Kinetic equation for strongly interacting dense Fermi systems

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ABSTRACT

We review the non-relativistic Green’s-function approach to the kinetic equations for Fermi liquids far from equilibrium. The emphasis is on the consistent treatment of the off-shell motion between collisions and on the non-instant and non-local picture of binary collisions.

The resulting kinetic equation is of the Boltzmann type, and it represents an interpolation between the theory of transport in metals and the theory of moderately dense gases. The free motion of particles is renormalised by various mean field and mass corrections in the spirit of Landau’s quasiparticles in metals. The collisions are non-local in the spirit of Enskog’s theory of non-ideal gases. The collisions are moreover non-instant, a feature which is absent in the theory of gases, but which is shown to be important for dense Fermi systems.

In spite of its formal complexity, the presented theory has a simple implementation within the Monte-Carlo simulation schemes. Applications in nuclear physics are given for heavy-ion reactions and the results are compared with the former theory and recent experimental data.

The effect of the off-shell motion and the non-local and non-instant collisions on the dynamics of the system can be characterised in terms of thermodynamic functions such as the energy density or the pressure tensor. Non-equilibrium counterparts of these functions and the corresponding balance equations are derived and discussed from two points of view. Firstly, they are used to prove the conservation laws. Secondly, the role of individual microscopic mechanisms in fluxes of particles and momenta and in transformations of the energy is clarified.
Nous examinons la technique des fonctions de Green non relativistes appliquée aux équations cinétiques pour les liquides de Fermi hors équilibre. L’accent est mis sur le traitement cohérent des effets hors couche entre les collisions ainsi que sur l’aspect non local et non instantané des collisions binaires.

L’équation cinétique résultante est de type Boltzmann et représente une interpolation entre la théorie du transport dans les métaux et la théorie des gaz modérément denses. Le mouvement libre des particules est renormalisé par diverses corrections de masse et de champ moyen dans le même esprit que pour les quasi-particules de Landau dans les métaux. Les collisions sont non locales au sens de la théorie d’Enskog des gaz réels. De plus ces collisions ne sont pas instantanées, caractéristique absente de la théorie des gaz, mais dont nous montrons l’importance dans les systèmes de Fermi denses.

Malgré sa complexité formelle, la théorie que nous présentons est facile à implanter dans les simulations Monte-Carlo. Nous appliquons notre méthode aux réactions d’ions lourds en physique nucléaire et confrontons les résultats à ceux de l’ancienne théorie ainsi qu’aux données expérimentales récentes.

Les effets hors couche, de la non localité et de la non instantanéité des collisions sur la dynamique du système peuvent se traduire en termes de fonctions thermodynamiques telles que la densité d’énergie ou le tenseur de pression. Nous explicitons les équivalents hors équilibre de ces fonctions ainsi que les équations bilans associées et nous les discutons de deux points de vue différents: premièrement pour prouver les lois de conservation et deuxièmement pour clarifier le rôle des mécanismes microscopiques individuels dans les flux de particules ou d’impulsions et dans les transformations de l’énergie.
1. INTENTION

The initial intention was to prepare a review article which covers the latest progress in a variety of physical fields dealing with non-equilibrium many-body systems. During the last decade, kinetic theories developed within the chemical, nuclear, plasma and solid-state physics have started to merge whereas previously they were based on rather distinct approaches. It turned out that to cover all essential concepts on a basis of a unified theory exceeds the frame of a review article. We have been encouraged by a community of theoretical physicists to extend the manuscript into a monograph.

The manuscript is aimed for a wide audience of theoretical physicists interested in non-equilibrium many body systems. Selected chapters can be studied by advanced undergraduate students. Advanced chapters (denoted by stars) are addressed to a growing community of physicists having at least rudimentary knowledge of Green’s functions. We expect particular interest from physicists involved in nuclear matter only for which field we give applications as not to drive reader’s attention into many directions. For non-experts in nuclear matter, we first review properties of nuclear matter which are discussed in the light of experience from other fields.

The first part reviews selected work from kinetic theories of five different systems: moderately dense gases, electronic Fermi liquids in metals, electronic transport in semiconductors, non-ideal plasma, and nuclear matter. These scattered topics are used to introduce and enlighten physical properties studied later within the kinetic theory.

The second part provides the rigorous derivation from non-equilibrium quantum statistics. All steps are introduced in their historical background, from the simplest approximations to their recent form. This scheme allows the reader to benefit from preliminary knowledge of the kinetic theory (the rudimentary kinetic theory belongs to introductory courses for physicists) and to identify a suitable point to start.

The third part discusses the kinetic theory and its implementation to nuclear physics. In the figures we present realistic values of important physical quantities and demonstrate the accuracy of various approximations. This
part also provides practical advice for implementation of non-local corrections into numerical treatments. They are explained in the context of quantum-molecular-dynamics simulations of heavy ion reactions.

The fourth part is devoted to thermodynamic properties implied by the kinetic theory. It includes the law of acting masses, the particle flows, the density of energy, and the stress tensor. These properties are discussed on two levels, from balance equations and from their quantum statistical definitions. The first level, which explains a link between the kinetic theory and thermodynamics, allows the reader to learn thermodynamic relations in an easy way. The second level is aimed for experts in non-equilibrium quantum statistics. We prove the internal consistency of the kinetic theory and discuss shortcomings of previous approaches.

The text is structured so that a reader not interested in technical details can follow selected chapters. In this case, the reader will approach the theory from the quasiclassical picture and learn how to implement it in practise.
2. SOURCE

The full text of the book is available at:

http://www.ed-phys.fr/articles/anphy/abs/2001/01/annales012001/annales012001.html

or can be ordered as book: ISBN: 2-86883-541-4

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