If an electron can be in 2 places at once, Why Can’t You?

Electrons do it. Photons do it. PHYSICS LEGEND ROGER PENROSE thinks he finally knows why you and I can’t do it too. By Tim Folger

PHOTOGRAPH BY DAVID BARRY
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Penrose, a physician, and Lionel Sciama, a leading 1950s advocate of large-scale scientific experiments, are among the most well-known Penroses. The equations of quantum mechanics give us a powerful tool for studying and predicting the behavior of particles in an atom smash, the nuclear reactions that make the sun shine, and the chemical processes that underlie biology. For Penrose, this is not nearly enough.

Quantum mechanics gives us wonderful predictions and experimental confirmations for small-scale scenarios, but it gives us nonsense at ordinary scales, he says, and this is a serious flaw. "If you just ignore the strange implication for a young physicist entering academia today, it's a mere theoretical abstraction. It is a very real aspect of how the subatomic world works, and it has been experimentally confirmed in countless places. One of the clearest demonstrations comes from a classic physics setup called the double-slit experiment.

In this test, a beam of light is projected through two parallel slits cut in an opaque barrier and then onto a white screen. When light hits the screen, it doesn't produce just two overlapping regions of brightness. Instead, something strange appears: a series of alternating light and dark stripes, called an interference pattern. The 19th-century explanation for this was that light is a wave and that light waves overlap after passing through the slits. The light waves seem to be hallowed out of thin air, but it's not so surprising when you consider how quantum mechanics works.

The quantum mechanical solution to the problem is that light is a wave, and waves have the ability to interfere with each other. When two waves meet, they can add together to create a larger wave, or they can cancel each other out, creating a dark zone. This is why the interference pattern is always visible, no matter how small the screen or how much the light is dimmed. For Penrose, this is a key point in understanding the nature of reality.
What is gravity?

For nearly 40 years, Penrose has been working on twistor theory, a radically original description of gravity, space, and time. Rather than treating space-time as an empty arena in which physical events unfold, Penrose postulates that objects called twisters build the fabric of space-time from the ground up.

Three Different Views of Quantum Weirdness (and What It Means)

A: According to the archetypal view of quantum mechanics, called the Copenhagen interpretation, a system (represented here by a child’s block) does not occupy a definite state or location. When we look, only one of two versions—two states but that every one of them exists in its own alternate universe. Each universe we never observe the block in two states at once.

B: The many-worlds interpretation insists that the system occupies all its possible states but that every one of them exists in its own alternate universe. Each universe only, which is why we never observe the block in two states at once.

C: In Penrose’s interpretation, gravity holds our universe together. If a block generates a separate gravitational field. Over time, the energy required to maintain these multiple fields causes the block to settle in one state only—the one that we observe.

A few years ago, Penrose figured out how to perform that experiment. Instead of a speck of dust, he chose to bounce radiation off it to see if it was in one or two states at the same time. If Penrose is right, the mirror would remain in a dual existence for no more than a second before collapsing. The higher the energy involved, the longer the process takes depends on the degree of instability. Electrons, atoms, and molecules are so small that their gravity, and hence the amount of energy needed to keep them in duplicate states, is negligible.

To Penrose, the failures are a clue that physicists are on the wrong path. Most believe that quantum theory is fundamentally sound but that our understanding of gravity must change. Penrose says that rather than seeking to change Einstein’s theory of gravity, we should study how gravity affects the object small enough to exist in the borderland between the quantum world of atoms and the human world of visible objects.

An object the size of a speck of dust would provide a perfect test. At this scale, an object is small enough to be strongly affected by the rules of quantum mechanics but large enough to be observable. Current theory predicts that such an object could exist in more than one location and could remain in that split state almost indefinitely. If there were a way to observe the speck without disturbing it, we would see quantum strange- ness laid bare: a macroscopic thing sitting in two places at the same time, confounding reality as we know it.

Penrose is convinced that conventional quantum theory seems absurd because it is incomplete. Specifically, it ignores the effects of gravity. On atomic or subatomic scales, gravity is so weak compared with the other forces that most physicists see no problem with leaving it out of the picture. But in Penrose’s view, the only way to understand the quantum world is to consider all the forces that act on it. To do that, he is combining Einstein’s relativistic quantum physics in a way nobody has considered before.

