bound to a nucleus by electrical attraction.

But most of an atom - more than 99 percent of it - is empty space filled with invisible energy.

So from a quantum-world view, we and the things around us are mostly empty space. The way we experience ourselves and other things in the classical world is really just "a figment of our imaginations shaped by our senses," explains ASU Regents' Professor David Ferry.

For more than a century, scientists and engineers have struggled to come to a satisfactory conclusion about the missing link that bridges the classical and quantum worlds and enables a transition from that world of mostly empty space to the familiar environment we experience through our senses.

One proposed scenario based on these questions was investigated in a dissertation written by Adam Burke to earn his doctorate in electrical engineering in 2009 from ASU's Ira A. Fulton Schools of Engineering.

To try working out an answer to some of the questions, Burke teamed with Ferry, a professor in the School of Electrical, Computer and Energy Engineering, Tim Day, who recently earned his doctorate in electrical engineering from the school, physicist Richard Akis, an associate research professor in the school, Gil Speyer, an assistant research scientist for the engineering schools' High Performance Computing Initiative, and Brian Bennett, a materials scientist with the Naval Research Laboratory.

The result is an article published recently in the research journal *Physical Review Letters* and featured on PhysOrg.com, a science, technology and research news website. It describes the transition from quantum to classical world as a "decoherence" process that involves a kind of evolutionary progression somewhat analogous to Charles Darwin's concept of natural selection.

The authors built on two theories called decoherence and quantum Darwinism, both proposed by Los Alamos National Laboratory researcher Wojciech Zurek.

The decoherence concept holds that many quantum states "collapse" into a "broad diaspora," or dispersion, while interacting with the environment. Through a selection process, other quantum states arrive at a final stable state, called a pointer state, which is "fit enough" (think "survival of the fittest" in Darwinian terms) to be transmitted through the environment without collapsing.

These single states with the lowest energy can then make high-energy copies of themselves that can be described by the Darwinian process and observed on the macroscopic scale in the classical world.

The experiments arose from using advanced scanning gate microscopy to obtain images of what are called quantum dots.

Burke, now doing research in a post-doctoral program at the University of New South Wales in Sydney, Australia, explains it like this:

Imagine the quantum dot as a billiard table in which the quantum point contacts are the two openings through which a ball could enter or leave the dot, and the interior walls of the dot act as bumpers.

If there were no friction on the table, a billiard ball with an initial trajectory would bounce off of these walls until eventually finding an exit and leaving the dot (this is the decoherence part).

Or it might find a trajectory that does not couple to the openings and would therefore be a surviving pointer state, what is called a diamond state.

One difference between the classical physics of billiard balls and the quantum physics of electrons is that an electron can tunnel through "forbidden phase space" to enter this diamond state, whereas a billiard ball entering from outside the dot would not find itself able to reach this diamond trajectory.

It is this isolated classical trajectory, and the buildup of an electron wave functions' amplitude along that trajectory, that is referred to as a scarred wave function.

To experimentally measure these scars, imagine that we can't see inside the walls of our billiard table, but we can count the billiard balls exiting the table. This is what is normally measured with the conductance of the quantum dot and its environment.

"We measure the current through the dot, the numbers of 'billiard balls' passing through it per second, to try to see how this changes when we move our probe around the 'billiard table,' " Ferry says.

Furthermore, there is the probe of the scanning gate microscope, which applies a small electric field. This can be pictured as a small circular bumper on the billiard table that can be moved around within the dot.

This small "bumper" is rastered left to right, top to bottom over the area of interest. If a ball is traveling along this diamond pattern it is perturbed by the bumper when it rasters into the trajectory.

Think of rastering like the way a television image works, with a pattern of scanning lines that cover the area on which the image is projected, or a set or horizontal lines composed of individual pixels that are used to form an image on a computer screen.

When this happens, the ball bounces off the perturbation, and takes a new course within the dot until finally coupling out one of the openings to be measured. The change in the ball's motion appears as a change in the conductance - the number of balls going through the openings in a given time.

Ferry explains: "With scanning gate microscopy, we monitor where these changes occur within the scans, and hopefully this gives us a map of the scarred wave functions corresponding to the pointer states."

Quantum mechanically, he says, a new electron will tunnel right into the diamond state, so the measurement can continue until the whole area is mapped.

The data that came from the team's experiment supports Zurek's theories of decoherence and quantum Darwinism, Burke says.

Ferry says these findings are just one step in a process that is open to conjecture, but they point toward a "smoking gun" for the existence of this quantum Darwinism and a new view in the search for evidence of how the quantum-to-classical world transition actually occurs.

If you can wrap your mind around all this, he says, "You open the door to a deeper understanding of what is really going on" at the core of physical reality.

Provided by Arizona State University