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Georgina Woodward: *on* 10/26/15 at 23:12pm U wrote Quote "How can one account for something that was at one point indefinite...

John Cox: *on* 10/26/15 at 17:57pm U wrote Luca, Thank-you for the link, and the thought. I will look into it. But...

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October 26, 2015

CATEGORY: Blog [back]
TOPIC: "Spookiness" Confirmed by the First Loophole-free Quantum Test [refresh]

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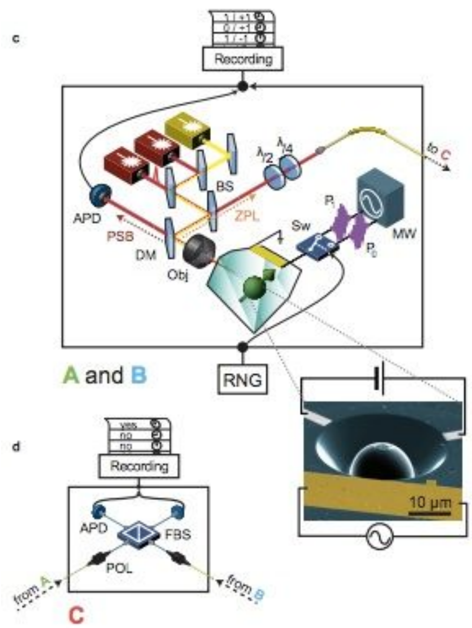
FQXi Administrator Zeeya Merali wrote on Aug. 26, 2015 @ 19:05 GMT

Spookiness, it seems, is here to stay. Quantum theory has been put to its most stringent "loophole free" test yet, and it has come out victorious, ruling out more common sense views of reality (well, mostly). Many thanks to Matt Leifer for bringing this experiment -- by a collaboration of researchers in the Netherlands, Spain, and the UK -- to my attention (arXiv:1508.05949).



Hensen et al, arXiv:1508.05949

A few years ago, I wrote a feature for *Science* about the quest to close loopholes in quantum entanglement experiments, with a number of groups around the world vying to perform the perfect test. ("Quantum Mechanics Braces for the Ultimate Test.") In that article, I quote quantum physicist and FQXi member Nicolas Gisin saying: "This race is on because the group that performs the first loophole-free test will have an experiment that stands in history."

We may now have a winner.

The test is a version of an experiment set out in the 1960s, by Irish physicist John Bell. He came up with a way of working out whether nature was really as spooky as it seems on the quantum level, or if a more common sense explanation was possible. The "sensible" view of the world, in this case, is taken to be "local" and "realistic." "Local," in this context, means that information cannot travel between objects faster than the speed of light, so instantaneous communication is impossible. "Realistic" means that the properties of particles are set before they are observed, and are not affected by measurements made on them. By contrast, quantum theory says that prior to measurement, particles can exist in a murky superposition state where their properties are not clearly defined; it's only upon measurement that their properties click and become well-defined. And quantum theory allows two entangled particles to become linked in such a way that when a measurement is performed on one (breaking it out of superposition, and clicking it into a well-defined state), the properties of its entangled partner will likewise become defined, instantaneously — no matter how far apart they are separated.

Bell suggested that experimenters should entangle a string of particles and measure how well their properties match up. He derived a theorem showing that the common sense view of the world (local realism) can only account for correlations between the particles up to a certain limit. If experiments measured a violation of that bound, then the common-sense view would have to be given up in favour of the spooky quantum one.

Those experiments were first carried out in the 1970s and, more famously and strictly, in 1980s, and have been performed many times since, and always seem to come down on the side of quantum theory. This has convinced most physicists that the world truly is bizarre on tiny scales.

Luca Valeri: *on* 10/26/15 at 16:11pm U wrote Hi jrc, I just finished to read Bell's Essay on Bertlmann's socks I cited...

Thomas Ray: *on* 10/26/15 at 13:33pm U wrote I'm not confused, Richard. Did you or did you not write: "Time is not an...