In Einstein’s theory, any object that has mass causes a warp in the structure of space and time around it. This warping produces the effect we experience as gravity. Penrose points out that tiny objects—dust specks, atoms, electrons—produce much weaker warps as well. Ignoring these warps is where most physicists go awry, he believes. If a dust speck is in two locations at the same time, each one should create its own distortions in space-time, yielding two superposed gravitational fields. According to Penrose’s theory, it takes energy to sustain these dual fields. The stability of a system depends on the amount of energy involved. The higher the energy the more stable the system is. Over time, an unstable system tends to settle back to its simplest, lowest-energy state—in this case, one object in one location producing one gravitational field. If Penrose is right, gravity yanks objects back into a single location, without any need to invoke observers or parallel universes.

How long the process takes depends on the degree of instability. Electrons, atoms, and molecules are so small that their gravity, and hence the amount of energy needed to keep them in duplicate states, is negligible. According to Penrose, they can persist that way essentially forever, as standard quantum theory predicts. Large objects, on the other hand, create such significant gravitational fields that the duplicate states vanish almost at once. Penrose calculates that a person could exist in a trillion-trillion of a second. For a dust speck, the process takes nearly a second—long enough that it might be possible to measure. Growing excited, he hoists himself to a more up- right position on his sofa. “Here is the scale where you should start to see differences between what quantum mechanics says and what reality does,” he says. “The superposition that is part of quantum mechanics is unstable for large objects; an object will assume one of the possible positions on a timescale of about a sec- ond. Is this true? Well, we have to do an experiment.”

Can a pattern have no pattern? Using only a note- book and a pencil, Penrose devised a way to test his ideas. What he had considered impossible. Researchers have since learned that certain chemicals naturally organize themselves into these patterns, some of which are now used to make minibrick coolings for poles and paths.
Penrose, who turns 74 in August, is hopeful that he will see the day when his ideas are vindicated. Not every physicist shares this optimism. Tony Leggett, a Nobel laureate at the University of Illinois at Urbana-Champaign, suspects the experiment will fail to show that gravity has any effect on quantum systems. “I take the quantum paradox as seriously as Penrose does,” Leggett says. “I’m personally convinced that somewhere between the level of the atom and human consciousness, something has to come in which changes the structure of quantum mechanics.”

The problem is that quantum theory has never yet failed to predict the outcome of any experiment. Without evidence of some such flaw in the theory, physicists are left groping in the dark for ways to improve it. “I think the odds of them being right are less than 5 percent,” he says.

David Deutsch, a theoretical physicist at Oxford University’s Centre for Quantum Computation, is a leading proponent of the many worlds theory. He turns the tables on Penrose, arguing that his quest is based more on metaphysical reluctance for reality to be a certain way, than historically that kind of motivation has never produced the right answers.”

Penrose responds that he is not changing quantum mechanics; he is merely putting it to a new, more rigorous test. “You can say we haven’t seen any violation of quantum mechanics, but that’s absolutely what you’d expect, because no experiment has ever been performed that comes remotely close to the level you’d need to see any violations. So unless you try to get to this level I’m aiming for, it’s not at all surprising that we haven’t been able to see any deviations,” he says.

If Bouwmeester’s experiment succeeds, it will show that Penrose is right, gravity forces the tiny mirror to move in two places at the same time. Both states of the photon perfectly retrace their paths and interfere with each other, so no photons ever hit the detector.

The Experiment: Can a photon be in two places at the same time?

Can a computer be intelligent? Penrose believes that the human brain performs feats that are beyond computational processes. He cites a famous proof by the logician Kurt Godel on the limitations of all mathematical systems as an idea that no computer could ever devise.

A light source shoots particles of light, or photons, at a beam splitter. According to standard theory, when a photon arrives at the beam splitter it splits into two states. One is reflected toward mirror 1; the other goes through the splitter to the tiny mirror, moving the mirror on the way out and restoring it to its initial position on the way back after reflecting off mirror 2. It is impossible to know which path the photon takes, as the tiny mirror exists in two states (moved and unmoved) at the same time. Both states of the photon perfectly retrace their paths and interfere with each other, so no photons ever hit the detector.

The Orthodox Quantum Mechanics View

The one Penrose rises from his one chair, preparing to pick up Max, his 4-year-old son, from school. He has no doubt that Max’s generation will learn physics lessons different from the confusing, incomplete story that Penrose got from Dirac all those years ago. “Is quantum mechanics the last word?” Penrose asks. “There is no reason to believe that.”