Researchers find a way to close both loopholes in testing entanglement with Bell's inequality

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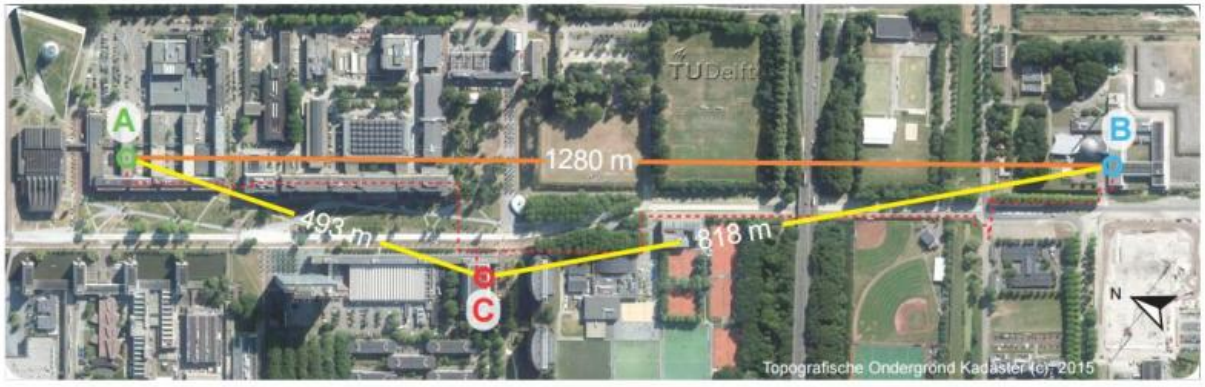

Aerial photograph of the campus of Delft University of Technology. Credit: arXiv:1508.05949 [quant-ph]

(Phys.org)—A team of researchers working at Delft University in The Netherlands, has perhaps succeeded in closing the two loopholes that have prevented proving that local realism does not hold at the quantum level. They have written a paper detailing their work and have uploaded it to the preprint server *arXiv* so that others may see it while it undergoes peer review prior to being published in a yet to be announced journal.

At issue is proving that quantum entanglement does not occur due to

some strange unexplainable communication factor, or variable as Einstein suggested—a task that has proved exceptionally challenging—so much so that despite nearly a century of trying, no one, until now apparently, has been able to do it.

One of the ways to "prove" that entanglement does not occur due to some unknown factor that allows for communication to move between two entanglement particles, is to cause entanglement to come about between two particles that are far enough apart that any unknown force allowing them to communicate, would have to travel faster than light, which everyone agrees cannot happen. That was one of the loopholes described by John Bell, who famously came up with a way to prove mathematically that it should be possible to distinguish between quantum mechanics and so-called hidden variables. If such variables existed, he noted, measurements of certain results would have to be less than a critical value. If an experiment could be run that violated that inequality, that would "prove" that quantum mechanics has at least some non-local characteristics. Another loophole, it has been noted, occurs because single photons are difficult to measure—some get lost during transmission, particularly if sending them at a great enough distance to overcome the first loophole, making experimental results difficult to verify.

In this new experiment, led by Ronald Hanson, the researchers set about closing both loopholes, which would theoretically shut the door on local realism. They set up two stations for creating photons entangled with an electron spin, far enough apart to close the first loophole. The entangled photons were all sent to a common third location via fiber cable where they were entangled under just the right conditions and measured (and tested for measurement with their entangled mate back at the original site). Knowing that the process would be highly inefficient, they arranged for the whole experiment to be repeated, over and over—at the end of nine days they had just 245 successes, but that was enough to

meet Bell's inequality rule, showing that there was no hidden variable allowing for communication between entangled pairs—"proving" that local realism does not always apply in the quantum world.

More information: Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km, arXiv:1508.05949 [quant-ph] arxiv.org/abs/1508.05949

Abstract

For more than 80 years, the counterintuitive predictions of quantum theory have stimulated debate about the nature of reality. In his seminal work, John Bell proved that no theory of nature that obeys locality and realism can reproduce all the predictions of quantum theory. Bell showed that in any local realist theory the correlations between distant measurements satisfy an inequality and, moreover, that this inequality can be violated according to quantum theory. This provided a recipe for experimental tests of the fundamental principles underlying the laws of nature. In the past decades, numerous ingenious Bell inequality tests have been reported. However, because of experimental limitations, all experiments to date required additional assumptions to obtain a contradiction with local realism, resulting in loopholes. Here we report on a Bell experiment that is free of any such additional assumption and thus directly tests the principles underlying Bell's inequality. We employ an event-ready scheme that enables the generation of high-fidelity entanglement between distant electron spins. Efficient spin readout avoids the fair sampling assumption (detection loophole), while the use of fast random basis selection and readout combined with a spatial separation of 1.3 km ensure the required locality conditions. We perform 245 trials testing the CHSH-Bell inequality $S \leq 2$ and find $S = 2.42 \pm 0.20$. A null hypothesis test yields a probability of $p = 0.039$ that a local-realist model for space-like separated sites produces data with a violation at least as large as observed, even when allowing for memory in the devices. This result rules out large classes of local realist theories,

and paves the way for implementing device-independent quantum-secure communication and randomness certification.