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Thermodynamics of Information Processing in Small Systems



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Thermodynamics Of Information Processing In Small Systems Springer Theses

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Thermodynamics of Information Processing in Small Systems Takahiro Sagawa, 2012-09-14 This thesis presents a general theory of nonequilibrium thermodynamics for information processing Ever since Maxwell's demon was proposed in the nineteenth century the relationship between thermodynamics and information has attracted much attention because it concerns the foundation of the second law of thermodynamics From the modern point of view Maxwell's demon is formulated as an information processing device that performs measurement and feedback at the level of thermal fluctuations By unifying information theory measurement theory and the recently developed theory of nonequilibrium statistical mechanics the author has constructed a theory of information thermodynamics in which information contents and thermodynamic variables are treated on an equal footing In particular the maximum work that can be extracted by the demon and the minimum work that is needed for measurement and information erasure by the demon has been determined Additionally generalizations of nonequilibrium relations such as a Jarzynski equality for classical stochastic systems in the presence of feedback control have been derived One of the generalized equalities has recently been verified experimentally by using sub micron colloidal particles The results obtained serve as fundamental principles for information processing in small thermodynamic systems and are applicable to nanomachines and nanodevices

Experiments on the Thermodynamics of Information Processing

Momčilo Gavrilov, 2017-08-01 This thesis reveals how the feedback trap technique developed to trap small objects for biophysical measurement could be adapted for the quantitative study of the thermodynamic properties of small systems The experiments in this thesis are related to Maxwell's demon a hypothetical intelligent neat fingered being that uses information to extract work from heat apparently creating a perpetual motion machine The second law of thermodynamics should make that impossible but how That question has stymied physicists and provoked debate for a century and a half The experiments in this thesis confirm a hypothesis proposed by Rolf Landauer over fifty years ago that Maxwell's demon would need to erase information and that erasing information resetting the measuring device to a standard starting state requires dissipating as much energy as is gained For his thesis work the author used a feedback trap to study the motion of colloidal particles in virtual potentials that may be manipulated arbitrarily The feedback trap confines a freely diffusing particle in liquid by periodically measuring its position and applying an electric field to move it back to the origin

Crossroad of Maxwell Demon Xavier Bouju, Christian Joachim, 2024-07-22 Written by leading experts in this field this proceedings volume originates from a workshop held in Toulouse on March 12 2023 organized by the ESIM European project Energy Storage Inside Molecules The book explores the intersection and convergence of various perspectives disciplines and research areas related to a modern version of the Maxwell demon at the nanoscale It presents interdisciplinary perspectives on topics such as intramolecular thermodynamics and single molecule motive power and overviews the realm of single objects be it atoms or molecules while also emphasizing on theoretical and experimental

approaches with or without the presence of supporting surfaces. Notably, this comprehensive collection represents the first instance where such intertwined contributions on diverse versions of the Maxwell demon are discussed within the context of the nanoscale. It is of great use to graduate students, postdoctoral fellows, and researchers who are interested in single molecule mechanics.

Information Thermodynamics on Causal Networks and its Application to Biochemical Signal Transduction Sosuke Ito, 2016-07-16 In this book, the author presents a general formalism of nonequilibrium thermodynamics with complex information flows induced by interactions among multiple fluctuating systems. The author has generalized stochastic thermodynamics with information by using a graphical theory. Characterizing nonequilibrium dynamics by causal networks, he has obtained a novel generalization of the second law of thermodynamics with information that is applicable to quite a broad class of stochastic dynamics, such as information transfer between multiple Brownian particles, an autonomous biochemical reaction, and complex dynamics with a time delayed feedback control. This study can produce further progress in the study of Maxwell's demon for special cases. As an application to these results, information transmission and thermodynamic dissipation in biochemical signal transduction are discussed. The findings presented here can open up a novel biophysical approach to understanding information processing in living systems.

Perspectives on Statistical Thermodynamics Yoshitsugu Oono, 2017-12-14 This original text develops a deep conceptual understanding of thermal physics and highlights the important links between statistical physics and classical thermodynamics. It examines how thermal physics fits within physics as a whole and is perfect for undergraduate and graduate students and researchers interested in a fresh approach to the subject.

Fluctuation Theorems under Divergent Entropy Production and their Applications for Fundamental Problems in Statistical Physics Yûto Murashita, 2022-01-20 This book presents the derivation of the fluctuation theorems with divergent entropy production and their application to fundamental problems in statistical physics. It explores the two basic aspects of the fluctuation theorems: i) Applicability in extreme situations with divergent entropy production, concluding that the fluctuation theorems remain valid under the notion of absolute irreversibility, and ii) utility in the investigation of classical enigmas in the framework of statistical physics, i.e. Gibbs and Loschmidt paradoxes. The book offers readers an overview of the research in fundamental statistical physics. Firstly, it briefly but skillfully reviews the modern development of fluctuation theorems to found the key theme of the book. Secondly, it concisely discusses historical issues of statistical physics in chronological order along with the key literature in the field. They help readers easily follow the key developments in the fundamental research of statistical physics.

