ABSTRACT

Entanglement is a fundamental feature of quantum mechanics which originated from the 1935 paper of Einstein, Podolsky and Rosen (EPR) and has been demonstrated in many quantum systems for development of quantum technology. Entanglement of photons occurs through polarization states generated in nonlinear parametric processes. The Optical parametric oscillator (OPO) constitutes a nonlinear process in which a pair of entangled photons (signal and idler) is generated when a light mode from a laser source (photon pump) interacts with atoms in a non-linear crystal lattice. Entanglement has been demonstrated in the above-threshold and below-threshold OPO both theoretically and experimentally through analytical and numerical solutions of time evolution equations. This has been achieved using adiabatic approximation methods, Van Loock-Furusawa criterion, equivalent Langevin equations used in Wigner representation and stochastic equations used in positive P representation. Both methods do not show how entanglement varies with time and do not involve polarization state dynamics under all conditions of interaction. The aim of the study is to demonstrate the dynamical evolution of continuous variable entanglement in a semi-classical OPO using general time evolving polarization state vectors arising from exact analytical solutions of Heisenberg's equations of the system through violation of Bell inequalities, under all conditions of interaction with frequency detuning. The objectives of the study are: to; obtain exact solutions of Heisenberg's equations to determine the time evolution operator and time evolving polarization state vectors of signal and idler photons; construct the Bell state vectors using the general time evolving polarization state vectors of signal and idler photons, and; test entanglement of polarization states of the signal-idler photon pair arising from the semi-classical OPO, under all conditions of interaction. We use Heisenberg's equations and matrix method to solve time evolution equations for the Hamiltonian of the model. The Bell state vectors are constructed using general time evolving polarization state vectors and entanglement is tested by use of reduced density matrices and Bell inequalities. We observe that the semi-classical OPO is a suitable tool for demonstration of dynamical evolution of entanglement of polarization bell state vectors under all conditions of interaction using exact solutions of Heisenberg's equations and form reduced density matrices which produce a greater violation of CHSH Bell's inequality beyond the Cirel'son's inequality. This study is significant in providing appropriate and elaborate way of displaying entanglement in the semi-classical OPO and widens the scope for implementation of various quantum key communication protocols such as quantum teleportation, quantum key distribution, and dense coding.