



Tommaso Ruggeri · Masaru Sugiyama

Classical and Relativistic Rational Extended Thermodynamics of Gases

 Springer

Extended Thermodynamics

Christina Papenfuß



Extended Thermodynamics:

Rational extended thermodynamics Ingo Mueller, Tommaso Ruggeri, 2013-03-07 Ordinary thermodynamics provides reliable results when the thermodynamic fields are smooth in the sense that there are no steep gradients and no rapid changes. In fluids and gases this is the domain of the equations of Navier-Stokes and Fourier. Extended thermodynamics becomes relevant for rapidly varying and strongly inhomogeneous processes. Thus the propagation of high frequency waves and the shape of shock waves and the regression of small scale fluctuations are governed by extended thermodynamics. The field equations of ordinary thermodynamics are parabolic while extended thermodynamics is governed by hyperbolic systems. The main ingredients of extended thermodynamics are field equations of balance type constitutive quantities depending on the present local state and entropy as a concave function of the state variables. This set of assumptions leads to first order quasi-linear symmetric hyperbolic systems of field equations; it guarantees the well-posedness of initial value problems and finite speeds of propagation. Several tenets of irreversible thermodynamics had to be changed in subtle ways to make extended thermodynamics work. Thus the entropy is allowed to depend on nonequilibrium variables; the entropy flux is a general constitutive quantity and the equations for stress and heat flux contain inertial terms. New insight is therefore provided into the principle of material frame indifference. With these modifications an elegant formal structure can be set up in which just as in classical thermostatics all restrictive conditions derived from the entropy principle take the form of integrability conditions. **Extended Irreversible Thermodynamics** David Jou, Jose Casas-Vazquez, Georgy

Lebon, 2012-12-06 Classical irreversible thermodynamics as developed by Onsager, Prigogine and many other authors is based on the local equilibrium hypothesis. Out of equilibrium any system is assumed to depend locally on the same set of variables as when it is in equilibrium. This leads to a formal thermodynamic structure identical to that of equilibrium. Intensive parameters such as temperature, pressure and chemical potentials are well-defined quantities keeping their usual meaning. Thermodynamic potentials are derived as Legendre transformations and all equilibrium thermodynamic relations retain their validity. The theory based on this hypothesis has turned out to be very useful and has achieved a number of successes in many practical situations of interest. In going however the recent decade has witnessed a surge beyond the classical formulation. There are several reasons for this. One of them is the development of experimental methods able to deal with the response of systems to high frequency and short wavelength perturbations such as ultrasound propagation and light and neutron scattering. The observed results have led to generalizations of the classical hydrodynamical theories by including memory functions or generalized transport coefficients depending on the frequency and the wavevector. This field has generated impressive progress in non-equilibrium statistical mechanics but for the moment it has not brought about a parallel development in non-equilibrium thermodynamics. An extension of thermodynamics compatible with generalized hydrodynamics therefore appears to be a natural subject of research. *Extended Thermodynamics* Ingo Müller, Tommaso

Ruggeri,2013-03-08 Physicists firmly believe that the differential equations of nature should be hyperbolic so as to exclude action at a distance yet the equations of irreversible thermodynamics those of Navier Stokes and Fourier are parabolic This incompatibility between the expectation of physicists and the classical laws of thermodynamics has prompted the formulation of extended thermodynamics After describing the motifs and early evolution of this new branch of irreversible thermodynamics the authors apply the theory to mon atomic gases mixtures of gases relativistic gases and gases of phonons and photons The discussion brings into perspective the various phenomena called second sound such as heat propagation propagation of shear stress and concentration and the second sound in liquid helium The formal mathematical structure of extended thermodynamics is exposed and the theory is shown to be fully compatible with the kinetic theory of gases The study closes with the testing of extended thermodynamics through the exploitation of its predictions for measurements of light scattering and sound propagation Extended Thermodynamics Systems Stanislaw Sieniutycz,Peter

