Experimental implementation of efficient linear optics quantum computation

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"How does one build a quantum computer?" has been identified as one of ten outstanding questions in physics of tremendous interest.[1] However the realisation of such a device has implications reaching far beyond the domain of physics. A quantum computer offers an exponential increase in computational power for particular tasks, and the possibility to simulate quantum mechanical systems – of great importance to the development of new materials. The study of quantum information has also provided great insight into the fundamental nature of quantum mechanics and will continue to do so.

While the most advanced prototype quantum computers have been demonstrated in nuclear magnetic resonance and ion trap systems, it is widely believed that such systems cannot be scaled beyond a modest number of qubits. Much attention has therefore turned to solid state proposals with their promise of inherent scalability. However, Knill, Laflamme and Milburn (KLM) have recently shown that efficient (ie scalable) linear optics quantum computation (ELOQC) is possible using only single photon sources, passive linear optical elements and photodetectors.[2]

A quantum bit (or qubit) is a two level quantum system that is the building block of a quantum computer. Photons make attractive qubits since they are easy to produce and manipulate, and are well isolated from the environment. Consequently, they have been widely used in quantum cryptography, where only single qubit operations are required. Unfortunately, quantum computation requires two qubit interactions, which are very difficult to realise between photons. The KLM scheme overcomes this problem by using the non-linear nature of measurement.

A significant simplification of the original scheme has been developed,[3] along with a detailed strategy for an experimental demonstration.[4] Together with single qubit rotations, a controlled not (CNOT) gate forms a universal set of gates for quantum computation. We describe an experimental test of ELOQC which involves the construction of a probabilistic CNOT gate requiring only a two photon source, as illustrated in Fig. 1. For qubits we use the horizontal (H) and vertical (V) polarisation state of photons generated through spontaneous parametric down conversion in a β-barium borate (BBO) crystal. A 130 mW pump beam at 351.1 nm produces pairs of "daughter" photons at 702±2.5 nm at a rate of ~30 000 s^{-1}.

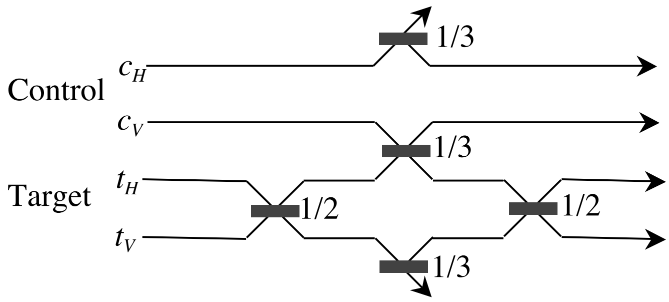

Fig 1. A schematic of the CNOT gate where the beamsplitter reflectivities are indicated. In this dual rail logic notation c_H and c_V are the two bosonic mode operators for the control qubit, and t_H and t_V those for the target.

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