Study finds single photons cannot exceed the speed of light

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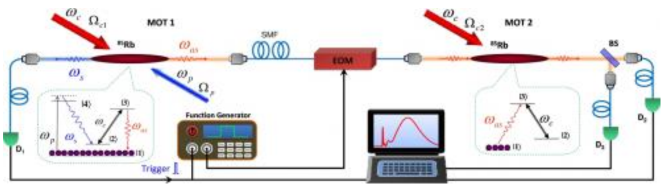

The experimental set-up used to detect the maximum speed of a single photon. Image credit: Shanchao Zhang, et al. ©2011 American Physical Society

(PhysOrg.com) -- The rule that nothing can travel faster than the speed of light, c, is one of the most fundamental laws of nature. But since this speed limit has only been experimentally demonstrated for information carried by large groups of photons, physicists have recently speculated as to whether single photons and the information carried by them may be able to exceed the speed of light. In a new study, physicists have performed the difficult task of producing single photons with controllable waveforms, and have shown that single photons also obey the speed limit c.

The physicists, led by Professor Shengwang Du from The Hong Kong University of Science and Technology in Hong Kong, China, have published their study on the ultimate speed of a single photon in a recent issue of Physical Review Letters. The results have implications for the maximum speed of information transmission by confirming that single photons obey causality; that is, an effect cannot occur before its cause.

"The greatest significance of our work is that our experimental results bring closure to the debate on the true speed of information carried by a single photon," Du told *PhysOrg.com*. "It deepens our understanding of the particle-wave duality of photons and the nature of quantum mechanics. It provides people a clear picture of photons (since the name was invented by Einstein more than 100 years ago) and corrects some 'wrong' and confusing pictures from before."

With recent advances in technology over the past several years, many groups of scientists have been investigating exactly how fast light can travel. Although previous studies have found that the "group velocity" of light can travel faster than c, the "signal velocity" - the speed at which information travels - cannot. In light of this finding, scientists have wondered whether single photons travel at the group velocity or the signal velocity.

To address this question, Du and his coauthors' demonstration required not only producing single photons, but separating the optical precursor, which is the wave-like propagation at the front of an optical pulse, from the rest of the photon. Previous experiments based on macroscopic electromagnetic wave propagation (involving lots of photons) have shown that the optical precursor is the fastest part in the propagation of an optical pulse. But this study is the first to experimentally show that optical precursors exist at the single-photon level, and that they are the fastest part of the single-photon wave packet.

In order to separate the optical precursor from the rest of the photon, the scientists generated a pair of photons, and then passed one of the photons through a group of cold rubidium atoms, while using an electro-optic modulator to shape the photon's waveform. The atoms had an effect called electromagnetically induced transparency (EIT), which enabled the scientists to separate the single-photon precursors from the main wave packet. As the optical precursor and main wave packet traveled through a second group of rubidium atoms, the scientists took measurements on the speed of the two photon components.

The scientists found that the precursor wave front of a single photon always travels at c, like the signal velocity of large groups of photons. The main as short as wave packet of a single photon travels no faster than c in any medium, and can be delayed up to 500 ns in a slow light medium where the group velocity is slower than c.

"In the slow light (with a group velocity slower than c) case, the central part of the main wave packet follows the group velocity," Du explained. "When the medium density increases (with more atoms), the slow group velocity decreases. In the fast light or superluminal (with a group velocity faster than c or negative group velocity) case, the main wave packet seems to get 'confused' and does not follow the group velocity. …We are sure that the main wave packet cannot travel faster than the precursor, which travels at c."

The results agree with previous studies that have analyzed single photons whose precursor and main wave form have not been separated, which have reported an oscillatory structure. The interference of the precursor and the slightly delayed main waveform can explain this structure.

In addition to bringing some closure to the debate on the true speed of information carried by a single photon, the result that single photons cannot travel faster than the speed of light will also likely have practical applications by giving scientists a better understanding of the transmission of quantum information.

"Because the amplitude of the rising front of the optical precursor is lossless in any medium (if the rise time of the edge is infinitely short or zero), optical precursors can be used to carry information for optical communication in a loss or absorptive medium, such as underwater optical communication," Du said, noting that optical precursors experience some loss in practice.

At the moment, as Du explained, optical precursor communication is limited by current technology, so it is not yet practical. However, he thinks that the technology will improve to make the method competitive with current communication techniques.

"In the future, when the electro-optical technology gets improved such that a step rising time can be