Salamon,1992-01-01 This multiauthored volume sketches the applications of nonequilibrium thermodynamics to complex systems These are characterized by an involved form of the Gibbs equation and include systems such as solutions of macromolecules magnetic hysteresis bodies viscoelastic fluids polarizable media fluids under stresses and in the presence of essential nonstationarities and high temperature gradients As a rule the so called internal variables and or dissipative fluxes are essential in the thermodynamic description of such systems **Extended Irreversible Thermodynamics** David

Jou,Georgy Lebon,José Casas-Vázquez,2010-09-16 The fast progress in many areas of research related to non equilibrium thermodynamics has prompted us to write a fourth edition of this book Like in the previous editions our main concern is to open the subject to the widest audience including students teachers and researchers in physics chemistry engineering biology and materials sciences Our objective is to present a general view on several open problems arising in non equilibrium situations and to afford a wide perspective of applications illustrating their practical outcomes and consequences A better comprehension of the foundations is generally correlated to an increase of the range of applications implying mutual feedback and cross fertilization Truly thermodynamic methods are widely used in many areas of science but surprisingly the active dynamism of thermodynamics as a field on its own is not sufficiently perceived outside a relatively reduced number of specialized researchers Extended irreversible thermodynamics EIT goes beyond the classical formalisms based on the local equilibrium hypothesis it was also referred to in an earlier publication by the authors Lebon et al 1992 as a thermodynamics of the third type as it provides a bridge between classical irreversible thermodynamics and rational thermodynamics enlarging at the same time their respective range of application The salient feature of the theory is that the fluxes are incorporated into the set of basic variables Classical and Relativistic Rational Extended Thermodynamics of Gases

Tommaso Ruggeri,Masaru Sugiyama,2021-04-22 Rational extended thermodynamics RET is the theory that is applicable to nonequilibrium phenomena out of local equilibrium It is expressed by the hyperbolic system of field equations with local

constitutive equations and is strictly related to the kinetic theory with the closure method of the hierarchies of moment equations. The book intends to present in a systematic way new results obtained by RET of gases in both classical and relativistic cases and it is a natural continuation of the book *Rational Extended Thermodynamics beyond the Monatomic Gas* by the same authors published in 2015. However, this book addresses much wider topics than those of the previous book. Its contents are as follows: RET of rarefied monatomic gases and of polyatomic gases; a simplified RET theory with 6 fields being valid far from equilibrium; RET where both molecular rotational and vibrational modes exist; mixture of gases with multi temperature. The theory is applied to several typical topics: sound waves, shock waves, etc., and is compared with experimental data. From a mathematical point of view, RET can be regarded as a theory of hyperbolic symmetric systems of which it is possible to conduct a qualitative analysis. The book represents a valuable resource for applied mathematicians, physicists, and engineers, offering powerful models for many potential applications such as reentering satellites into the atmosphere, semiconductors, and nanoscale phenomena.

Rational Extended Thermodynamics beyond the Monatomic Gas

Tommaso Ruggeri, Masaru Sugiyama, 2015-10-15. This book is dedicated to the recent developments in RET with the aim to explore polyatomic gas, dense gas, and mixture of gases in non equilibrium. In particular, we present the theory of dense gases with 14 fields which reduces to the Navier-Stokes-Fourier classical theory in the parabolic limit. Molecular RET with an arbitrary number of field variables for polyatomic gases is also discussed, and the theory is proved to be perfectly compatible with the kinetic theory in which the distribution function depends on an extra variable that takes into account a molecule's internal degrees of freedom. Recent results on mixtures of gases with multi temperature are presented together with a natural definition of the average temperature. The qualitative analysis and, in particular, the existence of the global smooth solution and the convergence to equilibrium are also studied by taking into account the fact that the differential systems are symmetric hyperbolic. Applications to shock and sound waves are analyzed together with light scattering and heat conduction, and the results are compared with experimental data. Rational extended thermodynamics (RET) is a thermodynamic theory that is applicable to non equilibrium phenomena. It is described by differential hyperbolic systems of balance laws with local constitutive equations. As RET has been strictly related to the kinetic theory through the closure method of moment hierarchy associated to the Boltzmann equation, the applicability range of the theory has been restricted within rarefied monatomic gases. The book represents a valuable resource for applied mathematicians, physicists, and engineers, offering powerful models for potential applications like satellites reentering the atmosphere, semiconductors, and nano scale phenomena.

