Tommaso Ruggeri
Masaru Sugiyama

# Rational Extended Thermodynamics beyond the Monatomic Gas

Springer

# Rational Extended Thermodynamics

**Gennadii V. Demidenko,Evgeniy Romenski,Eleuterio Toro,Michael Dumbser**

**Rational 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 fluctuation 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 propaga tion 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 vari ables 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     *Rational Extended Thermodynamics* Ingo Mueller,Tommaso Ruggeri,1998-04-17     **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    **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    Continuum Mechanics I-Shih Liu,2013-04-17 In this book the basic principles of continuum mechanics and thermodynam ics are treated in the tradition of the rational framework established in the 1960s typically in the fundamental memoir The Non Linear Field Theories of Mechanics by Truesdell and Noll The theoretical aspect of constitutive theories for materials in general has been carefully developed in mathemati cal clarity from general kinematics balance equations material objectivity and isotropic representations to the framework of rational thermodynamics based on the entropy principle However I make no claim that the subjects are covered completely nor does this book cover solutions and examples that can usually be found in textbooks of fluid mechanics and linear elasticity However some of the interesting examples of finite deformations in elastic materials such as biaxial stretching of an elastic membrane and inflation of a rubber balloon are discussed In the last two chapters of the book some recent developments in ther modynamic theories are considered Specifically they emphasize the use of Lagrange multipliers which enables the exploitation of the entropy principle in a systematic manner for constitutive equations and introduce some basic notions of extended thermodynamics Although extended thermodynamics is closely related to the kinetic theory of ideal gases very limited knowledge of kinetic theory is needed    **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      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      **The Thermodynamics of Linear Fluids and Fluid Mixtures** Miloslav Pekař,Ivan Samohýl,2013-11-19 In this book Samoh l and Peka 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      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 ther dynamics 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 au ence including

students teachers and researchers in physics chemistry engine ing 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 con quences A better comprehension of the foundations is generally correlated to an increase of the range of applications implying mutual feedback and cross fert ization Truly thermodynamic methods are widely used in many areas of science but surprisingly the active dynamism of thermodynamics as a eld on its own is not suf ciently perceived outside a relatively reduced number of specialized researchers Extended irreversible thermodynamics EIT goes beyond the classical f malisms 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 uxes are incorporated into the set of basic variables **Continuum Mechanics, Applied Mathematics and Scientific Computing: Godunov's Legacy** Gennadii V. Demidenko,Evgeniy Romenski,Eleuterio Toro,Michael Dumbser,2020-04-03 This book is a liber amicorum to Professor Sergei Konstantinovich Godunov and gathers contributions by renowned scientists in honor of his 90th birthday The contributions address those fields that Professor Godunov is most famous for differential and difference equations partial differential equations equations of mathematical physics mathematical modeling difference schemes advanced computational methods for hyperbolic equations computational methods for linear algebra and mathematical problems in continuum mechanics **Entropy** Andreas Greven,Gerhard Keller,Gerald Warnecke,2014-09-08 The concept of entropy arose in the physical sciences during the nineteenth century particularly in thermodynamics and statistical physics as a measure of the equilibria and evolution of thermodynamic systems Two main views developed the macroscopic view formulated originally by Carnot Clausius Gibbs Planck and Caratheodory and the microscopic approach associated with Boltzmann and Maxwell Since then both approaches have made possible deep insights into the nature and behavior of thermodynamic and other microscopically unpredictable processes However the mathematical tools used have later developed independently of their original physical background and have led to a plethora of methods and differing conventions The aim of this book is to identify the unifying threads by providing surveys of the uses and concepts of entropy in diverse areas of mathematics and the physical sciences Two major threads emphasized throughout the book are variational principles and Ljapunov functionals The book starts by providing basic concepts and terminology illustrated by examples from both the macroscopic and microscopic lines of thought In depth surveys covering the macroscopic microscopic and probabilistic approaches follow Part I gives a basic introduction from the views of thermodynamics and probability theory Part II collects surveys that look at the macroscopic approach of continuum mechanics and physics Part III deals with the microscopic approach exposing the role of entropy as a concept in probability theory namely in the analysis of the large time behavior of stochastic processes and in the study of qualitative properties of

models in statistical physics Finally in Part IV applications in dynamical systems ergodic and information theory are presented The chapters were written to provide as cohesive an account as possible making the book accessible to a wide range of graduate students and researchers Any scientist dealing with systems that exhibit entropy will find the book an invaluable aid to their understanding **Non-Fourier Heat Conduction** Alexander I. Zhmakin,2023-07-01 This book presents a broad and well structured overview of various non Fourier heat conduction models The classical Fourier heat conduction model is valid for most macroscopic problems However it fails when the wave nature of the heat propagation becomes dominant and memory or non local spatial effects become significant e g during ultrafast heating heat transfer at the nanoscale in granular and porous materials at extremely high values of the heat flux or in heat transfer in biological tissues The book looks at numerous non Fourier heat conduction models that incorporate time non locality for materials with memory such as hereditary materials including fractional hereditary materials and or spatial non locality i e materials with a non homogeneous inner structure Beginning with an introduction to classical transport theory including phase lag phonon and thermomass models the book then looks at various aspects of relativistic and quantum transport including approaches based on the Landauer formalism as well as the Green Kubo theory of linear response Featuring an appendix that provides an introduction to methods in fractional calculus this book is a valuable resource for any researcher interested in theoretical and numerical aspects of complex non trivial heat conduction problems **Thermomechanics of Viscoplasticity** Milan Micunovic,2009-04-20 This work examines the geometrical and thermodynamical properties of mechanical behavior of metals and many polymeric and paste like materials which are indispensable for developing a rational theory of viscoplasticity The book is intended for researchers as well as Ph D students in the fields of material science and continuum mechanics Anyone involved in the design of large scale industrial parts will also find this book highly useful The concepts and results illustrated in this work are readily applicable to the rapidly developing field of biomechanics *Diffusion and Mass Transfer* James S. Vrentas,Christine M. Vrentas,2016-04-19 A proper understanding of diffusion and mass transfer theory is critical for obtaining correct solutions to many transport problems Diffusion and Mass Transfer presents a comprehensive summary of the theoretical aspects of diffusion and mass transfer and applies that theory to obtain detailed solutions for a large number of important problems Par Multiscale Thermo-Dynamics Michal Pavelka,Václav Klika,Miroslav Grmela,2018-08-06 One common feature of new emerging technologies is the fusion of the very small nano scale and the large scale engineering The classical environment provided by single scale theories as for instance by the classical hydrodynamics is not anymore satisfactory The main challenge is to keep the important details while still be able to keep the overall picture and simplicity It is the thermodynamics that addresses this challenge Our main reason for writing this book is to explain such general viewpoint of thermodynamics and to illustrate it on a very wide range of examples Contents Levels of description Hamiltonian mechanics Irreversible evolution Reversible and irreversible evolution Multicomponent systems Contact

