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Photon reaches from beyond the grave in quantum trick

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EINSTEIN mockingly called it "spooky action at a distance": the finding that quantum particles can influence each other regardless of how far apart they are. We can only imagine his horror at a new experiment that extends the idea to time by entangling a pair of photons that never coexisted. As well as expanding the reach of quantum theory's baffling implications, the experiment could improve long-distance cryptography.

At the heart of the phenomena is entanglement, in which the quantum states of two entities become linked. The implications of this for spatially distant particles stumped even Einstein, but things got still stranger last year. Joachim von Zanthier of the University of Erlangen-Nuremberg in Germany and his colleagues showed that, in principle, entanglement could also work for particles that have never existed at the same time (*Optics Letters*, doi.org/bdwpsj).

Now Hagai Eisenberg of the Hebrew University of Jerusalem in Israel and colleagues have done the experiment, via a process called an entanglement swap.

If you have two pairs of entangled photons, taking one photon from each pair and entangling them disengages the two original pairs, and creates a second, fresh entanglement between the two, left out photons. Eisenberg's team used the swap to entangle a photon with one that no longer existed.

They started with an entangled pair of photons, 1 and 2, and then measured the quantum state of photon 1, which destroys the particle. Photon 2, however, lived on and, about 100 nanoseconds later, the team created a new pair of entangled photons, 3 and 4.

When the team entangled photon 2 with newborn photon 3, photon 4 also became entangled with photon 1 - even though 1 was by then "dead" (see diagram).

The team knew 4 was entangled with 1 by measuring 4's state, which depended on the states measured for 1, 2 and 3 (arxiv.org/abs/1209.4191v1). "Without the idea of entanglement, you cannot explain it," says von Zanthier, who was not involved in the latest experiment. "The future photon, which is not born, is strongly influenced by a photon that is already dead."

The result could boost quantum cryptography, in which entangled photons are used to transmit a secret key for ciphers. Entanglement makes the process secure because if a photon is intercepted, its partner registers this, allowing the key to be ditched.

Entanglement swapping can enable the process over enormous distances. Take an entangled pair, 1 and 2, created in London. Photon 2 can be sent to Paris, where an entanglement swap with another pair, 3 and 4, takes place. Photon 4 is now entangled with 1 - still in London - and can then be sent to Berlin. Quantum communication between London and Berlin is now possible, even though no single photon has travelled that distance. The process can be extended by further swaps, all the way to Beijing, say. But currently, London would have to hold on to its photons until the chain is complete - which gets trickier as the total distance increases.

The new experiment shows that London can measure its photons well before Beijing's even exist.

"London can already start working," says Johannes Kofler of the Max Planck Institute of Quantum Optics in Garching, Germany. "That's cool."