Physicists demonstrate quantum interference between two photons of different frequencies

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(Phys.org) -- When two photons simultaneously enter two input ports of a beam splitter, their paths interfere destructively, which causes the photons to simultaneously exit the beam splitter through the same output port. Because this quantum interference effect changes the input into a different output, it could have applications in quantum information processing. But whereas the two photons are usually identical in experiments demonstrating this effect, a new study has demonstrated that quantum interference can also occur between two photons with different frequencies, giving researchers an additional degree of control.

The physicists, François Nguyen, Eva Zakka-Bajjani, Raymond Simmonds, and José Aumentado, of the National Institute of Standards and Technology in Boulder, Colorado, have published their study on the quantum interference between two single photons of different microwave frequencies in a recent issue of *Physical Review Letters*.

As the researchers explained, the experiment builds on research from 25 years ago showing quantum interference for two photons having the same frequency.

"In the original experiment by Hong, Ou and Mandel in 1987, they used a semitransparent mirror as a mixing element or 'beam splitter' for interfering two optical paths or 'spatial," Nguyen told Phys.org. "In our experiment, we have used parametric frequency conversion as a mixing element or beam splitter for stationary photons or excitation modes defined by their frequency ('quantized electrical modes'). In both cases, the experiment is a demonstration of a two-photon quantum interference, but in our case, a new degree of freedom for photon-photon interaction is explored."

In previous experiments, the two photons' identical frequencies are confirmed by the way the photons are generated in the first place. Through a technique called parametric down-conversion, an input (or "pump") photon travels through a non-linear crystal and is split into two indistinguishable outgoing photons with the same frequency. These photons are then fed into two input ports of a beam splitter where they interfere and exit together from either one port or the other with a 50-50 chance.

Scientists can also perform experiments to test if photons generated from different sources have the same frequency. However, two photons with slightly different frequencies have been shown to exhibit quantum interference if the beam splitter is a passive mixing element, meaning that it doesn't require pump power, like a semi-transparent mirror. But in the new study, as the scientists explained, the beam splitter is an active element.

"In our case, the mixing element is active (requiring pump power) that can induce interference between photons with very different frequencies or 'colors,' also of very different energy (the additional pump energy makes up for this difference)," Nguyen said. "We believe this is the first time such a quantum two-photon interference based on a parametric effect (an active process) has been demonstrated."

He added that this effect could be used in optical systems, where it could provide another way to help process quantum information.

"Being able to induce an interaction between photons of different frequencies adds a new tool for processing quantum information with photons," he said. "This has been proposed in optical systems, in order to use not only the spatial or path information of a photon but also its energy. This paves the way for more fundamental investigations of quantum optics and information using superconducting artificial atoms and resonant circuits. Superconducting circuits enable us to prepare single-photon and complex photon states easily, the parametric interaction allows us to entangle those states amongst multiple resonant modes or simple entangle artificial atomic states, crucial to the development of a new quantum information-based technology."

In the future, the physicists plan to extend the experiments beyond microwave-frequency photons.

"We have done this between microwave modes or photons in a single resonator," Nguyen said. "It is possible to perform the same experiments between two independent resonators or other types of resonators such as mechanical systems, or propagating photons (microwave or optical). At the heart of our system is a highly nonlinear element, the tunable SQUID inductance. There are other nonlinear processes that can be accessed and we plan to investigate other interesting effects and entangling mechanisms. Now that our group has shown the utility of parametric processes with microwave photons, we anticipate more developments to come from other researchers in the growing community of quantum information specialists."

More information: François Nguyen, et al. "Quantum Interference between Two Single Photons of Different Microwave Frequencies." *PRL* 108, 163602 (2012). DOI: 10.1103/PhysRevLett.108.163602

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