Quantum theory

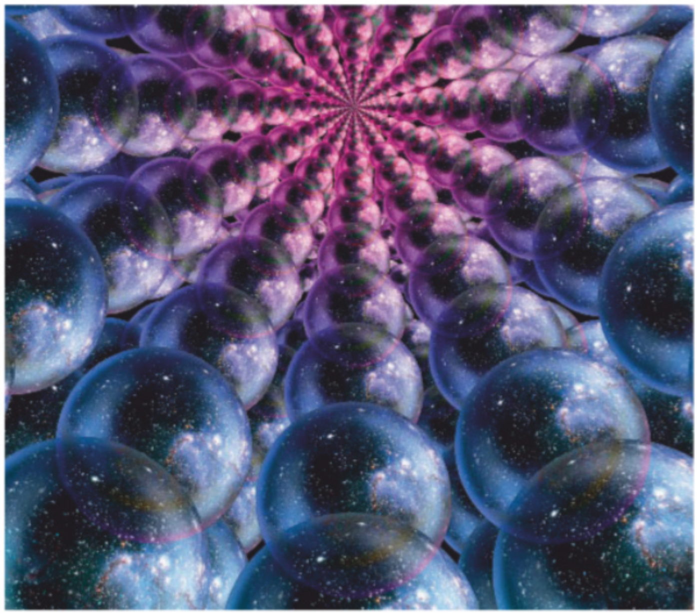
Proof of parallel universes?

A classic quantum theorem may prove that many worlds exist

Leah Crane

SOME ideas about the quantum world seem to suggest that there are many versions of you spread out across parallel universes. Now, two researchers have formulated a proof that attempts to show this is really true.

The proof involves a fundamental construct in quantum mechanics called Bell's theorem, which deals with situations in which particles interact with each other, become entangled and then go their separate ways. It is what is called a "no-go theorem", one designed to show that some assumption about how the world works isn't true.



DETLEV VAN RAVENSWAAY/SCIENCE PHOTO LIBRARY

Reality may split into many worlds, which can merge again later

Bell's theorem rests on three assumptions. First, that there is local causality, meaning that objects can only affect what is near them and an effect must happen after its cause. Next, events aren't all predetermined by some external force. The last assumption is that every measurement has only one outcome, a stipulation that is simply called "one world".

Tests of Bell's theorem have already shown that all of these assumptions can't be true at once. Measuring one of a pair of entangled particles always seems to affect the other. That is true when the two are separated by vast distances and the measurements are made too quickly for any signal, even moving at the speed of light, to have travelled between them.

Conventionally, physicists say that this means local causality is violated, and it proves that entangled particles can change one another's measured states. But Mordecai Waegell and Kelvin McQueen at Chapman University in California interpret it differently. They argue in a paper submitted to the *British Journal for the Philosophy of Science* that local causality can be preserved – but only if there are many worlds.

"Everyone agrees that there's a contradiction if you accept all three axioms of Bell's theorem and the experimental results, so you've got to reject at least one," says McQueen. Rather than doing away with local causality, it actually makes most sense to get rid of the requirement for a single world, say McQueen and Waegell.

> **"It starts as an entanglement of particles, but then it becomes an entanglement of worlds"**

They worked through a classic thought experiment in which three entangled particles are sent to three detectors that are far away from one another. There are people taking measurements at each detector, called Alice, Bob and Charlie. First, Alice measures a quantum property of her particle called spin. Then Bob measures the same thing for his particle, followed by Charlie for her particle. Each measurement will either return a spin of up or down.

Based on the rules of entanglement, if we know what Alice measured, it narrows down the possible results from Bob and Charlie's measurements. If we know what both Alice and Bob measured, we can predict the exact result of Charlie's measurement. In the particular set-up that McQueen and Waegell consider, if Alice and Bob both get spin-up, Charlie must get spin-down.

But when the researchers calculated every possible outcome in a scenario including local causality, they found that Alice would have to get two different results from one measurement. Alice's particle must be both spin-up and spin-down when she measures it.

"We get a contradiction in what Alice measured: she must have gotten one result, and also must have gotten the other result," says McQueen. "That's not possible – not unless you have two Alices."

The solution, they say, is a hypothesis called semi-local worlds. In this scenario, when Alice makes a measurement, she splits into multiple Alices who get different results. The same goes for Bob and Charlie. The worlds of each of the measurers continue separately until they compare their results, at which point their worlds merge.

"The Bob that obtains a particular measurement is only going to meet an Alice that obtains a corresponding measurement," says Mateus Araújo at the University of Cologne in Germany. "It starts as entanglement of particles, but then when you do the measurement, it becomes an entanglement of worlds."

Many physicists are sceptical of the idea because it is difficult to test empirically. McQueen admits as much. "I don't think I could ever experimentally confirm that you have bifurcated into two versions of yourself," he says.

Waegell, however, says there may be a way to test it by taking extremely fast measurements of systems in the process of splitting into different worlds. But he isn't sure we will ever have the equipment to do so.

Many worlds might also make it easier to reconcile quantum mechanics with Einstein's theory of general relativity, says Waegell. The mismatch between these is one of the biggest problems in physics.

"I think Einstein probably would have hated this," says Araújo. Nevertheless, he says, it is just as plausible for the incorrect assumption in Bell's theorem to be the one stating there is only one world as it is to be local causality. ■