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Introduction

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The papers presented in this volume are dedicated to Matthieu H. Ernst on the occasion of his 60th birthday by many of his friends and colleagues. The breadth of topics covered here represents the many areas of nonequilibrium statistical mechanics addressed by Matthieu's own research over the past 35 years. A characteristic of his research always has been the identification of a fundamental new concept or tool, and exploration of its consequences through a detailed and systematic analysis. In this respect he is a splendid example of the Dutch "school" of statistical mechanics which has been so productive during this century. The work of Matthieu and his collaborators on a given topic is exhaustive, is an area of completed investigation for critical assessment of concepts, and is a secure basis for future inquiry. The topics Matthieu has addressed include the density dependence of transport coefficients, the algebraic decay of time correlation functions, the formal kinetic theory of dense hard spheres, exact solutions of the nonlinear Boltzmann equation, the kinetics of aggregation and gelation, the dynamics of lattice gas cellular automata, the chaotic properties of Lorentz lattice gases, and the kinetic theory of models exhibiting granular flow. As a result of his many contributions to statistical mechanics, Matthieu has often been an invited speaker at major international conferences and summer schools, has been on the Board of Editors of the *Journal of Statistical Physics*, and has served as the representative of the Netherlands on the IUPAP Commission for Statistical Physics.

Matthieu's thesis Work at Amsterdam in 1965, under the scientific direction of E. G. D. Cohen, appeared as the culmination of a rich decade in the development of nonequilibrium statistical mechanics and the beginning of another decade of intense and fruitful research in kinetic theory. The earlier concepts of Onsager and Machlup used to provide a statistical basis for macroscopic hydrodynamics had just been implemented by the development of linear response methods, leading to the important new formal results such as Green–Kubo expressions for the transport coefficients in the

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hydrodynamic equations. In parallel, the functional method of Bogoliubov was systematized by Green, Cohen, and others and led to formal virial expansions for the generalized Boltzmann transport equation for dense gases and for the transport coefficients for these gases. One of the contributions of Matthieu's thesis was a verification that the density expansion of the Green–Kubo expressions yields results equivalent to those obtained from the generalized Boltzmann equation. This equivalence showed that either kinetic theory methods or time correlation function methods could be used to study transport coefficients. However Ernst pointed out in his thesis that the coefficients in the virial expansions are the long-time limits of time-dependent expressions and the virial coefficients for transport coefficients are only useful if the expressions converge on time scales long compared to the time it takes for systems of a few particles to cease interacting. It was soon realized, partly as a result of Matthieu's thesis, that these expressions diverge due to sequences of correlated binary collisions among four or more particles in three dimensions, or three or more particles in two dimensions.

The dominant mechanism for these secular terms in the density expansion are correlated sequences of s binary collisions among s particles, where $s \geqslant 3$. It was recognized that such long-time collision events are unphysical artifacts of the density expansion—correlated collision events should be attenuated by collisional damping due to the rest of the particles. The selective resummation of the most divergent secular terms confirmed this fact and led to the conclusion that the transport coefficients are nonanalytic functions of the density. Clarifying this issue, however, posed new conceptual problems about the separation of microscopic and macroscopic time scales. The contributions from correlated collisions, even when resummed, lead to slow algebraic decays of the time correlations in the Green–Kubo expressions, the so-called "long-time tails." While these are integrable in three dimensions, leading to finite transport coefficients, they are not integrable in two dimensions so that the standard Navier–Stokes hydrodynamics does not exist in low dimensions. Even in higher dimensions, the time scale for dominance of a hydrodynamic description is not exponentially separated from that of the other microscopic modes. These conceptual problems and the collision mechanisms have been a recurring motivation for Matthieu's research in the subsequent 25 years. He and his collaborators, including E. Hauge, H. van Leeuwen, I. de Schepper, and H. van Beijeren, are certainly responsible for much of our current understanding of this evolving subject.

Much of Matthieu's research has focused on the hard-sphere system, which has the simplifying feature of a vanishingly small pair collision time. Exploitation of this fact, however, requires an extension of the Liouville dynamics to this singular potential. Together with W. Hoegy, H. van Leeuwen, and J. R. Dorfman, Matthieu devised the formal generators for the time dependence of a system of hard spheres. The pair potential is replaced by a binary scattering operator, but otherwise the many-body methods (e.g., cluster expansions) of nonequilibrium statistical mechanics can be implemented for a more direct study of complex many-body dynamical events. In this way, the kinetic theory for hard spheres has reached a quite sophisticated level, including quantitative accuracy almost up to the freezing transition; no comparable theory exists for any other potential. Together with his student, H. van Beijeren, Matthieu developed a formal kinetic theory for hard spheres that exposed qualitative features beyond those of density expansions and their resummations. For example, they revised the phenomenological Enskog kinetic equation and showed that the revised equation has the features needed for a correct nonequilibrium thermodynamics of pure fluids and mixtures, unlike the original Enskog equation. The revised Enskog equation entails the appearance of the exact equilibrium pair correlation function as a functional of the local density. This revision has been shown to extend the applicability of the kinetic theory to crystalline as well as to fluid phases. An interesting new study of elastic constants, transport coefficients, and broken symmetry effects for the hard-sphere crystal has been launched by Matthieu and his collaborators.

