Optical circuit enables new approach to quantum technologies

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Professor Jeremy O'Brien, Director of the University of Bristol's Centre for Quantum Photonics, and his Japanese colleagues have demonstrated a quantum logic gate acting on four particles of light -- photons. The researchers believe their device could provide important routes to new quantum technologies, including secure communication, precision measurement, and ultimately a quantum computer -- a powerful type of computer that uses quantum bits (qubits) rather than the conventional bits used in today's computers.

Unlike conventional bits or transistors, which can be in one of only two states at any one time (1 or 0), a qubit can be in several states at the same time and can therefore be used to hold and process a much larger amount of information at a greater rate.

"We have realised a fundamental element for processing quantum information—a controlled-NOT or CNOT gate—based on a recipe that was theoretically proposed 10 years ago," said Professor O'Brien. "The reason it has taken so long to achieve this milestone is that even for such a relatively simple circuit we require complete control over four single photons whizzing around at the speed of light!"

The approach taken by Professor O'Brien and his colleagues combined several methods for making optical circuits that must be stable to within a fraction of the wavelength of light, that is, nanometres. In 2001 optical quantum computing became possible when a theoretical recipe for realising this CNOT gate, as well as the other necessary components, was developed. However, the technological challenges associated with making the optical circuits have prevented its realisation until now. The implications for this new approach are far-reaching.

"The ability to implement such a logic gate on photons is critical for building up larger scale circuits and even algorithms," said Professor O'Brien. "Using an integrated optics on a chip approach that we have pioneered here at Bristol over the last several years will enable this to proceed far more rapidly, paving the way to quantum technologies that will help us understand the most complex scientific problems."

In the short term, the team expect to apply their new results immediately for developing new approaches to quantum communication and measurement and then for simulation tools in their lab. In the longer term, a small-scale quantum simulator based on a multi-photon optical circuit could be used to simulate processes which themselves are governed by quantum mechanics, such as superconductivity and photosynthesis. "Our technique could improve our understanding of such important processes and help, for example, in the development of more efficient solar cells," said Professor O'Brien. Other applications include the development of ultra-fast and efficient search engines, designing high-tech materials and new pharmaceuticals.

The leap from using one photon to two photons is not trivial because the two particles need to be identical in every way and because of the way these particles interfere, or interact, with each other. There is no direct analogue of this interaction outside of quantum physics.

"Now that we can implement the fundamental building blocks for quantum circuits, the move to a larger scale devices will become our focus. Because of the increasingly complexity the results will be just as exciting" said Professor O'Brien. "Each time we add a photon, the complexity of the problem we are able to investigate increases exponentially, so if a one-photon quantum circuit has 10 outcomes, a two-photon system can give 100 outcomes and a three-photon system 1000 solutions and so on."

The Centre for Quantum Photonics now plans to use their chip-based approach to increase the complexity of their experiment not only by adding more photons but also by using larger circuits.

The research is published in *Proceedings of the National Academy of Sciences.*

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