Lecture Notes in Physics

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199

Recent Developments in Nonequilibrium Thermodynamics

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CONTENTS

LECTURES

EARLY APPLICATIONS OF EXTENDED IRREVERSIBLE THERMODYNAMICS

R.E. Nettleton ................................................... 1

Introduction
Non-equilibrium thermodynamics of relaxation without inertial effects
Inertial effects in thermal conduction and diffusion
Scalar rate processes
Viscoelasticity in polycrystals
Microscopic approaches
Thermodynamic theorems
Review and discussion

EXTENDED THERMODYNAMICS - PAST, PRESENT, FUTURE

I. Müller ........................................................ 32

Introduction.
Extended thermodynamics as part of linear irreversible thermodynamics and its motivation by kinetic theory of gases
Rational thermodynamics of non-reacting simple mixtures
Extended thermodynamics as part of rational thermodynamics with Lagrange multipliers
Outlook

AN APPROACH TO EXTENDED IRREVERSIBLE THERMODYNAMICS

I. MACROSCOPIC ASPECTS

G. Lebon ......................................................... 72

Introduction
The theories of non-equilibrium thermodynamics
The rigid heat conductor
The extended theory of thermo-viscous fluids
Concluding remarks

II. FLUCTUATION THEORY

J. Casas-Vázquez and D. Jou .................................... 105

Introduction
A physical interpretation of the nonequilibrium entropy
Equilibrium fluctuations of dissipative fluxes
IV

Nonequilibrium fluctuations of dissipative fluxes
Equilibrium third moments and nonequilibrium second moments of
fluctuations of dissipative fluxes
Nonequilibrium heat fluctuations in solids: comparison with an in-
formation theoretical approach
Electric current fluctuations
Conclusions

III. NONEQUILIBRIUM EQUATIONS OF STATE AND COMPARISON WITH GENERALIZED
HYDRODYNAMICS

C. Pérez-García ................................................... 124
Introduction
EIT again
Time correlation functions
Nonequilibrium corrections to the thermodynamic variables
Generalized equations of state in nonequilibrium systems
Final remarks

EXTENDED IRREVERSIBLE THERMODYNAMICS AND CHEMICAL KINETICS

L. S. García-Colín ........................................... 144
Introduction
Review of standard concepts
Fluctuations in chemical systems
Flux-force relations in chemical systems
Chemical fluctuations in EIT

NONSTATIONARY RELATIVISTIC THERMODYNAMICS AND SOME COSMOLOGICAL PROBLEMS

D. Pavón .......................................................... 166
Introduction
Formal development of NSRT
Cosmic evolution and NSRT
Entropy production in the leptonic period
Survival of protogalaxies
Phenomenological coefficients of radiative fluids

GENERALIZED GIBBS EQUATIONS IN IRREVERSIBLE THERMODYNAMICS

B. C. Eu ........................................................... 176
Introduction
Kinetic theory, modified moment method and generalized Gibbs rela-
tion
Axiomatic formulation of irreversible thermodynamics
Variational principle
Nonlinear transport processes
Concluding remarks

NONEQUILIBRIUM THERMODYNAMICS: A HIDDEN VARIABLE APPROACH

F. Bampi and A. Morro .............................................. 211

Introduction
Materials with hidden variables
Macromolecular solutions and electromagnetic continua through hidden variables
Linear thermo-viscous fluids
An application of the viscous fluid model: ultrasonic attenuation in metals
Rate-type materials as systems with hidden variables
Hidden variable thermodynamics and extended irreversible thermodynamics

FLUCTUATIONS AROUND EQUILIBRIUM

J. M. Rubí .......................................................... 233

Introduction
Fluctuations of thermodynamical and non-thermodynamical quantities.
Einstein theory.
Onsager reciprocal relations
The Gaussian-Markov process
The fluctuation-dissipation theorem
Long time tails
Light scattering

THEORIES OF FLUCTUATIONS IN NONEQUILIBRIUM SYSTEMS

A.-M. S. Tremblay ............................................... 267

Introduction
Equilibrium statistical mechanics
Fluctuations in dissipative steady states
A short overview of some of the current literature on nonequilibrium fluctuations
MICROSCOPIC APPROACHES TO NONLINEAR HYDRODYNAMICS

J.J. Brey ........................................................ 316

Introduction
Formal solutions of the Liouville equation
Gradient expansion of transport equations
The time correlation functions in the ring approximation
Long time tails
Other results and some comments