Continuum Thermodynamics and Constitutive Theory Christina Papenfuß, 2020-05-16. This book presents different thermodynamic approaches in the area of constitutive theory: thermodynamics of irreversible processes, rational thermodynamics, and extended thermodynamics. These different approaches are analyzed with respect to their presuppositions as well as to their results, and each method is applied to several important examples. In many cases, these

examples are archetypes for numerous technologically important materials i.e. complex materials having an internal structure. Some of the examples dealt with in this book are liquid crystals, colloid suspensions and fiber suspensions. The book well serves students and researchers who have basic knowledge in continuum mechanics and thermodynamics. It provides a systematic overview of the vast field of thermodynamic constitutive theory beginning from a historical perspective and concluding with outstanding questions in recent research.

Thermodynamic Approaches in Engineering Systems

Stanislaw Sieniutycz, 2016-05-20. *Thermodynamic Approaches in Engineering Systems* responds to the need for a synthesizing volume that throws light upon the extensive field of thermodynamics from a chemical engineering perspective that applies basic ideas and key results from the field to chemical engineering problems. This book outlines and interprets the most valuable achievements in applied non-equilibrium thermodynamics obtained within the recent fifty years. It synthesizes nontrivial achievements of thermodynamics in important branches of chemical and biochemical engineering. Readers will gain an update on what has been achieved, what new research problems could be stated and what kind of further studies should be developed within specialized research. Presents clearly structured chapters beginning with an introduction, elaboration of the process and results summarized in a conclusion. Written by a first class expert in the field of advanced methods in thermodynamics. Provides a synthesis of recent thermodynamic developments in practical systems. Presents very elaborate literature discussions from the past fifty years.

Non-equilibrium Thermodynamics of Superfluid Helium and Quantum Turbulence Maria Stella Mongiovi, David Jou, Michele Sciacca, 2025-07-23. This book puts together non-equilibrium thermodynamics, heat transport properties of superfluid He II and thermodynamic and dynamic aspects of quantum turbulence. A one-fluid extended model of superfluid helium with heat flux as an additional independent variable is presented and compared with the two-fluid model to explore how both models complement each other. Important features arise in rotating situations and in superfluid turbulence characterized by quantized vortices leading to strong nonlinearities between heat flux and temperature gradient. The dynamics of vortex lines and their interaction with heat dynamics, a central topic in superfluid turbulence, is dealt with by introducing the vortex line density as an independent variable and writing its dynamical equations considering the transitions from laminar to turbulent flows and from diffusive to ballistic regimes. Classical and quantum turbulence are compared from a mesoscopic view and from their energy spectra. The work also explores some parallelisms of quantum vortex thermodynamics with cosmic string thermodynamics and black hole thermodynamics exhibiting duality connections amongst them. It emphasizes didactical views over specialistic details and may be used as an introduction to nonequilibrium thermodynamics of superfluid helium and its heat transport properties: second sound, nonlocal transport, nonlinear connections with quantum turbulence. The book is useful to researchers in superfluid helium in heat transport and in thermodynamics of cosmic strings and black holes. The diversity and complexity of its several physical equations will be inspiring for researchers in mathematical physics.