Statistical Mechanics for Athermal Fluctuation Kiyoshi Kanazawa, 2017-11-20 The author investigates athermal fluctuation from the viewpoints of statistical mechanics in this thesis. Stochastic methods are theoretically very powerful in describing fluctuation of thermodynamic quantities in small systems on the level of a single trajectory and have been recently developed on the basis of stochastic thermodynamics. This thesis proposes for the first time a systematic framework to describe athermal fluctuation, developing stochastic

thermodynamics for non Gaussian processes while thermal fluctuations are mainly addressed from the viewpoint of Gaussian stochastic processes in most of the conventional studies First the book provides an elementary introduction to the stochastic processes and stochastic thermodynamics The author derives a Langevin like equation with non Gaussian noise as a minimal stochastic model for athermal systems and its analytical solution by developing systematic expansions is shown as the main result Furthermore the author shows a thermodynamic framework for such non Gaussian fluctuations and studies some thermodynamics phenomena i e heat conduction and energy pumping which shows distinct characteristics from conventional thermodynamics The theory introduced in the book would be a systematic foundation to describe dynamics of athermal fluctuation quantitatively and to analyze their thermodynamic properties on the basis of stochastic methods

Smart Service Management Maria Maleshkova, Niklas Kühl, Philipp Jussen, 2021-01-26 This book presents the main theoretical foundations behind smart services as well as specific guidelines and practically proven methods on how to design them Furthermore it gives an overview of the possible implementation architectures and shows how the designed smart services can be realized with specific technologies Finally it provides four specific use cases that show how smart services have been realized in practice and what impact they have within the businesses The first part of the book defines the basic concepts and aims to establish a shared understanding of terms such as smart services service systems smart service systems or cyber physical systems On this basis it provides an analysis of existing work and includes insights on how an organization incorporating smart services could enhance and adjust their management and business processes The second part on the design of smart services elaborates on what constitutes a successful smart service and describes experiences in the area of interdisciplinary teams strategic partnerships the overall service systems and the common data basis In the third part technical reference architectures are presented in detail encompassing topics on the design of digital twins in cyber physical systems the communication between entities and sensors in the age of Industry 4 0 as well as data management and integration The fourth part then highlights a number of analytical possibilities that can be realized and that can constitute or be part of smart services including machine learning and artificial intelligence methods Finally the applicability of the introduced design and development method is demonstrated by considering specific real world use cases These include services in the industrial and mobility sector which were developed in direct cooperation with industry partners The main target audience of this book is industry focused readers especially practitioners from industry who are involved in supporting and managing digital business These include professionals working in business development product management strategy and development ranging from middle management to Chief Digital Officers It conveys all the basics needed for developing smart services and successfully placing them on the market by explaining technical aspects as well as showcasing practical use cases

Thermodynamics and Synchronization in Open Quantum Systems Gonzalo Manzano Paule, 2018-07-04 This book explores some of the connections between dissipative and quantum effects from a theoretical point of view It

focuses on three main topics the relation between synchronization and quantum correlations the thermodynamical properties of fluctuations and the performance of quantum thermal machines Dissipation effects have a profound impact on the behavior and properties of quantum systems and the unavoidable interaction with the surrounding environment with which systems continuously exchange information energy angular momentum and matter is ultimately responsible for decoherence phenomena and the emergence of classical behavior However there is a wide intermediate regime in which the interplay between dissipative and quantum effects gives rise to a plethora of rich and striking phenomena that has just started to be understood In addition the recent breakthrough techniques in controlling and manipulating quantum systems in the laboratory have made this phenomenology accessible in experiments and potentially applicable **Single Molecule**

Biophysics and Poisson Process Approach to Statistical Mechanics Susanta K Sarkar, 2016-04-01 This is an overview of single molecule physics the study of both equilibrium and non equilibrium properties at the single molecule level It begins with an introduction to this fascinating science and includes a chapter on how to build the most popular instrument for single molecule biophysics the total internal reflection fluorescence TIRF microscope It concludes with the Poisson process approach to statistical mechanics explaining how to relate the process to diverse areas and see how data analysis and error bars are integral parts of science **Mathematical Foundations and Applications of Graph Entropy** Matthias

