Step by step engineered entanglement with atoms and photons in a cavity

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Entanglement is a central feature of quantum theory, which characterizes composite systems made of spatially separated parts. After having interacted, quantum particles remain generaly connected at a distance by immaterial links which can be used to process information in non-classical ways. Cryptography, teleportation and other simple quantum logic operations can be performed with entangled states involving a few particles. Even if most practical applications seem still remote, the language and ideas of quantum information processing have already proven to be very useful and very efficient tools to understand and formulate in a deep and precise way fundamental concepts in quantum theory.

All quantum information processing experiments rely on the ability to engineer and manipulate in a controlled way entangled states of several particles. So far, this goal has been achieved with twin-photon beams produced in downconversion processes, with ion traps and with atom-cavity experiments. At Ecole Normale Superieure in Paris, we perform cavity quantum electrodynamics experiments with circular Rydberg atoms sent one at a time through a high Q cavity containing a field made of zero or one microwave photon in a well defined quantum state. Classical pulses applied on the atoms before and after their interaction with the quantum field allow us to perform preset unitary transformation on them. Quantum Rabi pulses corresponding to a coherent exchange of energy between atoms and cavity photons provide the essential tool to realize engineered atom-photon and atom-atom entanglement.

Combining classical and quantum Rabi pulses of various durations, we have performed two particle entanglement experiments including quantum logic gate demonstrations and single photon quantum non-demolition measurements. We have very recently extended these manipulations to three particle systems, realizing a step by step controlled entangled state of the Greenberger-Horne-Zeilinger type, which involves two atoms and a zero or one photon state. The three components of this entangled state are finally separated by centimeter scale distances. We will describe these experiments and discuss their present limitations and expected improvements.