Slow and stored light using Rydberg atoms

J. Ruseckas[1], I. A. Yu[2], and G. Juzeliūnas[1]

[1]Institute of Theoretical Physics and Astronomy, Vilnius University, Saulėtekio ave. 3, LT-10257 Vilnius, Lithuania
[2]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

Atoms excited to high-lying Rydberg states with a principal quantum number *n* above 50 have recently attracted a significant attention [1]. The strong interaction between the Rydberg atoms has been used in quantum information processing [2], studies of interacting many-body systems [3] as well as non-linear quantum optics for slow light at the level of individual quanta [4–7]. This is achieved by coherently coupling slowly propagating photons to strongly interacting atomic Rydberg states under the conditions of the electromagnetically induced transparency (EIT) [4]. In a usual Rydberg EIT, a ladder atom-light coupling configuration is typically employed involving an atomic ground state, an intermediate excited state and a Rydberg state. Here we propose to use a more complicated double tripod level scheme. In the double tripod scheme two probe laser fields are propagating inside the atomic medium leading to a two component (spinor) slow light, which has been recently demonstrated experimentally [8].

First, we present a method to create two-photon states in a controllable way using the interaction between Rydberg atoms. The main ingredient of the procedure is storage and retrieval of the slow light into two coherences of an atomic medium under conditions of EIT [8]. Interaction between the atoms during the storage period creates entangled pairs of atoms in a superposition state that is orthogonal to the initially stored state. Restoring the slow light from this new atomic state one can produce a two-photon state with the second-order correlation function determined by the atom-atom interactions and the storage time. In addition, measurement of the restored light allows one to probe the atom-atom coupling by optical means, with the sensitivity that can be increased by increasing the storage time.

Subsequently we investigate Rydberg EIT involving the double tripod level scheme. In comparison to previously used schemes for quantum nonlinear optics with Rydberg states, the double tripod scheme can combine spin-orbit coupling for the spinor slow light with an interaction between photons. In a ladder atom-light coupling configuration the interaction is always attractive independent from the detuning [7]. In contrast, in the proposed scheme the interaction can become repulsive if the one-photon detunings have opposite signs.

[1] M. Saffman, T. G. Walker, and K. Mølmer, Rev. Mod. Phys. **82**, 2313 (2010).
[2] E. Urban *et al.*, Nat. Phys. **5**, 110 (2009).
[3] P. Schauss *et al.*, Science **347**, 1455 (2015).
[4] D. Petrosyan, J. Otterbach, and M. Fleischhauer, Phys. Rev. Lett. **107**, 21360 (2011).
[5] A. V. Gorshkov *et al.*, Phys. Rev. Lett. **107**, 133602 (2011).
[6] D. Chang, V. Vuletić, and M. D. Lukin, Nature Photonics **8**, 685 (2014).
[7] O. Firstenberg *et al.*, Nature **502**, 71 (2013).
[8] M.-J. Lee *et al.*, Nat. Commun. **5**, 5542 (2014).