Invitation to Submit

Fluctuation Theorem: 30 Years
Guest Editors: Lamberto Rondoni and Debra J. Searles

Nonequilibrium Quantum Field Processes and Phenomena
Guest Editors: Esteban Calzetta and Bei Lok Hu

Non-equilibrium Phase Transitions
Guest Editors: Carlos E. Fiore and Silvio C. Ferreira

Entropies, Information Geometry and Fluctuations in Non-equilibrium Systems II
Guest Editor: Eun-jin Kim

Topical Collection

Disorder and Biological Physics
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Randomness and Entropy Production
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Section Information

The field of non-equilibrium phenomena is growing in interest day by day; in fact, one may argue that almost any observable macroscopic phenomenon occurs in non-equilibrium conditions. To make any sense, this statement requires a definition of equilibrium, the status that must be violated for non-equilibrium to be established. In this respect, one notes that there are very many notions of equilibrium. Remaining within the realm of physics, and of thermodynamics in particular, the most relevant equilibria are the following: mechanical equilibrium (material objects remain at rest, subjected to no net forces); chemical equilibrium (the composition of an extended body does not change in time, and hence, possible chemical reactions are balanced, and no net transport of mass takes place); thermal equilibrium (the object of interest does not change its state if isolated from its environment). When concomitant, these three equilibria give rise to thermodynamic equilibrium. From a microscopic point of view, the conditions for thermodynamic equilibrium include that the elementary constituents of the objects of interest are very many, and that they interact so that atomic or molecular properties be rapidly homogenized in space. There are various degrees in which these conditions can be violated, but it is obvious that a vast range of phenomena, particularly of interest in present science and technology, do not fit the definition of thermodynamic equilibrium and call for specific approaches.

Section Non-equilibrium Phenomena

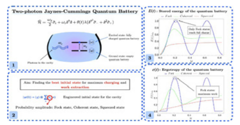
Featured Papers

DOI:10.3390/e23050612

Characterization of a Two-Photon Quantum Battery: Initial Conditions, Stability and Work Extraction

Authors: Anna Delmonte, Alba Crescente, Matteo Carrega, Dario Ferraro and Maura Sassetti

Abstract: We consider a quantum battery that is based on a two-level system coupled with a cavity radiation by means of a two-photon interaction. Various figures of merit, such as stored energy, average charging power, energy fluctuations, and extractable work are investigated, considering, as possible initial conditions for the cavity, a Fock state, a coherent state, and a squeezed state. We show that the first state leads to better performances for the battery. However, a coherent state with the same average number of photons, even if it is affected by stronger fluctuations in the stored energy, results in quite interesting performance, in particular since it allows for almost completely extracting the stored energy as usable work at short enough times.

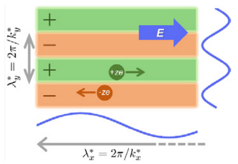


DOI:10.3390/e24040500

Stochastic Density Functional Theory on Lane Formation in Electric-Field-Driven Ionic Mixtures: Flow-Kernel-Based Formulation

Author: Hiroshi Frusawa

Abstract: Simulation and experimental studies have demonstrated non-equilibrium ordering in driven colloidal suspensions: with increasing driving force, a uniform colloidal mixture transforms into a locally demixed state characterized by the lane formation or the emergence of strongly anisotropic stripe-like domains. Theoretically, we have found that a linear stability analysis of density dynamics can explain the non-equilibrium ordering by adding a non-trivial advection term. This advection arises from fluctuating flows due to non-Coulombic interactions associated with oppositely driven migrations. Recent studies based on the dynamical density functional theory (DFT) without multiplicative noise have introduced the flow kernel for providing a general description of the fluctuating velocity. Here, we assess and extend the above deterministic DFT by treating electric-field-driven binary ionic mixtures as the primitive model. First, we develop the stochastic DFT with multiplicative noise for the laning phenomena. The stochastic DFT considering the fluctuating flows allows us to determine correlation functions in a steady state. In particular, asymptotic analysis on the stationary charge-charge correlation function reveals that the above dispersion relation for linear stability analysis is equivalent to the pole equation for determining the oscillatory wavelength of charge–charge correlations. Next, the appearance of stripe-like domains is demonstrated not only by using the pole equation but also by performing the 2D inverse Fourier transform of the charge–charge correlation function without the premise of anisotropic homogeneity in the electric field direction.

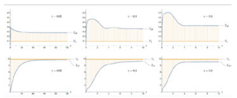


DOI:10.3390/e24070870

Quantum Thermodynamic Uncertainties in Nonequilibrium Systems from Robertson-Schrödinger Relations

Authors: Hang Dong, Daniel Reiche, Jen-Tsung Hsiang and Bei-Lok Hu

Abstract: Thermodynamic uncertainty principles make up one of the few rare anchors in the largely uncharted waters of nonequilibrium systems, the fluctuation theorems being the more familiar. In this work we aim to trace the uncertainties of thermodynamic quantities in nonequilibrium systems to their quantum origins, namely, to the quantum uncertainty principles. Our results enable us to make this categorical statement: For Gaussian systems, thermodynamic functions are functionals of the *Robertson-Schrödinger uncertainty* function, which is always non-negative for quantum systems, but not necessarily so for classical systems. Here, quantum refers to noncommutativity of the canonical operator pairs. From the *nonequilibrium free energy*, we succeeded in deriving several inequalities between certain thermodynamic quantities. They assume the same forms as those in conventional thermodynamics, but these are nonequilibrium in nature and they hold for all times and at strong coupling. In addition we show that a fluctuation-dissipation inequality exists at all times in the nonequilibrium dynamics of the system. For nonequilibrium systems which relax to an equilibrium state at late times, this fluctuation-dissipation inequality leads to the Robertson-Schrödinger uncertainty principle with the help of the Cauchy-Schwarz inequality. This work provides the microscopic quantum basis to certain important thermodynamic properties of macroscopic nonequilibrium systems.



DOI:10.3390/e24091222

Stochastic Thermodynamics of an Electromagnetic Energy Harvester

Authors: Luigi Costanzo, Alessandro Lo Schiavo, Alessandro Sarracino and Massimo Vitelli

Abstract: We study the power extracted by an electromagnetic energy harvester driven by broadband vibrations. We describe the system with a linear model, featuring an underdamped stochastic differential equation for an effective mass in a harmonic potential, coupled electromechanically with the current in the circuit. We compare the characteristic curve (power vs. load resistance) obtained in experiments for several values of the vibration amplitude with the analytical results computed from the model. Then, we focus on a more refined analysis, taking into account the temporal correlations of the current signal and the fluctuations of the extracted power over finite times. We find a very good agreement between the analytical predictions and the experimental data, showing that the linear model with effective parameters can describe the real system, even at the fine level of fluctuations. Our results could be useful in the framework of stochastic thermodynamics applied to energy harvesting systems.