geometry Appendix Mathematical aspects **Solving Problems in Thermal Engineering** Viktor Józsa,Róbert Kovács,2019-10-24 This book provides general guidelines for solving thermal problems in the fields of engineering and natural sciences Written for a wide audience from beginner to senior engineers and physicists it provides a comprehensive framework covering theory and practice and including numerous fundamental and real world examples Based on the thermodynamics of various material laws it focuses on the mathematical structure of the continuum models and their experimental validation In addition to several examples in renewable energy it also presents thermal processes in space and summarizes size dependent non Fourier and non Fickian problems which have increasing practical relevance in e g the semiconductor industry Lastly the book discusses the key aspects of numerical methods particularly highlighting the role of boundary conditions in the modeling process The book provides readers with a comprehensive toolbox addressing a wide variety of topics in thermal modeling from constructing material laws to designing advanced power plants and engineering systems **Mesoscopic Theories of Heat Transport in Nanosystems** Antonio Sellitto,Vito Antonio Cimmelli,David Jou,2016-02-03 This book presents generalized heat conduction laws which from a mesoscopic perspective are relevant to new applications especially in nanoscale heat transfer nanoscale thermoelectric phenomena and in diffusive to ballistic regime and at the same time keep up with the pace of current microscopic research The equations presented in the book are compatible with generalized formulations of nonequilibrium thermodynamics going beyond the local equilibrium The book includes six main chapters together with a preface and a final section devoted to the future perspectives as well as an extensive bibliography **Waves And Stability In Continuous Media - Proceedings Of The 13th Conference On Wascom 2005** Roberto Monaco,Salvatore Rionero,Tommaso Ruggeri,G Mulone,2006-03-27 The book contains recent contributions in the field of waves propagation and stability in continuous media In particular the contributions consider discontinuity and shock waves stability in fluid dynamics small parameter problems kinetic theories towards continuum models non equilibrium thermodynamics and numerical applications The volume is the fourth in a series published by World Scientific since 1999 The following distinguished authors contribute to the present book S Bianchini R Caflish C Cercignani Y Choquet Bruhat C Dafermos L Desvillettes V Giovangigli H Gouin I Muller D Parker B Straughan M Sugiyama and W Weiss **Proceedings, "WASCOM 2005"** Roberto Monaco,Giuseppe Mulone,Salvatore Rionero,Tommaso Ruggeri,2006 The book contains recent contributions in the field of waves propagation and stability in continuous media In particular the contributions consider discontinuity and shock waves stability in fluid dynamics small parameter problems kinetic theories towards continuum models non equilibrium thermodynamics and numerical applications The volume is the fourth in a series published by World Scientific since 1999 The following distinguished authors contribute to the present book S Bianchini R Caflish C Cercignani Y Choquet Bruhat C Dafermos L Desvillettes V Giovangigli H Gouin I Muller D Parker B Straughan M Sugiyama and W Weiss Contents On Whitham Equations for Camassa Holm S Abenda et al An Operational Description of

Stock Markets F Bagarello Vortex Layers in the Small Viscosity Limit R E Caflisch Integration of Partially Integrable Equations R Conte Waves and Vibrations in a Solid of Second Grade M Destrade Multicomponent Reactive Flows V Giovangigli Singularities for Prandtl s Equations G Lo Bosco et al Stability of Solitons of the ZakharovOCoRubenchik Equation F Oliveira Plain Waves and Vibrations in the Elastic Mixtures M Svanadze Extended Thermodynamics with Consistent Order W Weiss and other papers Readership Academics researchers and post graduates in mathematics and physics      Hyperbolic Problems: Theory, Numerics, Applications. Volume II Carlos Parés,Manuel J. Castro,Tomás Morales de Luna,María Luz Muñoz-Ruiz,2024-06-05 The present volume contains a selection of papers from the XVIII International Conference on Hyperbolic Problems Theory Numerics and Applications HYP2022 which was held on June 20 24 2022 in M laga Spain The goal of this series of conferences is to bring together scientists with interests in the theoretical applied and computational aspects of hyperbolic partial differential equations systems of hyperbolic conservation laws wave equations etc and of related mathematical models The chapters in this volume correspond to selected contributions related to numerical aspects and applications

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