Maximum Dissipation

Non-Equilibrium Thermodynamics and its Geometric Structure Henry W. Haslach Jr., 2011-01-15 Maximum Dissipation Non Equilibrium Thermodynamics and its Geometric Structure explores the thermodynamics of non equilibrium processes in materials The book develops a general technique created in order to construct nonlinear evolution equations describing non equilibrium processes while also developing a geometric context for non equilibrium thermodynamics Solid materials are the main focus in this volume but the construction is shown to also apply to fluids This volume also Explains the theory behind thermodynamically consistent construction of non linear evolution equations for non equilibrium processes Provides a geometric setting for non equilibrium thermodynamics through several standard models which are defined as maximum dissipation processes Emphasizes applications to the time dependent modeling of soft biological tissue Maximum Dissipation Non Equilibrium Thermodynamics and its Geometric Structure will be valuable for researchers engineers and graduate students in non equilibrium thermodynamics and the mathematical modeling of material behavior **Extended**

Irreversible Thermodynamics D. Jou, J. Casas-Vazquez, G. Lebon, 2011-06-27 Covers a wide spectrum of applications and contains a wide discussion of the foundations and the scope of the most current theories of non equilibrium thermodynamics The new edition reflects new developments and contains a new chapter on the interplay between hydrodynamics and thermodynamics **Understanding Non-equilibrium Thermodynamics** Georgy Lebon, David Jou, 2008-01-12 Our time is

characterized by an explosion of information and by an acceleration of knowledge A book cannot compete with the huge amount of data available on the Web However to assimilate all this information it is necessary to structure our knowledge in a useful conceptual framework The purpose of the present work is to provide such a structure for students and researchers interested by the current state of the art of non equilibrium thermodynamics The main features of the book are a concise and critical presentation of the basic ideas illustrated by a series of examples selected not only for their pedagogical value but also for the perspectives offered by recent technological advances This book is aimed at students and researchers in physics chemistry engineering material sciences and biology We have been guided by two apparently antagonistic objectives generality and simplicity To make the book accessible to a large audience of non specialists we have decided about a simplified but rigorous presentation Emphasis is put on the underlying physical background without sacrificing mathematical rigour the several formalisms being illustrated by a list of ample problems and problems Throughout this work we have been guided by the formula Get more from the less with the purpose to make a maximum of people aware of a maximum of knowledge from a minimum of basic tools Besides being an introductory text our objective is to present an overview as general as possible of the more recent developments in non equilibrium thermodynamics especially beyond the local equilibrium description **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 Samoh l and Peka 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 *Thermodynamics and Rheology* J. Verhás, 1997-03-31 This book presents a general classical field theory incorporating continuum mechanics electrodynamics and thermodynamics The continuum equations of material behavior are derived from the principles of Onsager s non equilibrium thermodynamics supplemented with dynamic degrees of freedom The book contains the basic principles and methods of modern continuum mechanics and of rheology Non equilibrium thermodynamics is discussed in detail Applications include elasticity thermoelasticity viscoelasticity plasticity rheoptics etc The models of rheology are developed within a consistent thermodynamic framework Viscoelastic and plastic response Ostwald s curve of generalized Newtonian fluids creep elasticity preceding plastic flow the rules of rheoptics etc are discussed and the empirical Cox Merz rule is proved The thermodynamic results are compared to the results of microscopic theories Several kinds of colloids polymers and liquid crystals are studied The technical level of the book is high It is designed for engineers physicists natural scientists and applied mathematicians *Statistical Physics And Thermodynamics Of Nonlinear Nonequilibrium Systems* Wolfgang Muschik, Werner Ebeling, 1993-03-27 In these proceedings it is shown that thermodynamical concepts are not old fashioned but still are most useful at the frontiers of modern science Among the contributors are well known experts such as Andresen Copenhagen Eu Montreal Gro mann Marburg Kawasaki Fuhuoha Maugin Paris Nicolis Bruxelles and Sz pfalusy Budapest The subject covers a wide field including recent developments in phenomenological thermodynamics statistical foundation of thermodynamical concepts thermodynamical concepts in nonlinear dynamics applications to nonlinear neural networks stochastic theory and transition processes *Hyperbolic Problems: Theory, Numerics, Applications* Heinrich Freistühler, Gerald Warnecke, 2013-12-01 The Eighth International Conference on Hyperbolic Problems Theory Nu merics Applications was held in Magdeburg Germany from February 27 to March 3 2000 It was attended by over 220 participants from many European countries as well as Brazil Canada China Georgia India Israel Japan Taiwan und the USA There were 12 plenary lectures 22 further invited talks and around 150 con tributed talks in parallel sessions as well as posters The speakers in the parallel sessions were invited to provide a poster in order to enhance the dissemination of information Hyperbolic partial differential equations describe phenomena of material or wave transport in physics biology and