Richard Gill: *on* 10/26/15 at 12:57pm U wrote Tom you are badly confused. You wrote "to counterexample Bell's theorem...

Georgina Woodward: *on* 10/26/15 at 11:30am U wrote Luca, I agree having a correlation is not the same as an entanglement but...

Luca Valeri: *on* 10/26/15 at 9:47am UT wrote By the way, here is a nice paper by Bertlmann himself about his memories...

Luca Valeri: *on* 10/26/15 at 9:41am UT wrote Georgina, just a short comment: 1. Having a correlation does not mean...

RECENT FORUM POSTS

Georgina Woodward: "Quote "How can one account for something that was at one point indefinite..." *in* "Spookiness"...

Robert McEachern: ""I simply do not know of anything that everyone would agree is true..." ..." *in* Alternative Models

But all experiments have loopholes, and to get a truly definitive result, these need to be closed. One such loophole is the "detection loophole". In many Bell tests, experimenters entangle photons and then measure their properties. The trouble is photons zip about quickly, and often simply escape from the experiment before being detected and measured. Physicists can lose as many as 80 per cent of the photons in their test. That means that experimenters have to make a 'fair sampling' assumption that the ones that they *do* detect are representative of the ones that have gone missing. For the conclusions to be watertight, however, you really want to keep track of all the subjects in your test.

It is easier to keep hold of entangled ions, which have been used in other experiments. The catch there, however, is that these are not often kept far enough apart to rule out the less spooky explanation that the two entangled partners simply influence each other, communicating at a speed that is less than the speed of light, during the experiment. This is known as the "communication loophole" or the "locality loophole."

In the new paper by Hensen et al, the authors describe measuring electrons with entangled spins. The entangled pairs have been separated by 1.3 km, to ensure that they do not have time to communicate (at a speed slower than the speed of light) over the course of the experiment.

They cleverly use a technique known as "entanglement swapping" to tie up both loopholes, combining the benefits of photons (which can travel long distances) with electrons (which are easier to monitor). Their electrons are placed in two different labs, 13km apart. The spin of each electron is then entangled with a photon and those two photons are fired off to a third location, where they are entangled with each other. As soon as the photons are entangled, BINGO, so too are the two original electron spins, seated in vastly distant labs. The team carried out 245 trials of the experiment, comparing entangled electrons, and report that Bell's bound is violated.

From their paper:

"Our experiment realizes the first Bell test that simultaneously addresses both the detection loophole and the locality loophole. Being free of the experimental loopholes, the setup can test local realist theories of nature without introducing extra assumptions such as fair-sampling, a limit on (sub-)luminal communication or the absence of memory in the setup. Our observation of a loophole-free Bell inequality violation thus rules out all *local realist theories that accept that the number generators timely produce a free random bit and that the outputs are final once recorded in the electronics. This result places the strongest restrictions on local realistic theories of nature to date."*

As a test of the foundations of reality, for most physicists, these experiments dot the i's and cross the t's. It seemed unlikely that given the other Bell tests performed so far — even with their loopholes — that quantum theory would be found wanting, in a loophole-free test. That's because each of the earlier experiments were so different from each other, and had different weaknesses, that nature would have to have been cunning, in quite different and particular kinds of ways in each previous experiment, to keep fooling us into thinking quantum theory was correct, if it is not. But it is important, nonetheless, to test quantum theory to its limits. After all, you never know.

There are also huge practical applications, though. A major motivation, as I explain in the Science feature, is that loophole free Bell tests are an essential step towards 'device-independent quantum cryptography' — creating a security system so tight that you could trust it even if you bought it from your worst enemy.

Such a device would go beyond those quantum cryptographic systems that are already in place, which use entanglement to add create "unhackable" keys. In those systems, you share a string of entangled particle pairs between two parties (the sender and receiver) and they each independently perform measurements of their set of particles to generate a matching string of 0s and 1s to make up a key that only they should know. If a hacker tries to eavesdrop on the system, their presence will disrupt the quantum key, alerting the legitimate users and raising an alarm.