Dehmer, Frank Emmert-Streib, Zengqiang Chen, Xueliang Li, Yongtang Shi, 2017-09-12 This latest addition to the successful Network Biology series presents current methods for determining the entropy of networks making it the first to cover the recently established Quantitative Graph Theory An excellent international team of editors and contributors provides an up to date outlook for the field covering a broad range of graph entropy related concepts and methods The topics range from analyzing mathematical properties of methods right up to applying them in real life areas Filling a gap in the contemporary literature this is an invaluable reference for a number of disciplines including mathematicians computer scientists computational biologists and structural chemists **Springer Handbook of Surface Science** Mario Rocca, Talat

Rahman, Luca Vattuone, 2021-01-14 This handbook delivers an up to date comprehensive and authoritative coverage of the broad field of surface science encompassing a range of important materials such as metals semiconductors insulators ultrathin films and supported nanoobjects Over 100 experts from all branches of experiment and theory review in 39 chapters all major aspects of solid state surfaces from basic principles to applications including the latest ground breaking research results Beginning with the fundamental background of kinetics and thermodynamics at surfaces the handbook leads the reader through the basics of crystallographic structures and electronic properties to the advanced topics at the forefront of current research These include but are not limited to novel applications in nanoelectronics nanomechanical devices plasmonics carbon films catalysis and biology The handbook is an ideal reference guide and instructional aid for a wide range of physicists chemists materials scientists and engineers active throughout academic and industrial research Quantum

Information Processing with Finite Resources Marco Tomamichel, 2015-10-14 This book provides the reader with the mathematical framework required to fully explore the potential of small quantum information processing devices As decoherence will continue to limit their size it is essential to master the conceptual tools which make such investigations possible A strong emphasis is given to information measures that are essential for the study of devices of finite size including Rnyi entropies and smooth entropies The presentation is self contained and includes rigorous and concise proofs of the most important properties of these measures The first chapters will introduce the formalism of quantum mechanics with particular emphasis on norms and metrics for quantum states This is necessary to explore quantum generalizations of Rnyi divergence and conditional entropy information measures that lie at the core of information theory The smooth entropy framework is discussed next and provides a natural means to lift many arguments from information theory to the quantum setting Finally selected applications of the theory to statistics and cryptography are discussed The book is aimed at graduate students in Physics and Information Theory Mathematical fluency is necessary but no prior knowledge of quantum theory is required

Statistical Thermodynamics of Nonequilibrium Processes Joel Keizer, 2012-12-06 The structure of the theory of thermodynamics has changed enormously since its inception in the middle of the nineteenth century Shortly after Thomson and Clausius enunciated their versions of the Second Law Clausius Maxwell and Boltzmann began actively pursuing the molecular basis of thermodynamics work that culminated in the Boltzmann equation and the theory of transport processes in dilute gases Much later Onsager undertook the elucidation of the symmetry of transport coefficients and thereby established himself as the father of the theory of nonequilibrium thermodynamics Combining the statistical ideas of Gibbs and Langevin with the phenomenological transport equations Onsager and others went on to develop a consistent statistical theory of irreversible processes The power of that theory is in its ability to relate measurable quantities such as transport coefficients and thermodynamic derivatives to the results of experimental measurements As powerful as that theory is it is linear and limited in validity to a neighborhood of equilibrium In recent years it has been possible to extend the statistical theory of nonequilibrium processes to include nonlinear effects The modern theory as expounded in this book is applicable to a wide variety of systems both close to and far from equilibrium The theory is based on the notion of elementary molecular processes which manifest themselves as random changes in the extensive variables characterizing a system The theory has a hierarchical character and thus can be applied at various levels of molecular detail

Imaging Brain Function With EEG Walter Freeman, Rodrigo Quiñan Quiroga, 2012-10-28 The scalp and cortex lie like pages of an open book on which the cortex enciphers vast quantities of information and knowledge They are recorded and analyzed as temporal and spatial patterns in the electroencephalogram and electrocorticogram This book describes basic tools and concepts needed to measure and decipher the patterns extracted from the EEG and ECoG This book emphasizes the need for single trial analysis using new methods and paradigms as well as large high density spatial arrays of electrodes for pattern sampling The deciphered

patterns reveal neural mechanisms by which brains process sensory information into precepts and concepts It describes the brain as a thermodynamic system that uses chemical energy to construct knowledge The results are intended for use in the search for the neural correlates of intention attention perception and learning in the design of human brain computer interfaces enabling mental control of machines and in exploring and explaining the physicochemical foundation of biological intelligence

Stochastic Systems with Time Delay Sarah A.M. Loos, 2021-09-18 The nonequilibrium behavior of nanoscopic and biological systems which are typically strongly fluctuating is a major focus of current research Lately much progress has been made in understanding such systems from a thermodynamic perspective However new theoretical challenges emerge when the fluctuating system is additionally subject to time delay e g due to the presence of feedback loops This thesis advances this young and vibrant research field in several directions The first main contribution concerns the probabilistic description of time delayed systems e g by introducing a versatile approximation scheme for nonlinear delay systems Second it reveals that delay can induce intriguing thermodynamic properties such as anomalous reversed heat flow More generally the thesis shows how to treat the thermodynamics of non Markovian systems by introducing auxiliary variables It turns out that delayed feedback is inextricably linked to nonreciprocal coupling information flow and to net energy input on the fluctuating level

