PHOTONIC QUBITS

A quantum delivery note

A technique for detecting the presence of a photon without destroying the quantum message it carries could ultimately lead to a loophole-free test of quantum non-locality.

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When a courier arrives and we are not at home, he will leave a note at the door. Discovering this note can be frustrating: it means we will have to stay at home the next day, or drive across town to pick up our letter. But it would be even more frustrating if the driver was in the habit of opening the envelope and reading the contents, or simply dumping it into the nearest garbage bin. This scenario is typical, however, for messages transmitted via quantum-communication channels. These messages consist of qubits carried by single elementary particles of light — photons — and encoded in their physical properties, for example, the polarization state. So far, the only way to detect the presence of a photon has been by destroying it.

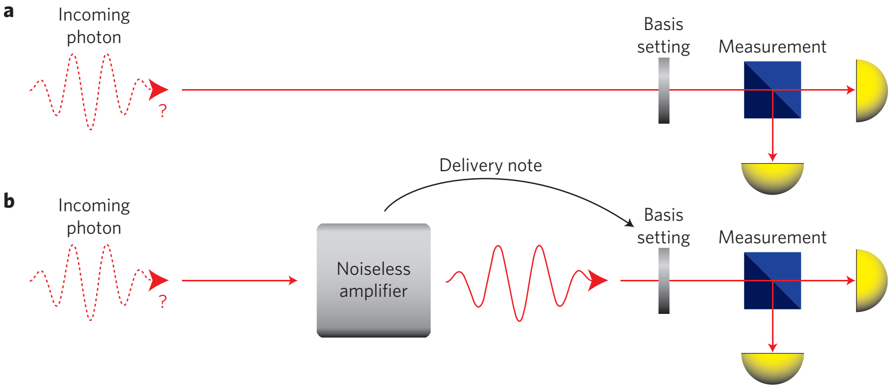

Figure 1 | The ‘quiet’ amplifier. **a**, The traditional approach to measuring photon polarization involves a random selection of basis settings. **b**, A noiseless amplifier, however, provides advanced warning that a photon is on its way.

Now, reporting in *Nature Physics*, Sacha Kocsis and his co-workers[1] present a proof-of-principle demonstration of a linear-optical circuit that heralds the arrival of a photon while preserving the quantum information it carries. Their technique involved subjecting both the vertical and horizontal polarization components of the incoming light to so-called noiseless amplification — a modified quantum-teleportation scheme that transfers the qubit encoded in these components onto another photon prepared elsewhere. Although the process destroys the original photon, its arrival is heralded with a classic ‘click’.

Unlike people, photon detectors do not leave home and are always ready for action — so why would they need a delivery note? The reason is that in many quantum-communication protocols the receiving party chooses its detection-basis setting randomly for each incoming photon (Fig. 1). Incorporating the ‘delivery note’ into the protocol enables one to postpone the choice until it is certain that the photon has arrived. This apparently minor detail opens up many new possibilities.

One of them is a realistic prospect of a long-awaited loophole-free test of quantum non-locality. Existing optical Bell inequality tests have been inconclusive because most photons are lost on their way from the entangled source to two spatially separated parties, Alice and Bob. Playing devil’s advocate, one could argue that the loss of each photon is not random, but somehow influenced by Alice and Bob’s detection settings, and then build a local realistic model based on this assumption[2]. But if Alice and Bob are in possession of noiseless amplifiers, they can set their detectors after receiving their delivery notes. Then, provided that no additional losses occur within Alice’s and Bob’s apparata, the detection loophole is closed.

From a practical rather than philosophical perspective, a loophole-free non-locality test could also help achieve the ultimate level of security in quantum key distribution (QKD). Existing implementations of QKD are reliant on the assumption that the photon emitters and detectors operate in accordance with their theoretical ideal behaviour. A cunning eavesdropper may be able to tamper with these devices or use their imperfections to break the encryption[3]. However, if the channel connecting Alice and Bob is capable of generating a dataset that violates the Bell inequality in a loophole-free fashion, its security is guaranteed by fundamental causality — that is, it becomes independent of scientific or technological principles on which their equipment operates[4].

