Surprises in the modeling of quantum metamaterials

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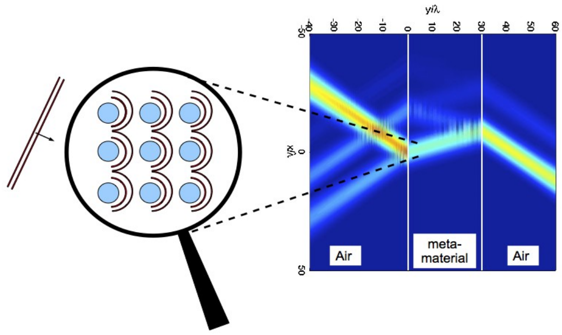

Fig. 1: Illustration of the behavior of a metamaterial. The metamaterial is heterogeneous, structured at a scale small compared to the wavelength of the incoming light. Nevertheless, it behaves as an homogeneous materials exhibiting unusual optical properties such as negative refraction.

Optical metamaterials are man-made materials exhibiting unusual optical properties. They behave as homogeneous materials (at least from some frequency ranges) whereas their optical properties arise from multiple scattering events *i.e.* from collective effects. This is illustrated in the Fig.1.

It has been suggested recently to introduce quantum emitters into metamaterials structures [1,2] in order to benefit from quantum effects to manipulate the propagation of light. As an example, quantum metamaterials could realized a photonics crystal with a band-gap that oscillates in time with the Rabi frequency of the quantum emitters[2].

Modeling quantum metamaterials starts with the choice of a hamiltonian that describes the quantum dynamics of the emitters and the electromagnetic field (modeled as a quantum object too). Although this seems as old as the quantum-optics theory itself, I will show that the choice of a hamiltonian to start with is not free of "surprises". I will explain that a result as old as the Power-Zienau-Woolley hamiltonian[3], intensively used to model the interaction of the quantum electromagnetic-field with matter, is actually not correct [4]. Indeed, I will show that it breaks the gauge-independence of the electromagnetic field and explain the consequences at the quantum level of the breaking of the gauge-independence.

References

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