Macroscopic Transport Equations For Rarefied Gas Flows Approximation Methods In Kinetic Theory Interaction Of Mechanics And Mathematics

Microscale Flow and Heat Transfer
Non-Equilibrium Reacting Gas Flows
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Applications of Chaos and Nonlinear Dynamics in Science and Engineering - Vol. 4
Kinetic Theory and Fluid Dynamics

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Microscale Flow and Heat Transfer Oxford University Press
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.
Cambridge University Press
The fast-paced growth in microelectromechanical systems (MEMS), microfluidic fabrication, porous media applications, biomedical assemblies, space propulsion, and vacuum technology demands accurate and practical transport equations for rarefied gas flows. It is well-known that in rarefied situations, due to strong deviations from the continuum regime, traditional fluid models such as Navier-Stokes-Fourier (NSF) fail. The shortcoming of continuum models is rooted in nonequilibrium behavior of gas particles in miniaturized and/or low-pressure devices, where the Knudsen number (Kn) is sufficiently large. Since kinetic solutions are computationally very expensive, there has been a great desire to develop macroscopic transport equations for dilute gas flows, and as a result, several sets of extended equations are proposed for gas flow in nonequilibrium states. However, applications of many of these extended equations are limited due to their instabilities and/or the absence of suitable boundary conditions. In this work, we concentrate on regularized 13-moment (R13) equations, which are a set of macroscopic transport equations for flows in the transition regime, i.e., Kn1. The R13 system provides a stable set of equations in Super-Burnett order, with a great potential to be a powerful CFD tool for rarefied flow simulations at moderate Knudsen numbers. The goal of this research is to implement the R13 equations for problems of practical interest in arbitrary geometries. This is done by transformation of the R13 equations and boundary conditions into general curvilinear coordinate systems. Next steps include adaptation of the transformed equations in order to solve some of the popular test cases, i.e., shear-driven, force-driven, and temperature-driven flows in both planar and curved flow passages. It is shown that inexpensive analytical solutions of the R13 equations for the considered problems are

comparable to expensive numerical solutions of the Boltzmann equation. The n.

Non-Equilibrium Reacting Gas Flows MDPI

Chaos and nonlinear dynamics initially developed as a new emergent field with its foundation in physics and applied mathematics. The highly generic, interdisciplinary quality of the insights gained in the last few decades has spawned myriad applications in almost all branches of science and technology—and even well beyond. Wherever quantitative modeling and analysis of complex, nonlinear phenomena is required, chaos theory and its methods can play a key role. his fourth volume concentrates on reviewing further relevant contemporary applications of chaotic and nonlinear dynamics as they apply to the various cuttingedge branches of science and engineering. This encompasses, but is not limited to, topics such as synchronization in complex networks and chaotic circuits, time series analysis, ecological and biological patterns, stochastic control theory and vibrations in mechanical systems. Featuring contributions from active and leading research groups, this collection is ideal both as a reference and as a 'recipe book' full of tried and tested, successful engineering applications.

Proceedings, "WASCOM 2007" Walter de Gruyter GmbH & Co KG

The idea for this book was conceived by the authors some time in 1988, and a first outline of the manuscript was drawn up during a summer school on mathematical physics held in Ravello in September 1988, where all three of us were present as lecturers or organizers. The project was in some sense inherited from our friend Marvin Shinbrot, who had planned a book about recent progress for the Boltzmann equation, but, due to his untimely death in 1987, never got to do it. When we drew up the first outline, we could not anticipate how long the actual writing would stretch out. Our ambitions were high: We wanted to cover the modern mathematical theory of the Boltzmann equation, with rigorous proofs, in a complete and readable volume. As the years progressed, we withdrew to some degree from this first ambition- there was just too much material, too scattered, sometimes incomplete, sometimes not rigor ous enough. However, in the writing process itself, the need for the book became ever more apparent. The last twenty years have seen an amazing number of significant results in the field, many of them published in incom plete form, sometimes in obscure places, and sometimes without technical details. We made it our objective to collect these results, classify them, and present them as best we could. The choice of topics remains, of course, subjective.

Computational Science – ICCS 2020 Springer Science & Business Media

This book covers concepts and the latest developments on microscale flow and heat transfer phenomena involving a gas. The book is organised in two parts: the first part focuses on the fluid flow and heat transfer characteristics of gaseous slip flows. The second part presents modelling of such flows using higher-order continuum transport equations. The Navier-Stokes equations based solution is provided to various problems in the slip regime. Several interesting characteristics of slip flows along with useful empirical correlations are documented in the first part of the book. The examples bring out the failure of the conventional equations to adequately describe various phenomena at the microscale. Thereby the readers are introduced to higher order continuum transport (Burnett and Grad) equations, which can potentially overcome these limitations. A clear and easy to follow step by step derivation of the Burnett and Grad equations (superset of the Navier-Stokes equations) is provided in the second part of the book. Analytical solution of these equations, the latest developments in the field, along with scope for future work in this area are also brought out. Presents characteristics of flow in the slip and transition regimes for a clear understanding of microscale flow problems; Provides a derivation of Navier-Stokes equations from microscopic viewpoint; Features a clear and easy to follow step-by-step approach to derive Burnett and Grad equations; Describes a complete compilation of few known exact solutions of the Burnett and Grad equations, along with a discussion of the solution aided with plots; Introduces the variants of the Navier-Stokes, Burnett and Grad equations, including the recently proposed Onsager-Burnett and O13 moment equations.

