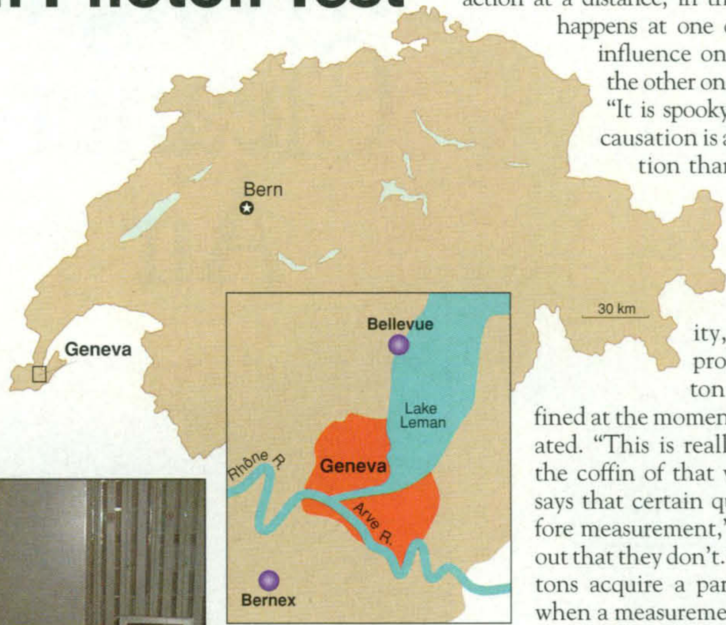
QUANTUM MECHANICS

Quantum Spookiness Wins, Einstein Loses in Photon Test

"I cannot seriously believe in [the quantum theory] because it cannot be reconciled with the idea that physics should represent a reality in time and space, free from spooky actions at a distance," wrote Einstein to the German physicist Max Born in March 1947. Einstein was particularly bothered by quantum theory's oddball claim that the states of two particles or photons can influence each other no matter how far apart they are. Despite Einstein's misgivings, researchers have gone on to demonstrate the reality of quantum spookiness, and now—just 140 kilometers as the photon flies from Bern, where Einstein did some of his greatest research—a Swiss group has provided the best demonstration yet of quantum "action at a distance."

The new result, announced earlier this month at a quantum computation workshop in Turin, Italy, and hailed as "very important" by Boston University theorist Abner Shimony, shows that links between quantum entities persist over distances of up to several kilometers. Some theorists have speculated that these correlations would weaken with distance, says another quantum mechanics expert, John Rarity of the Defence Evaluation and Research Agency in Malvern, United Kingdom. But in the Swiss result, "we've now got to 10 kilometers' separation, and quantum mechanics is apparently still holding."

As early as 1926, the Austrian physicist Erwin Schrödinger, a father of quantum theory, pointed out that the theory allows a single, pure quantum state—a particular polarization, for example—to be spread across two objects, such as a pair of simultaneously created photons. In the lingo of quantum mechanics, the photons are "entangled," and they remain entangled even when they fly apart. Then quantum theory predicts that a measurement on one photon will influence the outcome of a measurement on its distant twin. This is the action at a distance that Einstein detested, as it appears to be at odds with the prohibition of faster-than-light effects in his theory of special relativity. But short-range laboratory experiments, notably those of Alain Aspect and his colleagues in Paris in 1982, have backed the quantum claim.



Photons phone home. A photon source (on table), plugged into the Geneva telephone exchange (far left), sends pairs of correlated photons to two nearby villages (map).

With a little help from Swiss Telecom, Nicolas Gisin and his group at the University of Geneva have now demonstrated quantum action at a distance on a large scale by turning the countryside around Geneva into a giant quantum laboratory. Gisin's team created pairs of entangled photons, using a specially constructed, suitcase-sized generator in central Geneva, and sent them through fiber-optic lines to the two small villages of Bellevue and Bernex, 10.9 kilometers apart, where the streams of photons were analyzed and counted.

The total energy of each entangled pair is fixed, but the energy of each photon in a pair can vary within a narrow range. An analyzer is effectively an energy filter, offering each photon a random choice of either being counted, or of being lost from the experiment. Each photon makes its choice depending on its energy and the setting of the analyzer, explains Wolfgang Tittel, one of Gisin's colleagues. When the photon counts were relayed to Geneva via a second fiber-optic system and compared, they turned out to be correlated. Each photon in a pair knows what its distant partner does, and does the same thing.

"Even if you change a [setting] only on one end, it has an influence on what happens on the other end," Gisin says. "There is indeed spooky action at a distance, in the sense that what happens at one detector has some influence on what happens at the other one." Adds Shimony, "It is spooky in the sense that causation is a more subtle relation than we had ever realized. I think Einstein loses on this point."

The implication, says Rarity, is that certain properties of the photon twins aren't defined at the moment the pairs are created. "This is really another nail in the coffin of that world view which says that certain quantities exist before measurement," he says. "It turns out that they don't." Instead, the photons acquire a particular state only when a measurement is made on one of the pair, instantly determining the state of the other.

Shimony adds that the result is "pretty definitive disproof that entanglement falls off with distance," contrary to proposals by some, including the late British theorist David Bohm. Indeed, it hints that quantum events in a far corner of the universe might influence events here on Earth.

Gisin points to more down-to-earth implications for telecommunications, implications presumably not lost on Swiss Telecom: "If these correlations hold over very long distances ... then they could be exploited for a variety of applications, especially quantum cryptography." Contrary to Einstein's fears, quantum correlations can't be exploited to transfer information faster than light. "You cannot control what will be transmitted; therefore, you can't send an SOS message, or any other ... message, by means of quantum correlation," says Shimony. But these correlations could in principle create two perfect copies of random digits in two places. These could serve as the key to some code.

Not only would the transmission be error free; it might also be uncrackable. "Any eavesdropper who tried to eavesdrop these quantum channels would break the correlation," explains Gisin; the two parties could detect the intrusion by comparing parts of the received signals, which should be identical. Quantum spookiness might be just the thing to foil a spook.

–Andrew Watson

Andrew Watson is a science writer in Norwich, U.K.