It's Easier to Observe the Failure of Local Realism than Previously Thought

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(PhysOrg.com) -- Local realism is something we live with every day, even if we don't realize it. The principle of local realism combines two assumptions: locality and realism. Locality says that distant objects cannot directly and instantaneously influence each other (since nothing can travel faster than the speed of light). Realism says that the things we measure and sense are indeed really there apart from our measurements, and it's not just our measurements that make them exist.

While the principle of local realism is intuitive in our everyday classical world, physicists going back to Einstein's time have known that local realism can be violated in quantum physics. Experimentally, physicists can confirm that a quantum system has violated local realism (violating either locality or realism) by demonstrating the violation of Bell's inequality, which serves as a test of local realism.

But while scientists have experimentally observed the failure of local realism in laboratories, no one has ever observed any non-local or non-realistic system on the macroscopic scale. Physicists have usually attributed this fact to decoherence: when quantum systems become macroscopic, they unavoidable interact with their environment, causing them to rapidly lose their quantum features. More recently, physicists Johannes Kofler and Caslav Brukner at the University of Vienna in Austria have suggested an alternative view: that the classical world emerges from the quantum world because our measurements of classical systems are too fuzzy, or coarse-grained, to detect quantum features of nature.

Now, a team of scientists consisting of Hyunseok Jeong of Seoul National University in Korea, Mauro Paternostro of The Queen's University in the UK, and Timothy C. Ralph of the University of Queensland in Australia have investigated this issue further. But in stark contrast with the conclusions reached by Kofler and Brukner, the new analysis shows that, even when making only coarse-grained measurements, observers can still perceive an evident failure of local realism on the macroscopic scale, as shown by violating Bell's inequality. Until now, no one has shown that extremely unsharp measurements in the macroscopic limit can be used to reveal the failure of local realism.

"We showed that failure of local realism can in principle be observed even when measurements are performed on a macroscopic scale," Jeong told *PhysOrg.com*. "The 'extremely coarse-grained measurements' can be understood as measurements on the macroscopic scale. So, the greatest significance of our results is probably that the fuzziness of measurements cannot properly explain the appearance of the classical world on the macroscopic scale." Instead, Jeong thinks that decoherence is still the most likely explanation for why it is difficult to observe quantum properties, such as failure of local realism, in the macroscopic world.

In the scientists' proposal, they used two thermal states macroscopically distinguishable but quantum mechanically entangled, sending each to a distant observer. Each observer then performed a homodyne measurement on their thermal state to determine the location of the thermal state. The physicists found that Bell's inequality could be violated nearly up to the upper limit even when using the coarse-grained homodyne measurements.

"In general, it is relatively easier to make measurements more coarse-grained, while it is nontrivial to make measurements sharp enough to demonstrate strong quantum effects," Jeong explained. "In our proposal,

part of signal to be measured is lost by a beam splitter before an ideal detector so that the resolution of the measurement becomes low."

As the scientists explained, the failure of local realism means that at least one part of local realism - locality or realism - has been violated. To try to figure out if one or both parts failed when observed with coarse-grained measurements, the physicists compared their results with a test of realism called Leggett's inequality. The results passed this test, implying that realism had not been violated in their proposed measurement method, and that only locality had failed.

As the first theoretical demonstration that coarse-grained measurements can be used to observe the failure of local realism, this study could help physicists learn more about the nature of the boundary between the quantum and classical worlds. Jeong, Paternostro, and Ralph predict that it should be possible to test their proposal with small-scale experiments in the future.

More information: Jeong, Hyunseok (h.jeong37 [at] gmail.com); Paternostro, Mauro; and Ralph, Timothy C. "Failure of Local Realism Revealed by Extremely-Coarse-Grained Measurements." *Physical Review Letters* 102, 060403 (2009).