Rarefied Gas Dynamics Springer Science & Business Media

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.

Macroscopic Description of Rarefied Gas Flows in the Transition Regime Birkhäuser

Mathematical modelling of systems constituted by many agents using kinetic theory is a new tool that has proved effective in predicting the emergence of collective behaviours and self-organization. This idea has been applied by the authors to various problems which range from sociology to economics and life sciences.

Granular Gaseous Flows Springer Science & Business Media

This book presents the foundations of fluid mechanics and transport phenomena in a concise way. It is suitable as an introduction to the subject as it contains many examples, proposed problems and a chapter for self-evaluation.

Nonequilibrium Gas Dynamics and Molecular Simulation Springer Science & Business Media

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.

Interacting Multiagent Systems Springer Nature

Aimed at both researchers and professionals who deal with this topic in their routine work, this introduction provides a coherent and rigorous access to the field including relevant methods for practical applications. No preceding knowledge of gas dynamics is assumed.

Classical and Relativistic Rational Extended Thermodynamics of Gases Springer Science & Business Media

This book presents contributions on the following topics: discretization methods in the velocity and space, analysis of the conservation properties, asymptotic convergence to the continuous equation when the number of velocities tends to infinity, and application of discrete models. It consists of ten chapters. Each chapter is written by applied mathematicians who have been active in the field, and whose scientific contributions are well recognized by the scientific community.

Multiscale Thermo-Dynamics Cambridge University Press

The aim of this book is to present the theory and applications of the relativistic Boltzmann equation in a self-contained manner, even for those readers who have no familiarity with special and general relativity. Though an attempt is made to present the basic concepts in a complete fashion, the style of presentation is chosen to be appealing to readers who want to understand how kinetic theory is used for explicit calculations. The book will be helpful not only as a textbook for an advanced course on relativistic kinetic theory but also as a reference for physicists, astrophysicists and applied mathematicians who are interested in the theory and applications of the relativistic Boltzmann equation.

Rarefied Gas Dynamics Springer Science & Business Media

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Moment Method in Rarefied Gas Dynamics DEStech Publications, Inc

This advanced text presents a unique approach to studying transport phenomena. Bringing together concepts from both chemical engineering and physics, it makes extensive use of nonequilibrium thermodynamics, discusses kinetic theory, and sets out the tools needed to describe the physics of interfaces and boundaries. More traditional topics such as diffusive and convective transport of momentum, energy and mass are also covered. This is an ideal text for advanced courses in transport phenomena, and for researchers looking to expand their knowledge of the subject. The book also includes: • Novel applications such as complex fluids, transport at interfaces and biological systems, • Approximately 250 exercises with solutions (included separately) designed to enhance understanding and reinforce key concepts, • End-of-chapter summaries.

Modeling Evaporation in the Rarefied Gas Regime by Using Macroscopic Transport Equations Springer

The kinetic theory of gases as we know it dates to the paper of Boltzmann in 1872. The justification and context of this equation has been clarified over the past half century to the extent that it comprises one of the most complete examples of many-body analyses exhibiting the contraction from a microscopic to a mesoscopic description. The primary result is that the Boltzmann equation applies to dilute gases with short ranged interatomic forces, on space and time scales large compared to the corresponding atomic scales. Otherwise, there is no a priori limitation on the state of the system. This means it should be applicable even to systems driven very far from its eqUilibrium state. However, in spite of the physical simplicity of the Boltzmann equation, its mathematical complexity has masked its content except for states near eqUilibrium. While the latter are very important and the Boltzmann equation has been a resounding success in this case, the full potential of the Boltzmann equation to describe more general nonequilibrium states remains unfulfilled. An important exception was a study by Ikenberry and Truesdell in 1956 for a gas of Maxwell molecules undergoing shear flow. They provided a formally exact solution to the moment hierarchy that is valid for arbitrarily large shear rates. It was the first example of a fundamental description of rheology far from eqUilibrium, albeit for an unrealistic system. With rare exceptions, significant progress on nonequilibrium states was made only 20-30 years later.

