Inspecting teleported quantum information

It's a stock scene in many science-fiction films and novels: A mysterious alien vanishes from one location, while a perfect replica shimmers into existence somewhere else. Science fiction has long relied on teleportation to provide this convenient shortcut. Now, researchers have uncovered a new consequence of quantum theory that makes it possible, in principle, to achieve "quantum teleportation" of information.

"It's a means by which you can take apart an unknown quantum state into classical information and purely quantum information, send them through two separate channels, put them back together, and get back the original quantum state," says Charles H. Bennett of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y.

Bennett and his collaborators describe their scheme in the March 29 Physical Review Letters.

The notion of quantum teleportation hinges on the distinction between classical information (the kind conveyed by a newspaper or some other conventional medium) and quantum information (the kind represented by such characteristics as a microscopic particle's spin or a photon's polarization angle).

Classical information can be freely copied. It's not disturbed when observed, and it can't travel faster than the speed of light. In contrast, quantum information can't be observed without being disturbed, nor can it be copied reliably. "And it sometimes seems to propagate instantaneously," Bennett remarks.

The notorious Einstein-Podolsky-Rosen (EPR) effect stands as one of the more bizarre manifestations of this quantum waywardness (SN: 8/5/89, p.88). For example, suppose a single process within an atom simultaneously generates two photons that travel in opposite directions. According to quantum theory, neither photon has a particular polarization, or electric field orientation, until it's measured at a detector.

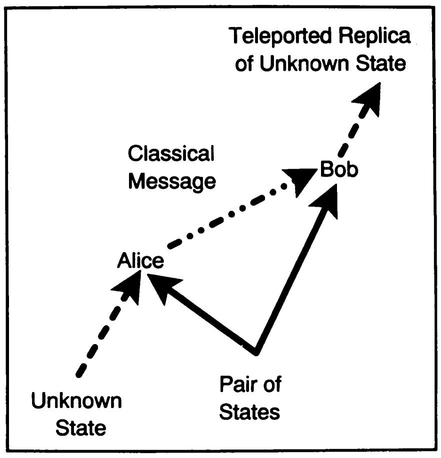
In fact, such a measurement transforms a photon's polarization from a range of possibilities into a specific, randomly chosen value. Surprisingly, measuring one photon's polarization causes the other photon of the EPR pair to acquire the opposite polarization at the same instant – even if the second photon is at the other end of the room or across the galaxy. "This is a phenomenon that cannot be explained by assuming that the two [photons] had [particular] polarizations at the moment they were created," Bennett notes.

Although this effect can't be harnessed to send controllable, faster-than-light messages, Bennett and his colleagues argue that it can be used to assist in the teleportation of information about a particle's quantum state (see diagram).

The sender, Alice, wants to convey to the receiver, Bob, a certain photon's unknown polarization. Instead of determining its polarization directly, and thereby disturbing it, she measures the relationship between the polarization angle of her mystery photon and that of a photon created in an EPR process. She then sends a message to Bob, using a conventional medium, to tell him that the two polarization angles are identical, are at right angles to each other, or have one of two other possible geometrical relationships.

Meanwhile, Bob has access to the second EPR photon. He can combine the classical information contained in Alice's message with the quantum information carried by his own EPR photon. This combination allows him to transform the quantum state of his EPR photon, which has never been anywhere near Alice's mystery photon, into an exact replica of the mystery photon's original quantum state. In effect, "Alice's measurement forces the other EPR particle to change in such a way that the classical information that comes out of her measurement enables someone else to produce a perfect copy of what went in," Bennett says.

However, although the EPR information travels instantly, the entire scheme still requires a finite amount of time. "It must be emphasized that our teleportation, unlike some science-fiction versions, defies no physical laws," the researchers say. "In particular, it cannot take place instantaneously . . . because it requires, among other things, sending a classical message from Alice to Bob."



Using quantum teleportation via a pair of EPR particles with correlated quantum states to convey a particle's unknown quantum state from Alice to Bob.

Though of no practical value, this exercise in quantum logic helps elucidate the crucial differences between classical and quantum information, Bennett says.

– I. Peterson

Synthesis in soot: The new molecular cages

A year ago, chemists at Pennsylvania State University discovered a new class of hollow, cage-like compounds, called metallo-carbohedrenes, or met-cars (SN: 4/18/92, p.250). Because of the compounds' molecular architecture – symmetrical balls built from 12 carbon atoms and eight metal atoms – scientists speculated that met-cars could make good catalysts, semiconductors, and possibly superconductors. But an annoying obstacle blocked the study of met-car materials: Only small numbers of the molecules could be produced, and then only in the gas phase.

Met-cars will no longer be shrouded in mystery. The Penn State team has found a way to synthesize bulk quantities of the molecules in the solid state, announced principal researcher A. Welford Castleman Jr. at last week's meeting of the American Chemical Society in Denver.

"This will open the door to exploring the chemistry of met-cars in a meaningful way," says Castleman. He and his colleagues describe their breakthrough in detail in the April 9 issue of Science.

The group made the first met-cars while creating and manipulating clusters of hydrocarbons and titanium in a plasma reactor with a technique called laser vaporization. "We could only make [limited batches of] molecules that way," notes Castleman. Still working with gaseous forms, the researchers discovered they could replace the hydrocarbons with a titanium-graphite rod. Since fullerenes – similarly cage-like – can be produced in the solid state by passing an electric current between two graphite rods in a chamber with helium, the team decided to try the same technique using titanium-graphite rods. They prepared their rods with titanium and later vanadium, pressing the metal and carbon powders together and baking them.

Indeed, the black soot that remained after the rods were vaporized contained met-cars (and often fullerenes). Once they analyzed the sooty substance – which happily proved to be stable in air – they tinkered with the composition of the rods. So far, the team can produce soot containing 1 percent met-cars, but they are working to improve that yield. They also hope to develop better methods for extracting the product, says Castleman.

Shiv Khanna, a theoretical physicist at Virginia Commonwealth University in Richmond, considers this work "extremely important." He notes, "From the beginning, we've wondered what structures met-cars could form and what physical properties they might have. Now real experiments will be able to tell us."

– K.F. Schmidt