Preface

This book aims to explain recent developments in Rational Extended Thermodynamics (RET), in particular those that have occurred since the publication of the book Rational Extended Thermodynamics, Second Edition (Springer, New York, 1998) by Ingo Müller and Tommaso Ruggeri.

RET is a phenomenological field theory capable of describing nonequilibrium phenomena with steep gradients and rapid changes in space-time out of local equilibrium. Classical thermodynamics of irreversible processes (TIP) relies essentially on the assumption of local equilibrium. Therefore, the validity range of RET is wider than that of TIP. Moreover, RET can predict the finite speed of disturbances because its basic system of field equations is hyperbolic. In contrast, TIP predicts the infinite speed of disturbances because of its parabolic character, which is fatal in a relativistic framework.

RET was strongly motivated by—and is in perfect agreement with—the kinetic theory, in particular, the system of moment equations derived from the Boltzmann equation. In RET, the differential system is closed by the universal principles: the objectivity principle, the entropy principle, and the principle of causality and stability. This permits an intimate connection between RET and the mathematical theory of hyperbolic systems with convex extension (symmetric systems). It is, therefore, possible to give a qualitative analysis, and the Cauchy problem is well posed. For example, a well-known theory of viscous heat-conducting fluids based on TIP is the classical Navier-Stokes-Fourier theory with five independent field variables: the mass density, the velocity and the temperature. On the other hand, RET adopts more independent field variables by incorporating nonequilibrium variables such as viscous stress and heat flux into the theory.

The limitation of the previous RET is, however, that its validity range has been restricted to rarefied monatomic gases. The present book presents the recent results that have overcome this limitation, that is, the results concerned with polyatomic gases, moderately dense gases, and mixtures of gases with multi-temperature.

The features of the book may be summarized as follows:

- We firstly explain the results of RET in the case of monatomic gases briefly, which are necessary to understand the progress in the new approach of RET.
- We present the hyperbolic theory of polyatomic and moderately dense gases with 14 fields, which, in the parabolic limit, reduces to the Navier-Stokes-Fourier theory. The singular limit of the theory of monatomic gases with 13 fields is also considered.
- We present some typical applications of the theory: sound wave, light scattering, shock wave, heat conduction, fluctuation. We compare the theoretical results with experimental data.
- The 14-field theory gives us a complete phenomenological model, but its differential system is rather complex. For this reason, we have constructed a simplified theory with six fields. This simplified theory preserves the main physical properties of the more complex theory of 14 variables, in particular when the bulk viscosity plays a more important role than the shear viscosity and the heat conductivity. This situation is observed in many gases such as rarefied hydrogen gases and carbon dioxide gases at some temperature ranges. This model is particularly interesting because it is also valid in a situation far from equilibrium.
- We present a theory of *molecular* RET with an arbitrary number of field variables by using the method of closure based on both the maximum entropy principle and the entropy principle. And we prove that two closures are equivalent.
- Recent results in respect of mixtures of gases with multi-temperature are presented together with a natural definition of the average temperature.
- Qualitative analysis of the differential system is done by taking into account the fact that, due to the convexity of the entropy, there exists a privileged field (*main field*) such that the system becomes symmetric hyperbolic. The existence of the global smooth solution and the convergence to equilibrium are also studied.
- We summarize open problems and try to provide an outlook on future studies.

This book is designed for applied mathematicians, physicists, and engineers. We hope that the methodology presented can offer powerful models for possible applications to, say, re-entry of a satellite into the atmosphere of a planet, semi-conductors, and nano-scale phenomena.

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