The idea of noiseless amplification was proposed and implemented in 2010[5] by the same research group who performed the present experiment. In that study, a superposition of the single-photon and vacuum states was ‘amplified’, in a probabilistic fashion, to increase the single-photon fraction. The original study was limited to a single optical mode and initially attracted attention primarily as an interesting observation that “the quantum noise associated with linear phase-insensitive amplifiers can be avoided by relaxing the requirement of a deterministic operation”[6]. However, only a few months later, another team of researchers noticed that applying the noiseless amplifier to two optical modes carrying a qubit facilitates device-independent QKD[7]. The device presented by Kocsis *et al.*[1] is largely a realization of this scheme.

Although the circuit is, as the authors themselves put it, “a major breakthrough in the amplification of quantum states”, it cannot yet be viewed as a plug-and-play appliance that would instantly boost the security of the quantum-communication terminal in your office. The delivery note generated by the device does not guarantee the delivery of the photon, but only increases its probability by up to a factor of five (from about 0.04 to 0.2)[1]. A fundamental limitation on this probability is imposed by the quantum efficiency of the ancillary single-photon sources used in the circuit[8]. Further detrimental effects on the fidelity of the protocol arise from potential multiphoton components contained in the initial state and the ancillary photons. Theoretical research is underway to mitigate these effects, and some promising ideas have already been announced[9,10]. ☐

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ASTRONOMY

Three for two

Wide binary-star systems — in which the stars are separated by at least 1,000 times the Earth–Sun distance — are challenging both to identify and to understand. Many binaries also have a third companion. For example, the reflection nebula DG 129 in Scorpius, pictured here, contains Pi Scorpii (on the right, appearing as one star at this resolution) — a young triple system with close binaries and a distant companion. Polaris is also a triple-star system. Bo Reipurth and Seppo Mikkola propose that wide binaries in fact originate from triple-star systems (*Nature* **492,** 221–224; 2012).

Given that some wide binaries lie as much as 100,000 Earth–Sun distance units apart, how do we know when two stars are binaries as opposed to 'optical doubles' that are totally unrelated but for their chance positions along the optical axis of the observer? Surveys of binary stars use one of two methods: either statistical analysis of the number excess of neighbours around a candidate star as compared with a random distribution; or measurement of the common proper motion of two well separated stars (the proper motion of a star is its true motion relative to other stars, such as the Sun). A study of excess neighbours concluded that 8.3% of the main sequence stars around the Northern Galactic Pole are wide binaries (M. Longhitano and B. Binggeli *Astron. Astrophys.* **509,** A46; 2010), which is consistent with a prior estimate of 9.5% using proper motion analysis (S. Lépine and B. Bongiorno *Astrophys. J.* **133,** 889; 2007).

Why are wide binaries so common? There's evidence that the stars form as small multistar systems. Focusing specifically on the evolution of newborn triple systems in a gravitational potential, Reipurth and Mikkola run *N*-body simulations — 180,218 of them to be exact — and find that 7.6% of them form stable hierarchical systems, consistent with the surveys above. There are also systems that are unstable yet bound, and disrupted systems with hyberbolic outer orbits. Stable systems tend to have a dominant single star and are well separated; dominant binaries would more easily perturb a light third star and lead to disruption.

Over a timescale of 100 million years, the authors show, most of the unstable systems break up. Although the number of stable triple systems stays roughly constant, they slowly 'unfold'. The systems are thus protected from disruption by passing stars during their 'infancy' as it takes tens and hundreds of millions of years for them to reach extreme length scales. The ejection of the single star to a wider orbit brings the binaries closer together, so that the triple system appears as a wide binary from afar.

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