Thermodynamic Equilibria and Extrema Alexander N. Gorban, Boris M. Kaganovich, Sergey P. Filippov, Alexandre V. Keiko, Vitaly A. Shamansky, Igor A. Shirkalin, 2006-07-19 Since the creation of classical equilibrium thermodynamics in the second part of the nineteenth century by Clausius Helmholtz Maxwell Gibbs and Boltzmann its potential has increased immeasurably due to the rapid development of numerical mathematics and computers Now models based on Gibbs's fundamental equations allow one not only to find the point of final equilibrium in a given system but also to examine the entire area thermodynamically attainable from a given initial point Moreover they are capable of finding in this area the equilibrium states partial equilibria of interest to a researcher for their extreme values of a considered parameter such as the concentration of useful or harmful products of a chemical process In doing so it appears possible to take into consideration in a strict thermodynamic form with no use of the time variable the limitations posed by chemical reaction rates and irreversible processes of mass energy and impulse transfer

Time Bertrand Duplantier, 2013-03-14 This eleventh volume in the Poincaré Seminar Series presents an interdisciplinary perspective on the concept of Time which poses some of the most challenging questions in science Five articles written by the Fields medalist C Villani the two outstanding theoretical physicists T Damour and C Jarzynski the leading experimentalist C Salomon and the famous philosopher of science H Price describe recent developments related to the mathematical physical experimental and philosophical facets of this fascinating concept These articles are also highly pedagogical as befits their origin in lectures to a broad scientific audience Highlights include a description of the manifold fundamental physical issues in play with time in particular with the changes of perspective implied by Special and General Relativity a mathematically precise discussion of irreversibility and

entropy in the context of Boltzmann's and Vlasov's equations a thorough survey of the recently developed thermodynamics at the nanoscale the scale most relevant to biological physics a description of the new cold atom space clock PHARAO to be installed in 2015 onboard the International Space Station which will allow a test of Einstein's gravitational shift with a record precision of 2×10^{-6} and enable a test of the stability over time of the fundamental constants of physics an issue first raised by Dirac in 1937 and last but not least a logical and clarifying philosophical discussion of Time's arrow a phrase first coined by Eddington in 1928 in a challenge to physics to resolve the puzzle of the time asymmetry of our universe and echoed here in a short poem in prose by C de Mitry This book should be of broad general interest to physicists mathematicians and philosophers

Electricity and Magnetism in Biology and Medicine Ferdinando Bersani, 2012-12-06 In the last few decades the research on bioelectromagnetics has expanded worldwide About one thousand researchers are now working in the field in a variety of institutions throughout the world including medical biological engineering and technical laboratories and protection agencies After many years of research a clear picture is now emerging Initially the research was mainly interested in the therapeutic applications of ELF electric and magnetic fields and the RF range was mainly taken into consideration with respect to thermal effects only Then the growing body of biological effects of ELF fields on cells and biological tissues particularly for the repair processes in bone have drawn the attention of researchers to non thermal effects ranging from static fields to microwaves A specific field of interest that has been the object of a large debate in the last twenty years has been the potential health risk associated with electric power production and distribution and more recently with domestic and industrial appliances In the last few years the explosion of the market for cellular phones has highlighted the issue of possible health dangers related to their use and to the widespread presence of base stations The first World Congress on Electricity and Magnetism in Biology and Medicine was held in Orlando Florida in 1992 and collected the widest amount of contributions from almost all the major researchers involved in the field

The Thermodynamics of Linear Fluids and Fluid Mixtures Miloslav Pekař, Ivan Samohýl, 2013-11-19 In this book Samohýl and Pekař offer a consistent and general non equilibrium thermodynamic description for a model of chemically reacting mixtures This type of model is frequently encountered in practice and up until now chemically reacting systems out of equilibrium have rarely been described in books on non equilibrium thermodynamics Readers of this book benefit from the systematic development of the theory this starts with general principles going through the applications to single component fluid systems and finishing with the theory of mixtures including chemical reactions The authors describe the simplest mixture model the linear fluid and highlight many practical and thermodynamically consistent equations for describing transport properties and reaction kinetics for this model Further on in the book the authors also describe more complex models Samohýl and Pekař take special care to clearly explain all methodology and starting axioms and they also describe in detail applied assumptions and simplifications This book is suitable for graduate students in chemistry materials science and chemical engineering as well as professionals working in

these and related areas

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