Dynamics of Light in Strongly Scattering Random Media: Breakdown of Diffusion, Anderson Localization and Random Lasers

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Disordered materials have considerable potential for the nonlinear optical [1] and laser [2] technologies. Meanwhile, the effect of disorder on the propagation of light is still not completely understood, even in the linear, passive media. The least explored and, at the same time, the most interesting phenomena occur for large, strongly disordered samples: Similarly to electrons in disordered metals, electromagnetic waves are expected to be trapped by disorder that prohibits any propagation, the phenomenon known as the Anderson localization.

The regime of light propagation in a disordered sample (single scattering, diffusion, or localization) can be probed by sending into the sample a short light pulse and by studying the intensity $I(\mathbf{r},t)$ of light transmitted through the sample. For long times, where localization effects are expected to show up, a complete statistical description of $I(\mathbf{r},t)$ is not available. We present a mathematically simple and physically transparent theoretical approach [3,4] that allows us to describe the average intensity $\langle I(\mathbf{r},t)\rangle$ and the correlation function $\langle I(\mathbf{r},t)I(\mathbf{r}_1,t_1)\rangle$ for times up to the so-called Heisenberg time, which is the time it takes a photon to visit the whole sample. We show that the localization effects grow in magnitude linearly with time and hence may be of importance even in nominally diffusing (i.e. weakly scattering) samples. Our results have a pictorial interpretation in the framework of path picture of wave propagation: The probability that two paths cross inside the sample grows linearly with path length (and hence with time), and becomes of order unity for times of the order of the Heisenberg time, leading to a breakdown of the diffusion picture of light propagation beyond the Heisenberg time.

Our results may be of particular importance in the context of recent achievements in the filed of "random lasers", lasers with the feedback provided by the multiple scattering [2]. The lasing threshold of a random laser is determined by the quasi-modes that have the smallest losses (i.e. the longest life times), and it is the same modes that determine the long-time behavior of intensity transmitted through the random sample in the absence of pump.

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2. D. Wiersma, *Nature* **406,** 132 (2000).
3. S.E. Skipetrov and B.A. van Tiggelen, *Phys. Rev. Lett.* **92,** 113901 (2004).
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