engineering especially in the field of fluid mechanics Despite considerable progress the mathematical theory is still struggling with fundamental open problems concerning systems of such equations in multiple space dimensions For various applications the development of accurate and efficient numerical schemes for computation is of fundamental importance Applications touched in these proceedings concern one phase and multiphase fluid flow phase transitions shallow water dynamics elasticity extended thermodynamics electromagnetism classical and relativistic magnetohydrodynamics cosmology Contributions to the abstract theory of hyperbolic systems deal with viscous and relaxation approximations front tracking and wellposedness stability of shock profiles and multi shock patterns traveling fronts for transport equations Numerically oriented articles study finite difference finite volume and finite element schemes adaptive multiresolution and artificial dissipation methods

Complexity and Complex Chemo-Electric Systems Stanislaw Sieniutycz, 2021-02-09 Complexity and Complex Chemo Electric Systems presents an analysis and synthesis of chemo electric systems providing insights on transports in electrolytes electrode reactions electrocatalysis electrochemical membranes and various aspects of heterogeneous systems and electrochemical engineering The book describes the properties of complexity and complex chemo electric systems as the consequence of formulations definitions tools solutions and results that are often consistent with the best performance of the system The book handles cybernetics systems theory and advanced contemporary techniques such as optimal control neural networks and stochastic optimizations adaptive random search genetic algorithms and simulated annealing A brief part of the book is devoted to issues such as various definitions of complexity hierarchical structures self organization examples special references and historical issues This resource complements Sieniutycz recently published book Complexity and Complex Thermodynamic Systems with its inclusion of complex chemo electric systems in which complexities emergent properties and self organization play essential roles Covers the theory and applications of complex chemo electric systems through modeling analysis synthesis and optimization Provides a clear presentation of the applications of transport theory to electrolyte solutions heterogeneous electrochemical systems membranes electro kinetic phenomena and interface processes Includes numerous explanatory graphs and drawings that illustrate the properties and complexities in complex chemo electric systems Written by an experienced expert in the field of advanced methods in thermodynamics and related aspects of macroscopic physics

The Breadth and Depth of Continuum Mechanics Constantine M. Dafermos, Daniel D. Joseph, Frank M. Leslie, 2012-12-06 This volume collects papers dedicated to Jerry Ericksen on his sixtieth birthday December 20 1984 They first appeared in Volumes 82 90 1983 1985 of the Archive for Rational Mechanics and Analysis At the request of the Editors the list of authors to be invited was drawn up by C M Dafermos D D Joseph and F M Leslie The breadth and depth of the works here reprinted reflect the corresponding qualities in Jerry Ericksen's research teaching scholarship and inspiration His interests and expertness center upon the mechanics of materials and extend to everything that may contribute to it pure analysis algebra geometry through all aspects of theoretical mechanics to fundamental experiment all of

these illuminated by an intimate and deep familiarity with the sources even very old ones He is independent of school and contemptuous of party spirit his generosity in giving away his ideas is renowned but not everyone is capable of accepting what is offered His writings are totally free of broad claims and attributions beyond his own study Some are decisive some are prophetic and all are forthright His work has served as a beacon of insight and simple honesty in an age of ever more trivial and corrupt science The authors of the memoirs in this volume are his students colleagues admirers and above all his friends Nonlinear Hyperbolic Problems: Theoretical, Applied, and Computational Aspects Andrea Donato, Francesco Oliveri, 2013-03-08

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