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Preface: Mesoscopic Methods in Engineering and Science

Matter, conceptually classified into fluids and solids, can be completely described by the microscopic physics of its constituent atoms or molecules. However, for most engineering applications a macroscopic or continuum description has usually been sufficient, because of the large disparity between the spatial and temporal scales relevant to these applications and the scales of the underlying molecular dynamics. In this case, the microscopic physics merely determines material properties such as the viscosity of a fluid or the elastic constants of a solid. These material properties cannot be derived within the macroscopic framework, but the qualitative nature of the macroscopic dynamics is usually insensitive to the details of the underlying microscopic interactions.

The traditional picture of the role of microscopic and macroscopic physics is now being challenged as new multi-scale and multi-physics problems begin to emerge. For example, in nano-scale systems, the assumption of scale separation breaks down; macroscopic theory is therefore inadequate, yet microscopic theory may be impractical because it requires computational capabilities far beyond our present reach. This new class of problems poses unprecedented challenges to mathematical modeling as well as numerical simulation and requires new and non-traditional analysis and modeling paradigms. Methods based on mesoscopic theories, which connect the microscopic and macroscopic descriptions of the dynamics, provide a promising approach. They can lead to useful models, possibly requiring empirical inputs to determine some of the model parameters, which are sub-macroscopic, yet indispensable to the relevant physical phenomena. The area of complex fluids focuses on materials such as suspensions, emulsions, and gels, where the internal structure is relevant to the macroscopic dynamics. An important challenge will be to construct meaningful mesoscopic models, by extracting all the macroscopically relevant information from the microscopic dynamics.

There already exist mesoscopic methods such as the Lattice Gas Cellular Automata (LGCA), the Lattice Boltzmann Equation (LBE), Discrete Velocity Models (DVM) of the Boltzmann equation, Gas-Kinetic Schemes (GKS), Smoothed Particle Hydrodynamics (SPH), and Dissipative Particle Dynamics (DPD). Although these methods are sometimes designed for macroscopic hydrodynamics, they are not based upon the Navier–Stokes equations; instead, they are closely related to kinetic theory and the Boltzmann equation. These methods are promising candidates to effectively connect microscopic and macroscopic scales and thereby substantially extend the capabilities of numerical simulations. For this reason, they are the focus of the International Conference Series on Mesoscopic Methods in Engineering and Science (ICMMES, http://www.icmmes.org).

The inaugural ICMMES Conference was held at the Technical University of Braunschweig, Germany, July 25–30, 2004. This special issue of the *Journal of Statistical Physics* devoted to this conference includes 16 papers, most of them concerning the Lattice Boltzmann Equation (LBE). The papers cover recent advances in the theory, analysis, modeling, and applications of the LBE method. The maturity of the LBE method is attested by the gradual replacement of heuristic approaches by rigorous mathematical analysis and the clarification of the connection between the LBE and kinetic theory. The papers on modeling include the formulation of new models for ferrofluids, thermo-hydrodynamics and a Voronoi model for inviscid fluids. The most rapid developments have occurred in applications of the LBE method to new classes of problems. This broadening of the application of LBE is reflected in the special issue through papers on LBE applications to complex fluids. These include suspensions, interfacial phenomena, non-Newtonian fluids, and microfluidics. Other papers presented during ICMMES-2004 in the field of computational fluid dynamics (CFD) will appear in a special issue of *Computers and Fluids*.

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