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Quantum logic using photon-exchange interactions

J.D. Franson, T.B. Pittman, *Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20723; E-mail: franson@jhuapl.edu*

Nonlinear optical effects at the two-photon level are usually negligible because of the weak electric field associated with a single photon. In addition, conventional mechanisms for the production of nonlinear phase shifts require both photons to interact with the same atom, which is unlikely to occur in an ordinary medium containing a large number of atoms. Although nonlinear phase shifts of this kind can be enhanced using cavity QED or electromagnetically induced transparency (EIT), we are investigating a new approach that is based on the use of photon-exchange interactions.[1] In this approach, a state containing two excited atoms in the medium could have been produced in two different ways: Photon 1 may have excited atom A while photon 2 excited atom B, or photon 1 may have excited atom B while photon 2 excited atom A. Under the appropriate conditions, constructive interference between these two processes can produce a factor of two enhancement in the probability of there being two excited atoms, which in turn can produce a nonlinear phase shift if a suitable sequence of laser pulses is applied to the medium while the photons are contained within it.

A more detailed theoretical analysis has now been performed that includes all of the modes of the electromagnetic field. Raman transitions are used to induce the absorption of a photon and the creation of a superposition of excited atomic states (a Dicke state). The absorption of two photons into the same superposition of atomic states occurs at a rate which is twice as large as the rate for a single photon in the medium. This gives rise to a nonlinear dependence of the response of the medium to a sequence of laser pulses and a corresponding nonlinear phase shift that can be used to implement quantum logic operations. We have recently developed a simple sequence of three laser pulses that can be used to generate a nonlinear phase shift of 180 degrees for a two-photon state. A similar approach based on the use of Stark shifts rather than Raman transitions will also be described. The preliminary results of an on-going experimental investigation will be presented.

1. J.D. Franson and T.B. Pittman, Phys. Rev. A **60,** 917–936 (1999).