UNIFIED THEORY OF INTERNAL AND EXTERNAL FLUCTUATIONS

J.M. Sancho and M. San Miguel ........................................ 337

Introduction
Standard approaches to internal and external fluctuations
Unified theory of internal fluctuations and external gaussian white noise
A chemical example

DYNAMICS OF NONEQUILIBRIUM TRANSITIONS

M. San Miguel .................................................... 353

Introduction
Fluctuations in a periodically driven system
Escape times: effect of nonmarkovicity and multiplicative fluctuations
Relaxation time in systems driven by external noise

NOISE IN ELECTRICAL SYSTEMS

J.E. Llebot ...................................................... 372

Introduction
Some elements of noise theory
Flicker noise
Some theoretical models for Flicker noise

SEMINARS

FUNDAMENTAL REMARKS ON EVALUATING DISSIPATION INEQUALITIES

W. Muschik ....................................................... 388

ON CLASSICAL NONEQUILIBRIUM THERMODYNAMICS AND ITS EXTENSIONS

S. Lengyel ....................................................... 398
ON EXTENDED ONSAGERIAN THERMODYNAMICS
D.K. Bhattacharya ........................................ 407

RELATIVISTIC GENERALIZED HYDRODYNAMICS
M.L. Ekiel-Jezewska and L.A. Turek ................................................ 414

VARIATIONAL PRINCIPLES IN EXTENDED IRREVERSIBLE THERMODYNAMICS.
APPLICATION TO HEAT AND MASS TRANSFER
S. Sieniutycz ................................................ 421

EXTENDED THERMODYNAMICS OF DENSE GASES
G.M. Kremer and C. Beevers ........................................ 429

STEADY STATES RESULTING FROM COUPLED CHEMICAL OSCILLATORS
K. Bar Eli ................................................ 437

FLUCTUATIONS IN NON-LINEAR VISCOELASTIC SYSTEMS
G. Brunk ................................................ 446

VISCOELASTIC MODELS FOR BROWNIAN MOTION IN FLUID WITH SPIN
A. Pérez-Madrid and J.M. Rubí ........................................ 454

CORRELATION FUNCTIONS OF PROCESSES DRIVEN BY EXTERNAL COLORED NOISE
A. Hernández-Machado and M. San Miguel ........................................ 461

A NON-RENORMALIZED AND A RENORMALIZED DESCRIPTION OF THE
FOKKER-PLANCK DYNAMICS
F. Sagués and L. Garrido ........................................ 468

THE EQUATION WHICH GOVERNS IRREVERSIBILITY IN CONTINUUM MECHANICS
A. Paglietti ................................................ 474

NONEQUILIBRIUM STATISTICAL MECHANICS OF DILUTE RELATIVISTIC PLASMAS
X. Barcons and R. Lapiedra ........................................ 482

LIST OF PARTICIPANTS ........................................... 484
Nonequilibrium thermodynamics and statistical physics are nowadays such active and fast-developing fields that, in the lapse of a five-day autumn school, only a few selected topics can be discussed. The themes developed during the 1983 session of the "Escuela de Termodinámica de Bellaterra" (ETB) mainly concerned extended irreversible thermodynamics and its connection with fluctuation theory and kinetic theory of gases.

By extended irreversible thermodynamics (EIT) is meant a theory wherein the dissipative fluxes (heat flux, viscous pressure tensor...) are considered as independent variables. This is at variance with the classical thermodynamic theories, wherein the fluxes are dependent quantities related to the spatial derivatives of the conserved variables (density, concentrations, temperature ...).

High-frequency experiments have emphasized the need to consider the inertial (relaxational) effects of the fluxes when the frequency of the experiment becomes comparable to the inverse of the relaxation times of the fluxes. The latter become "slow" variables and must be included among the set of basic variables. As a consequence, EIT is no longer based on the local equilibrium hypothesis and provides therefore an extension of the classical thermodynamics of irreversible processes. For the present time, EIT is not a univocal theory, but assumes many faces: some are based on purely macroscopic arguments, others are described in a mesoscopic framework (fluctuation theory) or are motivated by microscopic bases like the kinetic theory of gases.

EIT is especially useful in treating high-frequency phenomena (ultrasounds, light and neutron scattering) and in describing systems with relatively long relaxation times (solids at low temperatures, superfluids, rarefied gases, some viscoelastic fluids ...).