Macroscopic Transport Equations for Rarefied Gas Flows Springer Nature

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

Extended Thermodynamics Springer

Model reduction and coarse-graining are important in many areas of science and engineering. How does a system with many degrees of freedom become one with fewer? How can a reversible micro-description be adapted to the dissipative macroscopic model? These crucial questions, as well as many other related problems, are discussed in this book. All contributions are by experts whose specialities span a wide range of fields within science and engineering.

Transport Theory Springer Nature

It is well established that rarefied flows cannot be properly described by traditional hydrodynamics, namely the Navier-Stokes equations for gas flows, and the Fourier's law for heat transfer. Considering the significant advancement in miniaturization of electronic devices, where dimensions become comparable with the mean free path of the flow, it is well established that rarefied flows cannot be properly described by traditional hydrodynamics, namely the Navier-Stokes equations for gas flows, and the Fourier's law for heat transfer. Considering the significant advancement in miniaturization of electronic devices, where dimensions become comparable with the mean free path of the flow, the study of rarefied flows is extremely important. This dissertation includes two main parts. First, we look into the heat transport in solids when the mean free path for phonons are comparable with the length scale of the flow. A set of macroscopic moment equations for heat transport in solids are derived to extend the validity of Fourier's law beyond the hydrodynamics regime. These equations are derived such that they remain valid at room temperature, where the MEMS devices usually work. The system of moment equations for heat transport is then employed to model the thermal grating experiment, recently conducted on a silicon wafer. It turns out that at room temperature, where the experiment was conducted, phonons with high meanfree path significantly contribute to the heat transport. These low frequency phonons are not considered in the classical theory, which leads to failure of the Fourier's law in describing the thermal grating experiment. In contrast, the system of moment equations successfully predict the deviation from the classical theory in the experiment, and suggest the importance of considering both low and high frequency phonons at room temperature to capture the experimental results. In the second part of this study, we look into the gas-surface interactions for conventional gas dynamics when the gas flow is rarefied. An extension to the well-known Maxwell boundary conditions for gas-surface interactions are obtained by considering velocity dependency in the reflection kernel from the surface. This extension improves the Maxwell boundary conditions by providing an extra free parameter that can be fitted to the experimental datafor thermal transpiration effect in non-equilibrium flows. The velocity dependent Maxwell boundary conditions are derived for the Direct Simulation Monte Carlo (DSMC) method and theregularized 13-moment (R13) equations for conventional gas dynamics. Then, athermal cavity is considered to test and study the effect of these boundary conditions on the flow formation in the slip and early transition regime. It turns out that using velocity dependent boundary conditions allows us to change the size and direction of the thermal transpiration force, which leads to marked changes in the balance of transpiration forces and thermal stresses in the flow.

An Introduction to Fluid Mechanics and Transport Phenomena Springer Science & Business Media
The well known transport laws of Navier-Stokes and Fourier fail for the simulation of processes on lengthscales in the order of the mean free path of a particle that is when the Knudsen number is not small enough. Thus, the proper simulation of flows in rarefied gases requires a more detailed description. This book discusses classical and modern methods to derive macroscopic transport equations for rarefied gases from the Boltzmann equation, for small and moderate Knudsen numbers, i.e. at and above the Navier-Stokes-Fourier level. The main methods discussed are the classical Chapman-Enskog and Grad approaches, as well as the new order of magnitude method, which avoids the short-comings of the classical methods, but retains their benefits. The relations between the various methods are carefully examined, and the resulting equations are compared and tested for a variety of standard problems. The book develops the topic starting from the basic description of an ideal gas, over the derivation of the Boltzmann equation, towards the various methods for deriving macroscopic transport equations, and the test problems which include stability of the equations, shock waves, and Couette flow.

The Mathematical Theory of Dilute Gases John Wiley & Sons
From Kinetic Models to Hydrodynamics serves as an introduction to the asymptotic methods necessary to obtain hydrodynamic equations from a fundamental description using kinetic theory models and the Boltzmann equation. The work is a survey of an active research area, which aims to bridge time and length scales from the particle-like description inherent in Boltzmann equation theory to a fully established “continuum” approach typical of macroscopic laws of physics.The author sheds light on a new method—using invariant manifolds—which addresses a functional equation for the nonequilibrium single-particle distribution function. This method allows one to find exact and thermodynamically consistent expressions for: hydrodynamic modes; transport coefficient expressions for hydrodynamic modes; and transport coefficients of a fluid beyond the traditional hydrodynamic limit. The invariant manifold method paves the way to establish a needed bridge between Boltzmann equation theory and a particle-based theory of hydrodynamics. Finally, the author explores the ambitious and longstanding task of obtaining hydrodynamic constitutive equations from their kinetic counterparts. The work is intended for specialists in kinetic theory—or more generally statistical mechanics—and will provide a bridge between a physical and mathematical approach to solve real-world problems.