Scientists cast doubt on renowned uncertainty principle

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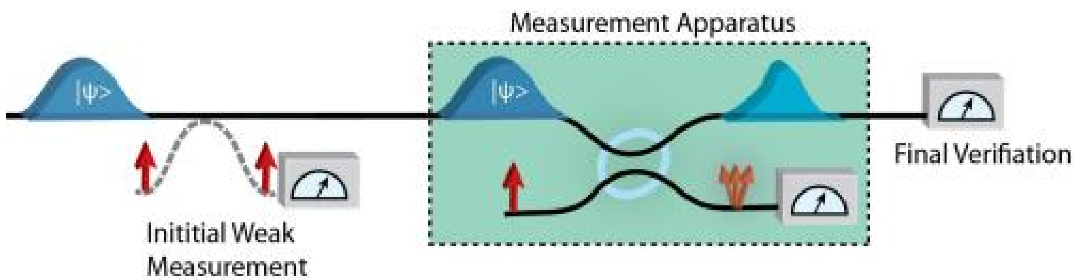


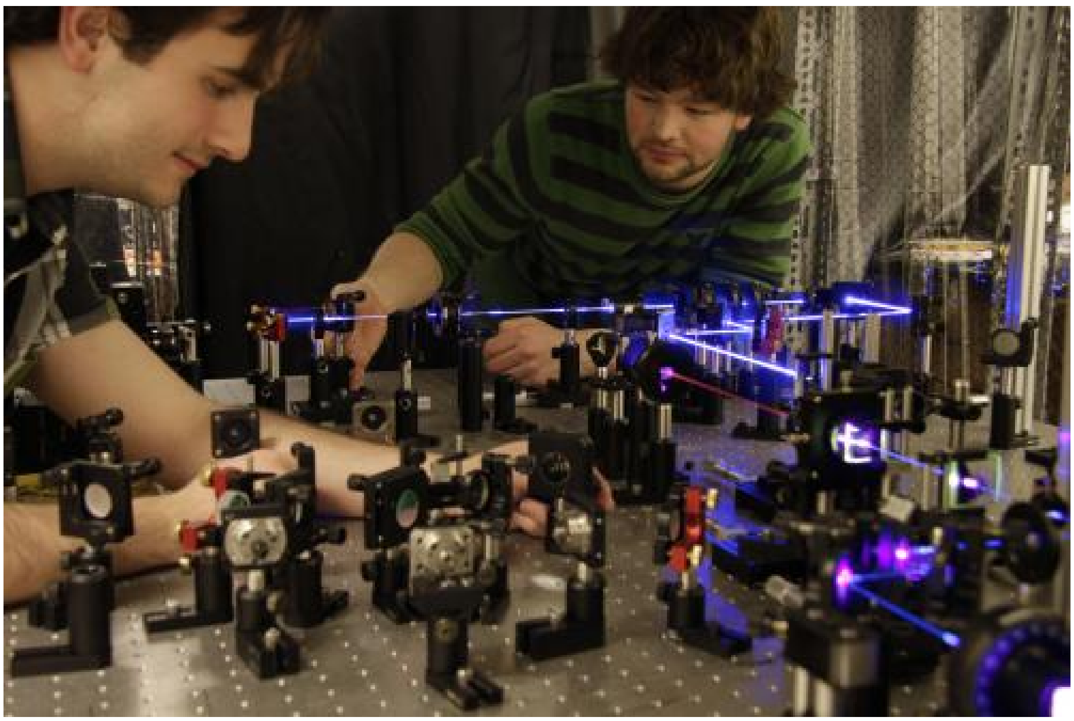
This is a general method for measuring the precision and disturbance of any system. The system is weakly measured before the measurement apparatus and then strongly measured afterwords. Credit: Lee Rozema, University of Toronto

Werner Heisenberg's uncertainty principle, formulated by the theoretical physicist in 1927, is one of the cornerstones of quantum mechanics. In its most familiar form, it says that it is impossible to measure anything without disturbing it. For instance, any attempt to measure a particle's position must randomly change its speed.

The principle has bedeviled quantum physicists for nearly a century, until recently, when researchers at the University of Toronto demonstrated the ability to directly measure the disturbance and confirm that Heisenberg was too pessimistic.

"We designed an apparatus to measure a property – the polarization – of a single photon. We then needed to measure how much that apparatus disturbed that photon," says Lee Rozema, a Ph.D. candidate in Professor Aephraim Steinberg's quantum optics research group at U of T, and lead author of a study published this week in Physical Review Letters.

"To do this, we would need to measure the photon before the apparatus but that measurement would also disturb the photon," Rozema says.



University of Toronto quantum optics graduate students Dylan Mahler (l) and Lee Rozema (r) prepare pairs of entangled photons to study the disturbance the photons experience after they are measured. The pair are part of a team that demonstrated the degree of precision that can be achieved with weak-measurement techniques, causing a re-evaulation of Heisenberg's uncertainty principle. Credit: Dylan Mahler, University of Toronto

In order to overcome this hurdle, Rozema and his colleagues employed a technique known as weak measurement wherein the action of a measuring device is weak enough to have an imperceptible impact on what is being measured. Before each photon was sent to the measurement apparatus, the researchers measured it weakly and then measured it again afterwards, comparing the results. They found that the disturbance induced by the measurement is less than Heisenberg's precision-disturbance relation would require.

"Each shot only gave us a tiny bit of information about the disturbance, but by repeating the experiment many times we were able to get a very good idea about how much the photon was disturbed," says Rozema.

The findings build on recent challenges to Heisenberg's principle by scientists the world over. Nagoya University physicist Masanao Ozawa suggested in 2003 that Heisenberg's uncertainty principle does not apply to measurement, but could only suggest an indirect way to confirm his predictions. A validation of the sort he proposed was carried out last year by Yuji Hasegawa's group at the Vienna University of Technology. In 2010, Griffith University scientists Austin Lund and Howard Wiseman showed that weak measurements could be used to characterize the process of measuring a quantum system. However, there were still hurdles to clear as their idea effectively required a small quantum computer, which is difficult to build.

"In the past, we have worked experimentally both on implementing weak measurements, and using a technique called 'cluster state quantum computing' to simplify building quantum computers. The combination of these two ideas led to the realization that there was a way to implement Lund and Wiseman's ideas in the lab," says Rozema.

It is often assumed that Heisenberg's uncertainty principle applies to both the intrinsic uncertainty that a quantum system must possess, as well as to measurements. These results show that this is not the case and demonstrate the degree of precision that can be achieved with weak-measurement techniques.

"The results force us to adjust our view of exactly what limits quantum mechanics places on measurement," says Rozema. "These limits are important to fundamental quantum mechanics and also central in developing 'quantum cryptography' technology, which relies on the uncertainty principle to guarantee that any eavesdropper would be detected due to the disturbance caused by her measurements."

"The quantum world is still full of uncertainty, but at least our attempts to look at it don't have to add as much uncertainty as we used to think!"

More information: The findings are reported in the paper "Violation of Heisenberg's Measurement-Disturbance Relationship by Weak Measurements". prl.aps.org/abstract/PRL/v109/i10/e100404

Provided by University of Toronto

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