The beginning of EIT may be traced back to Maxwell (1867) who included relaxational terms in his kinetic study of fluids. In the 1940's, Grad amplified Maxwell's method and elevated clearly the heat flux and the viscous pressure tensor to the status of independent variables. Cattaneo and Vernotte showed explicitly that the use of relaxational relations for the heat flux avoids the paradox of the propagation of temperature signals with an infinite speed. In the meantime, Machlup,
Onsager and Landau carried out some formal developments based on Onsager's identification of thermodynamic fluxes as time derivatives of state variables. Unfortunately, although this formalism allows for considerable simplification and an elegant presentation, it cannot be extended to such complicated systems as those encountered in hydrodynamics. At the end of the 50's, Nettleton (this volume) proposed a model describing viscoelastic and heat relaxations in fluids; however, at that time, Nettleton's ideas did not receive a sufficient audience. Unaware of Nettleton's contribution, Müller (this volume) developed in 1967 a formalism widely inspired by the kinetic theory with the specific aim of circumventing the problem of the infinite speed of propagation of thermal and viscous disturbances. But Müller did not pursue his work along this line. Later, in 1973, Lambermont and Lebon (this volume) rediscovered a generalized Gibbs equation leading to Maxwell-Vernotte-Cattaneo equations. Lebon's work, along with the collaboration with the group of the Autonomous University of Barcelona, contributed widely to the revival of the theory. It should also be mentioned that independently of the above-mentioned people, other researchers were very active in this field or in connected domains. Among them, let us quote Meixner, Nonnenmacher in Germany, Bampi and Morro (this volume), Ruggeri, Anile in Italy, Gyarmati’s group in Budapest (see Lengyel and Bhattacharya's contributions in this volume), García-Colín's (this volume) group in México, Eu (this volume), Grmela, Kranys, Israel in Canada, Kluitenberg in the Netherlands, Woods in the U.K., Hanley, Evans in the U.S.A. ...

It was obviously impossible to gather all the people working in EIT, but it is the editors' opinion that the texts collected in the present volume provide a wide illustration of the actual state of the art. The reader will find a multifaced aspect of the theory with applications in several fields. As in the previous sessions of the Bellaterra School of Thermodynamics, the objective was to join the pedagogical trends of a school with the incentive of fresh information on topics of current interest. This has been the spirit that guided most of the participants at the ETB'83 and it is hoped that the present proceedings will contribute to consolidate and impel EIT.

In his lecture, Nettleton reviews his early applications of EIT. Amongst other contributions, note the use of Onsager relations which lead to a connection between several physical coefficients accessible to measurement. Müller presents a new version of EIT, strongly motivated by kinetic theory, and derives explicit expressions for the various parameters appearing in the formalism. The lectures by Lebon, Casas-Vazquez and Jou, and Pérez-García present the Liège-Bellaterra version
of EIT at different levels: Lebon examines the purely macroscopic aspects illustrated by rigid heat conductors and the one-component fluid. Casas-Vázquez and Jou review their contributions on fluctuation theory in EIT. This mesoscopic level of description provides interesting and original information on the macroscopic coefficients. Pérez-García analyzes the EIT equations of state and their relations with generalized hydrodynamics. García-Colín asserts that the usual irreversible thermodynamics description of chemical reactions may in fact be considered as a special form of EIT. This interpretation leads to some conceptual advantages and clarifies some aspects of the fluctuation theory. Pavón offers a panoramic view of the repercussions of EIT in cosmology, by means of a relativistic formulation of the theory. Eu reviews his own work on kinetic theory and EIT on the basis of his modified moment method and presents several physical applications in nonlinear domains. Bampi and Morro propose an alternative to EIT starting from hidden variables which finally turn out to be related to dissipative fluxes, and carry out a comparison between both formalisms. Other developments in EIT are found in the seminars by Lengyel, Bhattacharya, Ekiel-Jezewska and Sieniutycz.

Rubí discusses equilibrium fluctuations in hydrodynamics, stressing various particular aspects like the fluctuation-dissipation theorem, long time tails and experimental light scattering. This lecture is complemented by Tremblay who reviews the latest progress in nonequilibrium fluctuations, mainly in hydrodynamical and electrical systems, with Brillouin light scattering as an example of comparison between theory and experiment. Brey presents some new ideas and results in higher-order hydrodynamics of simple fluids using a nonlinear response formalism in statistical mechanics. Sancho and San Miguel propose a unified theory of internal and external fluctuations and San Miguel studies the influence of fluctuations in the dynamics of nonequilibrium transitions. Llebot accounts for some applications of fluctuation theory to noise in electrical systems. Other recent topics have been treated in the seminars by Muschik, Bar-Eli, Brunk, Pérez-Madrid and Rubí, Hernández-Machado and San Miguel, Sagués and Garrido, Paglietti and Barcons and Lapiedra.

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J Casas-Vázquez, D. Jou and G. Lebon