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Strongly correlated photons in one-dimensional waveguides[1]

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One-dimensional waveguide naturally arises in nanophotonic systems. A line defect state in a photonic crystal with a complete band gap, for example, forms a true one-dimensional continuum of photons, since, within a certain frequency range, except for the guided modes, there are no other modes. To a great extent, all waveguides that are strongly confined, including high-index contrast dielectric nanowires, and plasmonic waveguides, can be well approximated as a one-dimensional system as well. Here we discuss a set of very unusual quantum optical effects, when a two-level atom is coupled to such a one-dimensional waveguide. We show that this system is described by a Hamiltonian that is an exact photonic analogue of the Anderson Hamiltonian in the infinite-U limit. Using this Hamiltonian, we show that a single photon injected into such a waveguide will be completely reflected on resonance by the two-level atom. In one-dimensional systems, therefore, one can use the spontaneous emission property of the atom, which was commonly thought of as a decoherence mechanism, to coherently control the transport properties of light. Moreover, we show that when two photons are incident, their transport properties become strongly correlated. We have developed a Bethe Ansatz technique to exactly solve for the transport properties of two photons in such a system. The theoretical predictions include the effects of single-photon switching, background fluorescence, as well as strong spatial attraction and repulsion of photons.

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