*** Draft press release for “Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres” by B. Hensen et al. ***

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Loophole-free Bell test crowns 80-years-old debate on nature of reality: Einsteins “spooky action” is real

In 1935, Einstein asked a profound question about our understanding of Nature: are objects only influenced by their nearby environment? Or could, as predicted by quantum theory, looking at one object sometimes instantaneously affect another far-away object? Einstein did not believe in quantum theory’s prediction, famously calling it “spooky action”.
Exactly 80 years later, a team of scientists led by professor Ronald Hanson from Delft University of Technology finally performed what is seen as the ultimate test against Einstein’s worldview: the loophole-free Bell test. The scientists found that two electrons, separated 1.3 km from each other on the Delft University campus, can indeed have an invisible and instantaneous connection: the spooky action is real.
The experiment, published in Nature today, breaks the last standing defence of Einstein’s iconic 1935 paper: it closes all the loopholes present in earlier experiments. The Delft experiment not only closes a chapter in one of the most intriguing debates in science, it may also enable a radically new form of secure communications that is fundamentally impossible to ‘eavesdrop’ into.

In two places at the same time?
“Quantum mechanics states that a particle such as an electron can be in two different states at the same time, and even in two different places, as long as it is not observed. This is called ‘superposition’ and it is a very counter-intuitive concept”, says lead scientist Professor Ronald Hanson. Hanson’s group works with trapped electrons, which have a tiny magnetic effect known as a “spin” that can be pointing up, or down, or - when in superposition - up and down at the same time. “Things get really interesting when two electrons become entangled. Both are then up and down at the same time, but when observed one will always be down and the other one up. They are perfectly correlated, when you observe one, the other one will always be opposite. That effect is instantaneous, even if the other electron is in a rocket at the other end of the galaxy”, says Hanson.
Already in 1935, just a few years after the development of quantum theory, this counterintuitive effect was seen as a reason to doubt the new theory. These objections were published in a famous scientific paper, known as ‘the EPR-paper’ (1935), named after its three authors: Einstein, Podolsky and Rosen. They stated there could still be undiscovered properties of particles, so called ‘hidden variables’, which would provide a more intuitive explanation of the predicted correlations: the two particles were just pre-programmed to be opposite, we just did not know it.

Bell Test
A major step was taken in 1964, when CERN scientist John Stewart Bell devised an experiment that could prove that ‘spooky action at a distance’ existed - the Bell Test - as it can rule out any ‘hidden variable’ as an explanation. During the past four decades, many Bell

experiments were performed, showing results that conflicted the ‘hidden variables’ explanation. Nonetheless, the debate didn’t just end there: as the opposing scientists stated: the Bell tests performed still contained ‘loopholes’, or back-doors that could invalidate the proof.
Basically, a Bell Test does a measurement on two sides of an entangled pair, choosing randomly between two possible ‘questions’ at both sides. Depending on which question is asked, a different property of the particle is measured. In a Bell test, quantum mechanics predicts that the outcomes, or ‘answers’ will be strongly correlated in a way that can’t be explained by any ‘hidden variable’ theory. Nonetheless, as opposing scientists said, alternative explanations could still not be fully excluded.
Firstly, it might be possible that the particles or the detectors were ‘secretly’ communicating to each other in some unknown way that might be beyond our current understanding of nature. By secretly sharing questions or answers between them (the locality loophole), they could be producing the observed correlations in a perfectly local manner. Secondly, if the experiment only detected a subset of prepared entangled pairs, they might not be representative of all of them (the ‘detection loophole’). With these loopholes open, the possibility of an alternative explanation cannot be fully excluded.

Loopholes
Over the last decade, advances in nanoscale technology allowed experiments to close these loopholes individually. For the first time, a group of scientists from The Netherlands, Spain and United Kingdom have now managed to close all loopholes simultaneously.
The scientists placed two diamonds on opposite sides of the Delft University campus, 1.3 km apart. Each diamond contained a tiny trap for single electrons, which have a magnetic property called a “spin”. They managed to entangle the electron spins and perform a Bell Test.
“We have two labs, one in the Faculty of Applied Sciences, and one on the other end of the campus in the Reactor Institute. The large distance between our detectors ensures that neither the detectors, nor the electrons can exchange information within the time it takes to do the measurement, and so closes the locality loophole. This exchange is limited by the speed of light, and the distance is too far for light to travel in the time it takes us to ask our electron spins a question and get an answer”, explains PhD-student Bas Hensen, lead-author of the study.
“We also close the detection loophole, because in this experiment we measure all our entangled pairs. This is the first time all loopholes are closed at the same time in a single experiment, and we still find that the invisible bond between the electrons is there: the first loophole-free Bell test”.

Secure communications
The experiment in Delft closes a chapter in one of the most intriguing debates in science. “It is one of the few experiments in physics that can directly test and even reject fundamental principles of nature” says Hanson. However, the experiment has practical value as well, as entanglement allows for a form of secure communication.
The measurement outcomes can be used as an encryption key: the key is fundamentally impossible to eavesdrop on as it doesn’t travel between two points, but is created through the instantaneous entanglement link. However, loopholes are potential backdoors for hackers, so quantum communication will only be inherently secure if all the loopholes are closed.

Note for editors, not for publication

For more information, please contact:
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More information, including free-to-use images and animations, will be made available on http://hansonlab.tudelft.nl/loophole-free-Bell-test

The paper: 'Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres' will become available here: http://nature.com/articles/doi:10.1038/nature15759

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