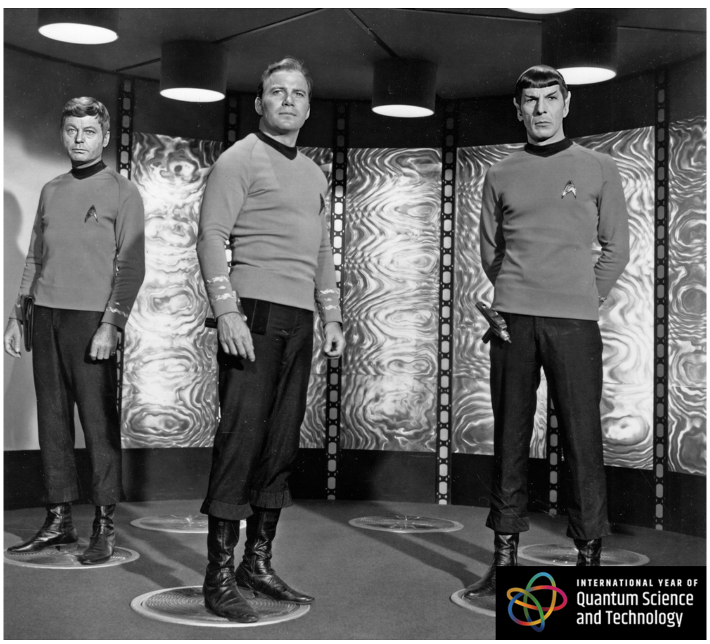
Quantum Milestones, 1993: Teleportation Is Not Science Fiction

Theorists proposed an idea they called quantum teleportation—a means of transferring the identity of one particle to another over some distance.

By **David Lindley**

For the ***International Year of Quantum Science and Technology****, we are republishing stories on the history of quantum physics from the archives of* Physics Magazine *and* APS News. *The* ***original version of this story*** *was published in* Physics Magazine *on January 8, 2010.*



The Enterprise crew popularized the concept of teleportation in the 1960s, but it wasn't until 1993 that theorists proposed a way to send a single quantum state from one place to another.
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Any attempt to measure an unknown quantum state yields incomplete information, according to the Heisenberg uncertainty principle, so you can't measure the state and then reproduce it precisely. But in 1993 researchers hit on a way to exactly copy an unknown quantum state from one particle to another as long as it remains unknown [**1**]. This ability to "teleport" quantum states may prove crucial to quantum computing and other information-processing technologies.

Teleportation came about serendipitously, says Charles Bennett of IBM Research in Yorktown Heights, New York, one of six coauthors who devised the process. At a 1992 conference, William Wootters of Williams College in Massachusetts described a curious result found by him and Asher Peres of the Technion–Israel Institute of Technology. They considered two identical but unknown quantum states, such as a pair of photons with unknown polarization. Wootters and Peres found that observers can learn more by performing a single measurement on the photon pair than by carrying out any number of separate measurements on the individual particles. The pair measurement is one that's made after the photons have been forced to interact in some way. They proposed a procedure that would allow the observers to guess the photons' original polarization with maximum confidence [**2**].

Discussing this finding at the conference and by email afterward, the six researchers added a new twist. They devised a way for two observers, who acquired the names Alice and Bob, to each take one of the identical particles to a different location and still perform the optimized measurement on the

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Teleporting an Unknown Quantum State via Dual Classical and Einstein-Podolsky-Rosen Channels

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An unknown quantum state $|\phi\rangle$ can be disassembled into, then later reconstructed from, purely classical information and purely nonclassical Einstein-Podolsky-Rosen (EPR) correlations. To do so the sender, "Alice," and the receiver, "Bob," must prearrange the sharing of an EPR-correlated pair of particles. Alice makes a joint measurement on her EPR particle and the unknown quantum system, and sends Bob the classical result of this measurement. Knowing this, Bob can convert the state of his EPR particle into an exact replica of the unknown state $|\phi\rangle$ which Alice destroyed.

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The existence of long range correlations between Einstein-Podolsky-Rosen (EPR) [1] pairs of particles raises the question of their use for information transfer. Einstein himself used the word "telepathically" in this context [2]. It is known that *instantaneous* information transfer is definitely impossible [3]. Here, we show that EPR correlations can nevertheless assist in the "teleportation" of an intact quantum state from one place to another, by a sender who knows neither the state to be teleported nor the location of the intended receiver.

a perfectly accurate copy.

A trivial way for Alice to provide Bob with all the information in $|\phi\rangle$ would be to send the particle itself. If she wants to avoid transferring the original particle, she can make it interact unitarily with another system, or "ancilla," initially in a known state $|a_0\rangle$, in such a way that after the interaction the original particle is left in a standard state $|\phi_0\rangle$ and the ancilla is in an unknown state $|a\rangle$ containing complete information about $|\phi\rangle$. If Alice now sends Bob the ancilla (perhaps technically easier

Credit: C. H. Bennett *et al*. [**1**]

pair. The method relies on giving each of the observers an additional particle. These new particles would be prepared in a quantum mechanically "entangled" state, so that a measurement by Alice on her new particle would influence the outcome of a measurement by Bob on his new particle, despite the physical separation (see **Special Feature: Quantum Milestones, 1935: What's Wrong with Quantum Mechanics?**).

The procedure is that Alice makes a measurement on her pair of particles—the entangled particle and the photon with unknown polarization. Her measurement influences the state of Bob's entangled particle, and she also sends Bob the results of her measurement by classical means. Bob then uses Alice's results to construct a measurement on his pair—the entangled particle and his copy of the original unknown photon state. He ends up with the same information that he could have obtained directly from the original pair if they were together.

It took further thought, Bennett says, for the collaborators to understand why the protocol works and to realize that they had discovered something quite unexpected. The procedure turns Bob's entangled particle into an exact replica of Alice's unknown state. So Bob is back to the original situation of having the two identical particles at the same location. Sending an exact copy of a quantum state from one place to another was far more interesting to the researchers than the original problem. Peres wanted to call the process "telepheresis," a word with purely Greek roots, but Bennett persuaded him that the Greek–Latin hybrid "teleportation" had already gained credence thanks to science fiction writers.

Teleportation requires both quantum information delivered through the entangled pair and classical information delivered through classical channels, which can transmit no faster than the speed of light. Moreover, Alice's measurements destroy her original unknown state, so it isn't "photocopied" without effect on the original particle, which would be forbidden by quantum mechanics.

The first demonstrations of teleportation came a few years later. Beyond its appeal as an example of quantum weirdness, teleportation provides a way to transfer quantum information among physical objects, says Christopher Monroe of the University of Maryland, College Park. If a practical quantum computer is ever built, he says, it will have to make use of different kinds of quantum bits, perhaps atoms for storage and photons for transmission. So teleportation would be a natural way to connect these components, he says.

David Lindley is a freelance science writer, now retired. His most recent book is ***The Dream Universe: How Fundamental Physics Lost Its Way*** (Penguin Random House, 2020).

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