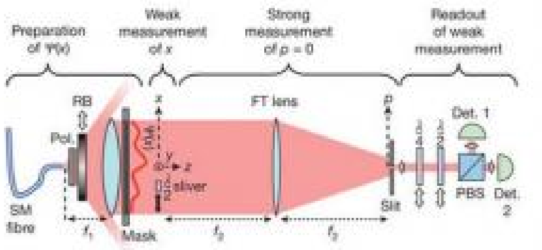
Canadian researchers devise method to directly measure the quantum wavefunction

16 June 2011, by Bob Yirka



Direct measurement of the photon transverse wavefunction. Image: Nature, doi:10.1038/nature10120

(PhysOrg.com) -- Physics researchers working at the National Research Council in Canada have succeeded in developing a way to directly measure the wavefunction of a photon. The technique, as described in their paper published in *Nature*, combines both strong and weak measurements, and offers researchers a new tool for use in understanding the intricacies of quantum mechanics. The wavefunction is a mathematical function that describes the quantum state of a particle.

Until now, physicists have had to resort to using quantum tomography to gather information about the real wavefunction (as opposed to the virtual one described by math formulas), a method that relies on indirect measurements and alters the target it's trying to measure in the process. This is because of Heisenberg's uncertainty principle, which states that the location and momentum of a single particle can't be simultaneously measured; because by its very nature, the waveform is altered by direct observation.

To get around that problem, the team, led by Jeff Lundeen, devised a method based on "weak" measurements, whereby an observation is made that only alters the particle just a little tiny bit and gives information about just one property of the particle at a time. Taking multiple such measurements of identical copies of a particle, such as a photon, gives more and more information, eventually approaching a very close approximation to the actual state of the system. In one respect this approach is similar to the way calculus is used to measure irregularly shaped objects by cutting it into a number that approaches infinity, virtual slices, then adding up the results. When combined with more certain "strong" measurement results, the procedure provides an accurate measurement of the wavefunction.

The wavefunction is a big deal in physics because it can be used to predict how a particle will react with other particles, where it will be at a given time, or how fast it will be traveling; measurements that are needed when building microelectronics, or one day perhaps a true quantum computer.

Lundeen points out that this new method doesn't actually provide any new information about the waveform; it's more like it provides researchers with a new tool. He also says the technique could be used to measure the waveform of other particles such as ions, electrons and molecules.

More information: Direct measurement of the quantum wavefunction, *Nature* 474, 188 - 191 (09 June 2011) doi:10.1038/nature10120

Abstract

The wavefunction is the complex distribution used to completely describe a quantum system, and is central to quantum theory. But despite its fundamental role, it is typically introduced as an abstract element of the theory with no explicit definition. Rather, physicists come to a working understanding of the wavefunction through its use to calculate measurement outcome probabilities by way of the Born rule. At present, the wavefunction is determined through tomographic methods, which estimate the wavefunction most consistent with a diverse collection of measurements. The

indirectness of these methods compounds the problem of defining the wavefunction. Here we show that the wavefunction can be measured directly by the sequential measurement of two complementary variables of the system. The crux of our method is that the first measurement is performed in a gentle way through weak measurement, so as not to invalidate the second. The result is that the real and imaginary components of the wavefunction appear directly on our measurement apparatus. We give an experimental example by directly measuring the transverse spatial wavefunction of a single photon, a task not previously realized by any method. We show that the concept is universal, being applicable to other degrees of freedom of the photon, such as polarization or frequency, and to other quantum systems-for example, electron spins, SQUIDs (superconducting quantum interference devices) and trapped ions. Consequently, this method gives the wavefunction a straightforward and general definition in terms of a specific set of experimental operations19. We expect it to expand the range of quantum systems that can be characterized and to initiate new avenues in fundamental quantum theory.

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