Optical CV quantum information

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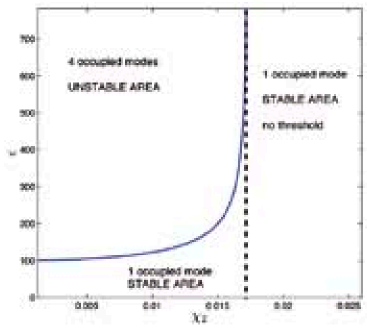
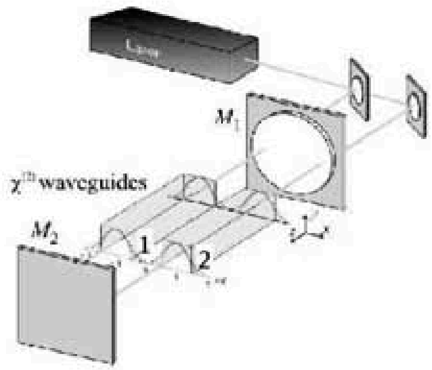
We have continued with this research, studying entanglement and states which exhibit the Einstein-Podolsky-Rosen (EPR) paradox, both central to quantum mechanics [1]. We have investigated both bipartite and tripartite entanglement, publishing an overview of our previous work [2]. The new systems we have investigated are combined downconversion and sum frequency generation [3], the quantum optical dimer [4], and sum frequency generation [5]. We have continued our collaborations with the experimental group of Olivier Pfister in the USA and one of us gave a lecture course at the Università dell'Insubria in Italy as part of their distinguished visiting professor program.



The first process [3] exhibits previously unknown stability properties and has three distinct operating regimes. There are three outputs, with the χ_1 nonlinearity responsible for downconversion of ω_0 pump photons to ω_1 and ω_3 and χ_2 combining ω_3 with ω_0 to produce ω_2. The figure shows the stability properties with $\chi_1 = 0.01$, cavity loss rates $\gamma_0 = \gamma_1 = \gamma_3 = 1$, and $\gamma_2 = 3$, as χ_2 and the pump amplitude are varied. The dashed line separates the regimes with and without threshold. We found that this system does produce tripartite entanglement, but in an asymmetric way.

The quantum optical dimer consists of two evanescently coupled nonlinear media inside a Fabry-Perot, as shown in the figure below.



In our work on this we showed that a demonstration of the EPR paradox is equal to a demonstration of bipartite entanglement. The cavities are pumped at a fundamental frequency and light at the harmonic frequency is produced by the nonlinear media. Under the appropriate conditions, bipartite entanglement at both frequencies is produced. This system has the advantages that it is modular and can be tuned by varying the cavity detunings, mirror losses and pumping rates. It may therefore be a good candidate, along with other nonlinear couplers, for the exhibition of asymmetric steering [6].

We have analysed sum frequency generation in terms of its ability to entangle modes at very different frequencies, which may have applications in quantum communication and teleportation. We found that, even though this process is used in many applications, very little was known about the quantum properties once it is enclosed in an optical cavity. We discovered that there is a threshhold above which nondegenerate downconversion becomes the dominant process, and that this system can also exhibit asymmetric steering.

References

[1] S.L. Braunstein and A.K. Pati, *Quantum Information with Continuous Variables* (Kluwer Academic, Dordrecht, 2003).
[2] M.K. Olsen, A.S. Bradley and M.D. Reid, Opt. Spec. **103**, 195 (2007).
[3] C. Pennarun, A.S. Bradley and M.K. Olsen, Phys. Rev. A **76** 063812 (2007).
[4] M.J. Mallon, M.K. Olsen and M.D. Reid, J. Phys. A **41**, 015501 (2007).
[5] M.K. Olsen and A.S. Bradley, *in press*, Phys. Rev. A.
[6] H.M. Wiseman, S.J. Jones and A.C. Doherty, Phys. Rev. Lett. **98**, 140402 (2007).