Team finds 'tipping point' between quantum and classical worlds

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If we are ever to fully harness the power of light for use in optical devices, it is necessary to understand photons - the fundamental unit of light. Achieving such understanding, however, is easier said than done. That's because the physical behavior of photons - similar to electrons and other sub-atomic particles - is characterized not by classical physics, but by quantum mechanics.

Now, in a study published in *Physical Review Letters*, scientists from Bar-Ilan University have observed the point at which classical and quantum behavior converge. Using a fiber-based nonlinear process, the researchers were able to observe how, and under what conditions, "classical" physical behavior emerges from the quantum world.

Up and Out of "Entanglement"

In the quantum world, pairs of photons are "entangled" - connected so that measurements performed on one affect the other, even when separated by great distances. This concept - which Albert Einstein called "spooky action at a distance" - leads to another counter-intuitive claim: that, when unobserved, the photons exist in all possible states simultaneously.

Using a well-established technique called broadband four-wave mixing (FWM), the scientists fired a laser through an optical fiber, generating entangled photon pairs, or bi-photons.

"FWM is an important source of single bi-photons for quantum communication schemes, especially for in-fiber applications," says the publication's first author, Rafi Vered. Vered is a PhD student whose work is supervised by both Dr. Avi Pe'er and Prof. Michael Rosenbluh, faculty members in Bar-Ilan University's Department of Physics and at the Bar-Ilan Institute of Nanotechnology and Advanced Materials (BINA).

"Rather than generating the bi-photons with high- or low-power laser pulses - which would cause the system to demonstrate either pure classical or quantum behavior - we focused on the intermediate power regime. At this intermediate power level, we were able to observe the transition point where the cross-over between 'spooky' quantum behavior and 'classical' wave physics takes place."

Power, Pulse and Interference Patterns

The researchers' experimental set-up focused on a unique interference phenomenon that affects only photon pairs, but not single photons. Quantifying this interference was made possible through the creation a kind of optic "obstacle course" in which the dual nature of light - encompassing both wave-like and particle-like behavior - could be revealed.

"In our experiment, we examined the way in which photon pairs act as particles, but also present wave-like patterns of interference," Pe'er explains, adding that this effect is strongly related to the quantum entanglement between the two photons of a bi-photon pair. "We were able to manipulate this interference by introducing an attenuator - a beam splitter - that deliberately broke the quantum entanglement between the photons."

According to Pe'er, the passage of light through the attenuator strips many of the photons from their bi-photon partners, and as a result, the probability of an intact photon-pair crossing the attenuator is much lower than the chances that a single photon will cross on its own. This change - which severely reduces bi-photon-specific interference - was mediated directly by the scientists through the application of varying levels of laser power.

"We generated bi-photon pairs by firing laser pulses over a large range of power levels," Vered explains, "and we found that when the number of bi-photon pairs is lower than a certain limit, its properties must be described by quantum mechanics. However, when a larger number of pairs successfully pass through, their behavior can be well predicted by classical physical principles. This allowed us to identify the 'point of transition' at which the quantum nature of light 'collapses' to conform to the rules that govern the classical, non-quantum world."

Ultra-Fast Bi-Photon Detection

Another achievement noted in the PRL publication is the scientists' ability to detect bi-photons at an unprecedentedly high rate.

"Our lab holds the world record for the generation and transmission of single bi-photons (up to 1014 bi-photons per second)," says Pe'er, an expert in quantum optics and laser physics. He adds that, until this recent work, such a record-breaking number of bi-photons was regarded, not as a feature, but as a bug.

"In this study, we introduced a fiber-based nonlinear process to generate bi-photons - pairs of entangled energy quanta," Pe'er says, explaining that the resultant broadband ultra-high flux (up to 1014 bi-photons per second in the actual experiment) means that nearly 100 photons can arrive at their destination every pico-second or so. "While this offers a huge improvement over other methods, until now there has been no corresponding photon-detection method capable of handling such a high flux without 'choking' on all the incoming data. Recently, we solved this problem by using different detection principle. In the detector, we employ a non-linear fiber - the same type used in transmission - which inverses the process and identifies the bi-photons as they arrive."

More Than One Way to See "Schroedinger's Cat"

According to Vered, an interesting aspect of the study is how it provides a concrete, optics-based perspective on quantum superposition - the idea that entangled quanta inhabit all possible states until they are observed.

"Any popular explanation of quantum theory usually begins with Schroedinger's cat - a thought experiment describing a cat inside a closed box, that may be either dead or alive," Vered says. "Rather than looking at the tipping-point between life and death, our experiment examines the point at which quantum behavior gives way to classical physics. Since quantum behavior kicks in at a very small scale, one could liken our results to identifying the transition point at which Schroedinger's cat shrinks to a small enough size to be perceived as being both alive and dead at the same time."

Provided by Bar-Ilan University

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