Conversion and storage of quantum states with orbital angular momentum in quantum memory scheme

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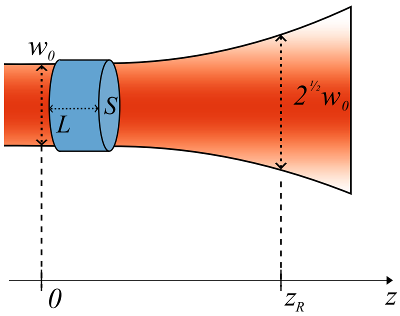
The study of quantum memory protocols to store the quantum-statistical properties of radiation is one of the priority areas of quantum optics and quantum computing since quantum memory is a significant part of many quantum computing schemes. The basic principle of quantum memory is based on various mechanisms of the interaction of light and matter [1, 2, 3]. Experimental implementations of devices for high-efficiency storage of quantum states are proposed [4].

In recent years, the possibility of not only storing but also converting a signal on memory cells has been actively discussed. An important requirement for the conversion protocols is a feasibility of the efficient writing of a multimode signal. The works [5, 6] are dedicated to the storage and shaping of various time and, respectively, spatial profiles of the quantum field. The storage of individual Hermite–Gaussian [7] and Laguerre–Gaussian [8] modes on ensembles of cold atoms was experimentally demonstrate. But no theoretical analysis of the storage and conversion of such modes on a memory cell was performed.

The Laguerre–Gaussian modes are of particular interest, because, as shown in [9], they have a certain orbital angular momentum (OAM). Such states can be used as a resource for constructing multipartite entangled states since they form an infinite-dimensional basis of a Hilbert space.

In our work, we are based on the protocol of Raman memory on cold atoms, described in [10, 11]:



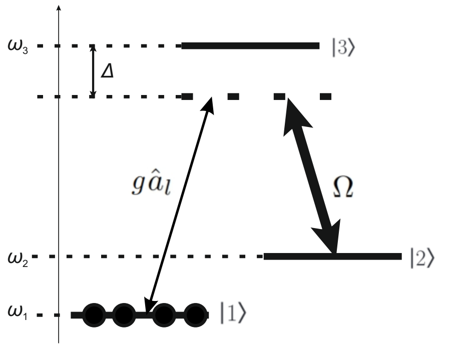


Figure 1: A cell with a cloud of cold atoms represented as a cylinder with a length of L and a transverse area of S.

We use the developed approach to the problem of conservation and transformation of the Laguerre–Gaussian modes. We demonstrate that it is possible to perform both storage and conversion of a quantum field varying the spatial profile of the driving field. In the storage case, we use plane waves as driving fields at both writing and readout stages to store and subsequently retrieve quantum-statistical properties of the field to the initial OAM mode. In the conversion case, Laguerre–Gaussian driving field is used on one of the stages (writing or readout) and the plane wave is used on another. This configuration of the driving fields we perform the retrieval of the quantum field from memory cell to another spatial mode with the OAM that differs from the OAM of the input field. The OAM of the quantum field could be changed significantly during the transformation (depending on the OAM of the control field). The appropriate choice of the geometric parameters of the fields allows for achieving high conversion efficiency.

The proposed protocol can also be widely used in quantum computations and quantum communication schemes, as it allows the use of quantum memory not only as a passive element of quantum computing schemes but also as a logic gate that implements the conversion of a quantum field.

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