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Radiative Transfer Theory for Low-Dimensional Multiple Scattering Systems

K. van Wijk (1) and M. Haney (2)

(1) Physical Acoustics Laboratory and Department of Geophysics, Colorado School of Mines, Golden CO 80401, USA (kasper@acoustics.mines.edu), (2) Geophysics Department, Sandia National Laboratories, Albuquerque NM 87185-0750, USA

We present an overview of our efforts in understanding multiple scattering in low-dimensional systems within the framework of radiative transfer (RT) theory. In a layered medium with general scattering and directional properties of a one-dimensional (1D) source, RT predicts that in strongly scattering media the wavefield breaks into a coherent, or wave-like, part and an incoherent, or diffusive, flow. The applicability of RT in finite 1D media can be explained via previously unknown connections between the applicability of RT in layered media and wavefield quantities known as propagation invariants. These propagation invariants form the basis of methods for Green function retrieval between receivers in disordered media. Numerical experiments confirm that the intensity flux, instead of the total intensity, is accurately modeled by RT everywhere in the 1D medium. While in layered media the intensity flux is a propagation invariant, the total intensity is prone to the interference effects that give rise to localization.

For 1D point scatterers, or thin beds, we derive the equivalence of the exponential decay of the transmitted wave predicted by the O'Doherty-Anstey formula with the coherent wave obtained from RT. The equivalence shows an underlying relationship between RT and mean field theory. Finite-difference simulations of the scalar and elastic wave equation with randomly placed thin beds reveal the diffusive behavior of the incoherent energy at late times, and the partition of P- and S-wave energy as predicted by RT. Ultrasonic multiple scattering measurements are described by RT over the entire range of times—from ballistic to diffusive energy propagation, allowing us to retrieve the scattering and absorption mean free paths independently, in a quasi-1D geometry.