Cooperative transmission and manipulation of light in planar slabs and arrays of atoms

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Understanding strong cooperative optical responses in dense and cold atomic ensembles is vital for fundamental science and emerging quantum technologies. Methodologies for harnessing cooperative interactions and characterizing light-induced quantum effects in such systems, however, are still lacking. Here we analyze transmission of light through slabs and arrays of atoms using both semiclassical methods that neglect quantum fluctuations and full quantum simulations. We identify quantum effects and nonlinear semiclassical phenomena, such as optical phase transitions, optical bistability, and analogies to vacuum Rabi splitting of cavity quantum electrodynamics. A crucial limitation for utilizing atoms as optical media is the inability of light to couple to atoms using both its electric and magnetic components that has led to the development of metamaterials. We show how to synthesize cooperative optical responses that correspond to those formed by arrays of magnetic dipoles and other multipoles, providing strong magnetic responses of atomic ensembles at optical frequencies.