Tangled Up in Quanta

Quantum entanglement is easy to describe but not easy to understand. Thornton (Ernie) Glover, formerly of Berkeley Lab, currently of the Sloan Foundation, gives one of the best one-minute explanations of quantum entanglement I know, so have a look.

What Glover calls red and blue in the video can be any number of quantum properties in a pair of particles prepared together, such as the spin orientation of electrons or the polarization of photons. The states remain superposed, like Schrödinger's alive-dead cat in a box, until one is measured. Because the two (or more) particles are entangled, measuring one instantly determines the state of the other—no matter how far apart they are.

Einstein called this "spooky action at a distance," but the effect has been demonstrated over distances of many kilometers, Alain Aspect by and other experimentalists using polarized photons. The act of measurement is called "collapsing the wave function." The wave function includes all possible outcomes of a particle's superposed states; collapsing it picks just one.

Consider a system of entangled electrons, all spin up or spin down. These might be the superposed bits of information, the "qbits," in a quantum computer. A few entangled electrons in nitrogen-vacancy centers of a ring-sized diamond, for example, could store more data than a classical supercomputer and, upon the collapse of the wave function, process it instantly.

Why does this seem weird? Because if two particles can be as far apart as from here to Jupiter, say, and measuring the state of the one here instantly fixes the state of the one there, then some kind of information must be traveling between the two much faster than the speed of light, which violates relativity theory.

For many young physicists who were already tackling quantum mechanical calculations in high school, this doesn't seem weird at all; their attitude is "get over it, that's just the way the world works." But not all physicists, even young ones, are so blasé.

Quantum entanglement suggests that information can indeed travel faster than light (although because it's completely random it may not be of much use to humans). The possibility arises that causes can come before their effects. Einstein claimed this shows that quantum mechanics is incomplete. He and his colleagues said extra terms were needed, what became known as hidden (local) variables.

First John Bell and later Alain Aspect disproved Einstein's argument for hidden variables, but other proposals followed and are still coming. Perhaps the best known is Hugh Everett's many worlds interpretation (MWI), which does away with collapsing wave functions by supposing that every possible state of every particle exists in its own parallel reality, and a single wave function covers them all. This idea has proved tremendously useful to science fiction writers; it gives us an infinity of not-quite-identical worlds to play in.

John Wheeler and Richard Feynman theorized that particles actually do reverse in time, an indirect way of avoiding the collapse of the wave function because (or so it seems to me) it leads to a universe that doesn't change: the same particles move backward and forward in time, constantly switching temporal direction, constituting everything we experience and know.

Wheeler and Feynman were the inspiration for my favorite theory, John Cramer's transactional interpretation of quantum mechanics, which posits two waves (estimates of probability) for every quantum event, one emitted forward in time, the other emitted backward, which meet and with a "handshake" settle the true state of the event. This is the basis, as far as real science goes, of Manolis Minakis's backwards-in-time experiment in my novel *Secret Passages*.

A recent, ingenious attempt to evade the paradoxes of quantum entanglement and the collapse of the wave function should also be mentioned, the QBism of Christopher Fuchs. Quoted by Amanda Gefter in Quanta Magazine, Fuchs describes physics as a "dynamic interplay between storytelling and equation writing"—right on!—and regards the wave function not as a description of reality but of our personal beliefs about and knowledge of reality at a given moment. Surely a simple storyteller has to cheer the prospect of human involvement in seemingly hands-off physics.

The measurements needed to collapse wave functions have long been a thorn in the side of those inclined to fret. Collapses happen all the time; the world goes on even when we're not looking. Who's doing the observing?

Einstein put the dilemma succinctly: "Is it enough that a mouse observes that the moon exists?"

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