Scientific Highlight

A ray of hope for quantum research

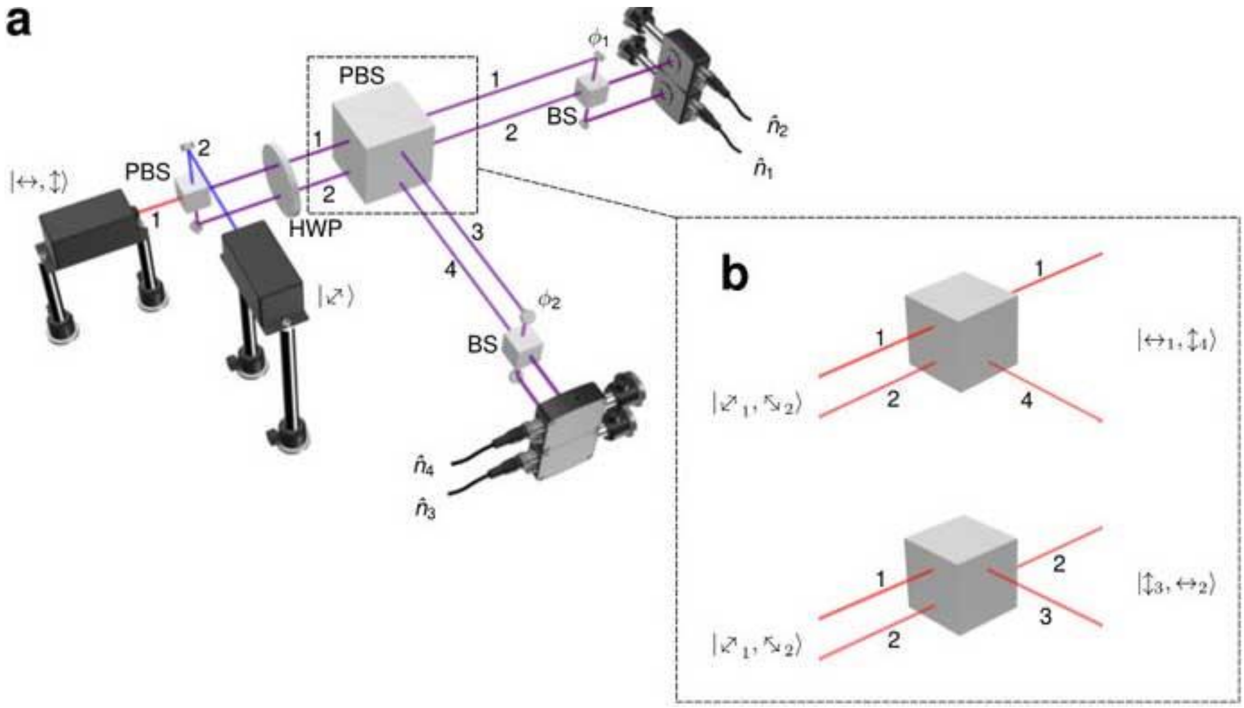
An HU research team and partners have for the first time directly measured the particle exchange phase of photons

This experiment provides direct evidence for an astonishing quantum phenomenon that is only observed in completely similar quantum objects. This represents an important step forward in quantum research.

The particles the research team is on the trail of are elusive. The physicists are investigating the quantum particles of electromagnetic waves, also called photons, which make up light. Photons can only be distinguished if they have different wavelengths, oscillate in different directions or are located at different points in space and time.

"If two photons that are indistinguishable in wavelength and direction of oscillation meet and separate again, they have in a sense lost their identity," explains Kurt Busch. "Imagine we send two twins through two doors into one room. When they step out again, we cannot determine whether they each used the same door to do so or not," adds Oliver Benson, a member of **IRIS Adlershof**. Nevertheless, something happens in quantum mechanics. According to the so-called symmetrisation postulate, there are two categories of elementary particles: Bosons and fermions. These types of particles differ in what happens when you swap them with each other.

In the example, this would mean that each of the twins leaves the room through the other door. In the case of bosons, nothing changes - in the case of fermions, the quantum me



Conceptual sketch of the interferometer setup: a: An entangled photon pair (red beam) is fed into the interferometer, which produces two different possibilities at the central polarising beam splitter (PBS), as shown in b: Either the photon in path 1 is transmitted and the photon in path 2 is reflected, or exactly the opposite. The quantum superposition of these scenarios leads to the interference between states that are physically reversed versions of each other, revealing the particle exchange phase φ_x. The blue beam is generated by an attenuated laser and serves as a reference signal to determine the effective optical path length differences, φ_1 and φ_2.

chanical wave function describing the particles receives a phase shift, which is also called the exchange phase. "In the twin example, you can perhaps think of it like this: If we send the two twins into the room in step and they come out of different doors, they continue to be in step. As bosons, the twins step out of the room with the same leg in front that they first used to step into the room. However, as fermions, they both need one more step and now walk with the other leg when leaving the room," says Benson. "That photons are bosonic could previously only be shown by indirect measurements and mathematical calculations," says Kurt Busch. "In our latest experiment, we have directly measured the particle exchange phase of photons for the first time, providing direct evidence for their bosonic character."

To directly demonstrate the exchange symmetry of a state for two identical particles, the team set up an optical apparatus with an interferometer. At the heart of the setup - the size of a small table - are two beam splitters. Two photons were then sent into the interferometer and guided through the beam splitter along two different paths. Along one of the two paths, the photons are interchanged with each other, while along the other they remain unchanged. At the exit of the interferometer, both photons were then superimposed again at the second beam splitter. "Depending on whether the photons are bosonic or fermionic, the two photons are then in step and amplify each other, or they are out of step and cancel each other out," the physicists explain.

Future improvements to the interferometer will provide a new tool for precision measurements with quantum light. At the same time, the experiment establishes a new method for generating and certifying quantum states of light. This is very important in the new field of quantum information processing, on the basis of which novel, much more powerful computers are currently being developed.

Direct observation of the particle exchange phase of photons
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Nat. Photonics, 2021, 15(9), 671.
DOI: 10.1038/s41566-021-00818-7