

Duality principle is 'safe and sound': Researchers clear up apparent violation of wave-particle duality

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Decades of experiments have verified the quirky laws of quantum theory again and again. So when scientists in Germany announced in 2012 an apparent violation of a fundamental law of quantum mechanics, a physicist at the University of Rochester was determined to find an explanation.

"You don't destroy the laws of [quantum mechanics](#) that easily," said Robert Boyd, professor of optics and of physics at Rochester and the Canada Excellence Research Chair in Quantum Nonlinear Optics at the University of Ottawa.

In their 2012 version of the famous Young two-split experiment, Ralf Menzel and his colleagues at the University of Potsdam simultaneously determined a photon's path and observed high contrast interference fringes created by the interaction of waves from the two slits.

"This result was extremely surprising, as one of the basic tenets of quantum mechanics holds that there should be no [quantum interference](#) when it is known through which slit the particle (a photon in this case) had passed," said Boyd.

Inspired by these intriguing results, Boyd and his colleagues replicated the Menzel experiment. Their findings were recently published online in an early edition of the *Proceedings of the National Academy of Sciences*.

"The data of the Menzel experiment were very clean, so we weren't surprised to obtain the same initial result," said Boyd. "My coworkers and I asked what could explain this apparent violation of a key principle of quantum mechanics. What we found is that the resolution of the problem requires great subtlety in the way that one needs to analyze the data for this type of measurement."

Following the method of Menzel and the Potsdam researchers, Boyd's group generated an entangled pair of photons, one called a signal and the other called an idler. By measuring the position of the idler photon, they thereby determined through which slit the signal photon had passed. They then observed that the signal photons produced an [interference pattern](#), in agreement with the results of the Potsdam group and in apparent conflict with the duality principle.

A careful examination of the results shows that the visibility of the interference pattern is stronger in some places and weaker in others. In particular, the strongest recorded visibility was much higher than the average visibility of the entire pattern.

Wave-particle duality suggests that elementary particles, like electrons and photons, cannot be completely described as either waves or particles, because they exhibit both types of properties. In the double-slit experiment, observing a photon pass through one of the two slits is an example of a particle-like property; a particle can only pass through one or the other. When two waves converge to form an interference pattern, the photon must have passed through both slits simultaneously—a wave-like property. Trying to measure both types of properties simultaneously, however, is problematic. The interference pattern disappears as soon as it is known through which slit the photon has passed.

Boyd and his colleagues discovered that the German physicists had inadvertently sampled the sections of high visibility with greater probability than the other sections. While only a handful of photons produced high visibility interference, they used the entire set of photons to determine the predictability of knowing through which slit they had passed.

This phenomenon, called biased sampling, occurs when certain measurements of a system are selected with a higher probability than others, and that subset of measurements is mistakenly taken to be representative of the entire system. In this case, the high visibility photon subsystem was more likely to be sampled. When Boyd's team "fairly" sampled each variable—giving each subsystem an equal opportunity to be detected and sampled—the problem went away and the results were consistent with the standard interpretation of quantum mechanics.

Boyd emphasizes that the Menzel group had interpreted its data just as anyone else would have. The results were both "strange" and "incredible," but it took Boyd and his colleagues nearly a year and a half to figure out what was going on. He said in some ways everyone is relieved that our understanding of quantum laws has been reaffirmed.

More information: *Proceedings of the National Academy of Sciences*,
www.pnas.org/content/early/2014/08/26/1400106111.abstract

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