Quantum Nonlinear Optics Without Photons, How to Excite Two or More Atoms Simultaneously with a Single Photon, and Other Unusual Properties of Ultra-Strongly-Coupled QED Systems

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Spontaneous parametric down-conversion is a well-known process in quantum nonlinear optics in which a photon incident on a nonlinear crystal spontaneously splits into two photons.

Here we propose an analogous physical process where one excited atom directly transfers its excitation to a pair of spatially separated atoms with a probability approaching 1. The interaction is mediated by the exchange of virtual rather than real photons. This nonlinear atomic process is coherent and reversible, so the pair of excited atoms can transfer the excitation back to the first one: the atomic analogue of the sum-frequency generation of light. The parameters used to investigate this process correspond to experimentally demonstrated values in ultrastrong circuit quantum electrodynamics.

This approach can be extended to realize other nonlinear interatomic processes, such as four-atom mixing, and is an attractive architecture for realising quantum devices on a chip. We show that four-qubit mixing can efficiently implement quantum repetition codes and, thus, can be used for error-correction codes.

A few recent references (mostly 2016-2021) on this topic (ultra-strong coupling cavity QED) are listed below and freely available online at: http://dml.riken.jp/pub/Ultra-strong/

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