Introduction to Part I: Fluctuation Relations

The contributions to Part I of this book are organized into three clusters of chapters, beginning with *theoretical foundations*. Spinney and Ford's opening chapter provides a pedagogical overview of fluctuation relations, summarizing key results in the field and emphasizing their connection with the second law of thermodynamics. These results are derived within the framework of continuous Markovian stochastic dynamics, in which the effects of thermal surroundings on the evolution of a system of interest are modeled by random noise. The next chapter, by Reid, Williams, Searles, Rondoni and Evans, takes a complementary approach, using fully deterministic equations of motion to model the system's evolution. The authors show that a number of related results follow directly from the consideration of an appropriately defined *dissipation function*. These results are then illustrated using a conceptually simple and experimentally accessible system: a micron-size bead trapped with laser tweezers. Finally, Rondoni and Jepps' chapter makes a distinction between physically motivated fluctuation relations, such as those considered in the first two contributions, and the study of similar results within the framework of dynamical systems theory, where the emphasis is on generality and mathematical rigor rather than specific physical realizations. By developing a rigorous formalism for physically motivated fluctuation relations, Rondoni and Jepps explore this distinction in detail, and illuminates a number of issues such as the relationship between transient and steady-state fluctuation relations.

The second cluster of chapters within Part I considers *experimental foundations*. The contribution by Bellon, Gomez-Solano, Petrosyan and Ciliberto reviews experiments in which the fluctuations of a system away from thermal equilibrium are measured and compared with theory. The experiments include a torsional pendulum, a polystyrene particle trapped optically in a double well, and a cantilever used for atomic force microscopy (AFM), and together they provide a set of experimental platforms for testing a variety of fluctuation relations. Next, Alemany, Ribezzi-Crivellari and Ritort provide an introduction and up-to-date review of an important application of fluctuation relations, namely the recovery of equilibrium free energy differences from out-of-equilibrium single molecule pulling experiments. Among other issues, this contribution discusses and illustrates the importance of using the appropriate microscopic definition of work.

Further developments are discussed in the third and final set of chapters of Part I. Sagawa and Ueda review the thermodynamics of feedback control, in which an external observer uses information about the fluctuations of a small system to guide its subsequent evolution, as in Maxwell's famous thought experiment. They discuss how fluctuation relations and the second law of thermodynamics itself are modified in this setting. Gaspard then gives an overview of the time-symmetry relations that are obeyed by out-of-equilibrium systems. His contribution focuses on both quantum and stochastic dynamics, and discusses applications to electron transport in mesoscopic circuits. In the closing chapter of Part I, Klages, Chechkin and Dieterich investigate and extend fluctuation relations in the context of anomalous dynamics, as modeled by Lévy flights, long-time correlated Gaussian stochastic processes and time-fractional kinetics. Such anomalous dynamics arise in physically relevant situations such as cell migration.