During the early 1980s there were several new developments in classical kinetic theory. One was the discovery of a rare exact solution to the nonlinear Boltzmann equation. A second class of developments related to the critical kinetics of coagulation and gelation. Together with E. Hendriks and R. Ziff, Matthieu explored a class of exact solutions to the Boltzmann equation and related kinetic equations for gelation and coagulation. This was followed by his study of a number of models for clustering, polymerization, and scaling, including, of course, asymptotic dynamics and asymptotic structures. An outgrowth of this interest in complex fluid behavior was his parallel interest in disordered lattice gases as discrete space models for phenomena such as percolation occurring in real fluids. More specifically, Matthieu was interested in exploring and testing kinetic theory methods developed for real fluids to describe the long-time tails and their applicability to complex processes such as percolation. As usual, much of this work was done in collaboration with his students in Matthieu's methodical fashion. The existing literature was transformed into the language of statistical mechanics and kinetic theory, and the diagrammatic resummations of the (repeated) ring kinetic theory identified and applied in detail to the bond and site percolation problems.

The explicit construction of fluid-type cellular automata by U. Frisch, B. Hasslacher, and Y. Pomeau in 1986 provided the first fully discrete space-time microdynamics consistent with the Navier–Stokes equations on the macroscopic scale. The potential for a more complete investigation of the long-time dynamics and its consequences for hydrodynamics was irresistible to Matthieu. Most of the early work by others was phenomenological and directed at effective computer simulation of high-Reynolds-number flow. Matthieu started from the basics, formulating the statistical mechanics for these discrete systems and then extending the many-body methods from continuous space-time non-equilibrium statistical mechanics (e.g., linear response theory, kinetic theory). He carried out an exhaustive study of equilibrium time correlation functions and their long-time dynamics. For a large class of cellular automata detailed calculations were performed that were suitable for stringent tests by computer simulation as a function of the model parameters (density, scattering law). In parallel, his collaborator D. Frenkel devised a novel means to extend the simulations several orders of magnitude longer in time for the special case of tagged particle motion. Frenkel and Ernst now have confirmed in great detail the existence of the long-time tails and the relevance of the ring kinetic theory for their quantitative description. More recent work has demonstrated the ability of the kinetic theory to describe the short- and intermediate time behavior as well. Since the consequences of these effects imply qualitative changes in our thinking about macroscopic dynamics, their quantitative validation for these models is of great importance.

Most recently, Matthieu has focused his attention on the dynamics of hard spheres with inelastic collisions. The qualitative features of this system are expected to represent those found in granular flows. Current phenomenology assumes a fluid dynamics description at the macroscopic level, although the origin of the hydrodynamic equations and associated transport coefficients have come from analogy with that for normal fluids. The physics community has approached this problem from a more fundamental point of view, mainly via computer simulation, with a number of provocative new results. Matthieu and collaborators have returned to the basics: formulation of the nonequilibrium statistical mechanics, kinetic theory, and application of methods from the theory of normal fluids. Past experience assures interesting new results for this field from him and his collaborators.

Matthieu and his collaborators have taken up the study of the chaotic properties of the systems he has studied by kinetic theory methods. Here one is interested in finding out how the transport properties of systems reflect the underlying chaotic dynamics that appears to be responsible for the approach to equilibrium. Matthieu, together with H. van Beijeren, C. Appert, and J. R. Dorfman, has a paper in this volume—submitted without his knowledge by his coauthors—which explores the chaotic properties of Lorentz lattice gases as simple examples of systems with interesting transport and chaotic properties. Remarkable new results are obtained which indicate how rich and exciting this new direction in transport theory may be.

It is difficult to assess the relative contributions of Matthieu Ernst as a creative scientist, an excellent mentor of young scientists, and instructor/provocateur of those fortunate to be his collaborators. His measure in all these respects is exceptional. The published work speaks for itself, often most directly in the large number of review articles for workshops and summer schools. More subtle but with equal impact is the influence on his students who will carry forward his style of methodical analysis of critical questions in nonequilibrium statistical mechanics.

In closing this introduction to Matthieu's work and accomplishments, we cannot fail to mention his wife, Liesje, and the important role she plays in the life of Matthieu and the lives of his students and collaborators. A gifted and busy artist, Liesje has nevertheless managed to be a source of encouragement and support to Matthieu and his many friends and colleagues. Certainly a primary reward for those working with Matthieu is the close friendship that his colleagues develop with Liesje as well. In a very real sense this volume is a tribute to them both.