Scaling analysis of localization transition for light in a 3D atomic system

Sergey E. Skipetrov

Laboratoire de Physique et Modélisation des Milieux Condensés, Université Grenoble Alpes & CNRS, 25 Avenue des Martyrs, Grenoble, France

A wave propagating in a disordered medium can be blocked due to strong scattering by heterogeneities of the medium—a phenomenon known as Anderson localization and first discovered for electrons in disordered conductors at low temperatures. In a three-dimensional (3D) disordered medium, a transition from spatially extended to localized eigenmodes takes place when disorder is increased. This Anderson localization transition is believed to exist for all types of quantum or classical waves (matter waves, light, sound, etc.). It is characterized by a critical exponent $\nu$ describing the divergence of the localization length $\xi$ at the critical point $\omega_c$: $\xi = |\omega - \omega_c|^{-\nu}$, where $\omega$ is the parameter that drives the transition (e.g., frequency or scatterer density). The value of $\nu$ depends on the macroscopic symmetries present in the disordered system (e.g., time-reversal symmetry, etc.) and its dimensionality $d$.

We have recently shown that optical modes of an ensemble of two-level atoms randomly distributed in 3D space are always extended, whatever the atomic number density [1], except if the atoms are placed in a strong external magnetic field (see Fig. 1) [2]. In the latter case, several factors such as the disorder in atomic positions, the dipole-dipole coupling between nearby atoms, and the anisotropy of the atomic medium induced by the magnetic field, can influence the nature of the localization transition that may be not necessary of Anderson type anymore.

In the present work, we report a finite-size scaling analysis of the localization transition in a random 3D ensemble of two-level atoms in an external magnetic field. Our approach is based on the analysis of percentiles $g_q$ of Thouless parameter $g$ and has been previously tested on the case of scalar waves [3]. We demonstrate the single-parameter scaling of $g_q$ for small $q$ (see Fig. 2) and estimate the critical exponent of localization transition $\nu = 1.42 \pm 0.04$ [4]. This value is compatible with Anderson transition of the 3D unitary universality class, suggesting that the optical localization transition under study is equivalent to the one expected for spinless electrons in the absence of time-reversal symmetry. We propose an experiment to observe the predicted transition [5].

---

4. S.E. Skipetrov, in preparation