Ghost exchange: Ferromagnetic-antiferromagnetic phase transition in linear optics of non-magnetic dielectrics

Evgenii Narimanov and Emroz Khan

Purdue University, 465 Northwestern Ave, West Lafayette, USA

While there exist many photonic equivalents for the physics originally associated with electronic systems, from Anderson localization [1] to Berezenskii-Kosterlitz-Thouless transition,[2] none of them operating in the linear regime offers the possibility of sign reversal of the exchange interaction inherent to strongly correlated interacting electronic systems. As a result, many exchange mediated phenomena of the condensed matter physics are currently beyond the reach of a linear photonic platform.

Here we break through this obstacle by mapping the effective Hamiltonian for the electronic exchange interaction to that of coupled optical modes, using the oscillatory properties of the recently discovered ghost coupling.[3] In particular, the propagating waves in a dielectric photonic crystal formed by alternating layers of biaxially anisotropic and high-index isotropic dielectric materials, satisfy the same Hamiltonian dynamics as the spins in the linear Ising models. Here, the effective Ising spin of the photonic system is defined as the corresponding (real) amplitude in the electromagnetic Bloch function, with the effective Ising Hamiltonian arising from the standard tight-binding expansion of the underlying wave equation.

With such mapping to the exchange-interaction mediated Ising spin chain, the lowest-frequency photonic guided mode corresponds to the ground state of strongly correlated spin system – and naturally shows the resulting “ferromagnetic”, “anti-ferromagnetic” - and “paramagnetic” states in the system’s phase diagram, as well as the corresponding phase transitions.

To conclude, with the recent discovery of the electromagnetic ghost waves, we established an exact correspondence between the linear electromagnetic wave propagating in biaxial dielectric composite materials, and the dynamics of strongly interacting electronic systems and their associated phase transitions. As ghost waves, have already been demonstrated in experiment [8], this brings many phenomena that were so far limited to electronic condensed matter physics, within the reach of practical photonics.

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