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Localization of Light in 3D by Point Scatterers

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A popular model to study the multiple scattering of waves in disordered media is the point-scatterer model in which resonant point scatterers (impurities) are randomly distributed in space with a uniform average density [1]. This model can be experimentally realized for light scattering by cold atoms [2]. It turns out, however, that Anderson localization of light in 3D cannot be achieved in this model because of near-field dipole-dipole interactions between scatterers – a phenomenon specific for light and absent for scalar waves (Schrödinger waves, sound) or vector elastic waves [3].

Dipole-dipole interactions can be partially suppressed by applying a strong external static magnetic or electric field [4–6]. In this case, the optical coupling between two atoms at a distance r reduces to [6]

$$G = \pm \frac{e^{ik_0 r}}{k_0 r} \left\{ \alpha_{\text{far}}(\theta) + \alpha_{\text{near}}(\theta) \left[\frac{i}{k_0 r} - \frac{1}{(k_0 r)^2} \right] \right\}, \quad (1)$$

where $\alpha_{\text{near}}(\theta)$ quantifies the strength of near-field coupling depending on the angle θ between the vector \mathbf{r} and the external field. Spatially localized states appear in the system only when the magnitude of $\alpha_{\text{near}}(\theta)$ is small (see Fig. 1) [6].

Another way to reduce the near-field coupling is to arrange scatterers in a regular structure – a photonic crystal – where no two atoms are closer than some minimal distance r_{min} . Weak disorder introduces localized states near band edges of the crystal as predicted earlier [7]. The critical properties of the associated localization transition bear signatures of the interplay between the band structure, the disorder, and the dipole-dipole coupling [8].

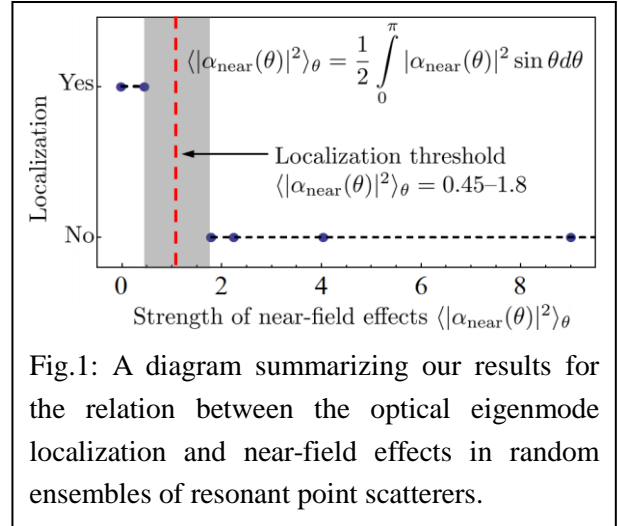


Fig.1: A diagram summarizing our results for the relation between the optical eigenmode localization and near-field effects in random ensembles of resonant point scatterers.

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