Those systems are fine, assuming you really have been sold a quantum cryptographic system. But an unsuspecting buyer could be tricked by a hacker purporting to sell a genuine quantum cryptographic device, who actually just gives them a black box, preprogrammed with a string of 0s and 1s that she's set up beforehand. The user would be none the wiser.

of...

John Cox: "Luca, Thank-you for the link, and the thought. I will look into it. But..." *in* "Spookiness"...

Eckard Blumschein: "Steve A, Well, I intend tersely voting for realism as a pragmatic attitude..." *in* Alternative Models of...

Gary Simpson: "Thanks for the feedback all. I was simply musing about whether the..." *in* Faster than Light

Eckard Blumschein: "Akinbo, Don't speculate too naively. You might trust in my knowledge even..." *in* Faster than Light

Steve Dufourny: "You are welcome. I have always liked your subjective and objective..." *in* New Podcast: Hawking...

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To get around this, in 1991, Artur Ekert came up with the idea for a device that had to verify its quantum credentials using a Bell test at the same time as generating the key, so the user would know that it was working correctly, and was genuinely using a quantum process to produce the key. But such "device independent quantum cryptography" can only be trusted if the Bell tests are watertight. As Gisin told me for the Science piece, "It's unlikely that nature is so malicious that it conspires with the apparatus to hold back particular photons just to fool us into thinking that quantum mechanics works," but, a "hacker—by definition—is malicious enough to exploit the detection loophole to fool us into thinking that a quantum process has taken place."

There is still another way that nature could be tricking us in quantum tests. It seems a bit outlandish, but it's possible that experimenters are somehow being manipulated into measuring certain properties in tests and not others, distorting the results. This is sometimes called the "freedom-of-choice" loophole. Last year, I wrote about a fun experiment that used light from distant quasars to help experimenters choose what measurements to make in the lab — in an attempt to rule out the possibility that the experimenters choices were being mysteriously biased by stuff in the experiment itself. That article appeared in Nature, "Cosmic Light Could Close Quantum Weirdness Loophole".

The authors touch on remaining loopholes at the end of their paper:

"Strictly speaking, no Bell experiment can exclude the infinite number of conceivable local realist theories, because it is fundamentally impossible to prove when and where free random input bits and output values came into existence. Even so, our loophole-free Bell test opens the possibility to progressively bound such less conventional theories: by increasing the distance between A and B (testing e.g. theories with increased speed of physical influence), using different random input bit generators (testing theories with specific free-will agents, e.g. humans), or repositioning the random input bit generators (testing theories where the inputs are already determined earlier, sometimes referred to as "freedom-of-choice"). In fact, our experiment already excludes all models that predict that the random inputs are determined a maximum of 690 ns before we record them, because the inequality is still violated for a much shorter spin readout."

(Updated to include my write up about this experiment for *Nature*, 27 August 2015: Quantum 'spookiness' passes toughest test yet. With comments from FQXi members Nicolas Gisin, Anton Zeilinger, and Matt Leifer.)

this post has been edited by the forum administrator

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John R. Cox replied on Aug. 28, 2015 @ 22:17 GMT

We can't say what an electron is, we have no model of a 'photon'. Isn't that spooky enough? jrc

report post as inappropriate

FQXi Administrator Zeeya Merali wrote on Aug. 26, 2015 @ 19:07 GMT

FQXi member Richard Gill (who commented on the Nature story for me) has also written up an account of the new work, including his own contribution here.

report post as inappropriate

Dan B Cohen replied on Aug. 27, 2015 @ 20:30 GMT

Nobel laureate Gerald Edelman wrote a series of technical books about human consciousness, beginning with The Mindful Brain (1978). His theories of consciousness remain dominant in psychology, neuroscience and psychology. He summarized his viewpoint in an article Naturalizing consciousness: A theoretical framework.

Edelman's held that human consciousness is a product of brain function. To prove this scientifically he proposed a theory to account for the properties of consciousness and provided a framework for the design and