Applications of transport models in the study of quantum plasmas

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Abstract

The present work is devoted to the development and application of various transport models to the study of dynamic phenomena characteristic to complex many-body quantum systems such as quantum plasmas are. In particular, several theoretical models used in literature are corrected or improved, at least partially. The applicability of the resulting models is tested against other, more precise theories or experimental results regarding realistic systems such as metal clusters, fullerenes or turbulent 2D electron gas.

Keywords: plasma; quantum; transport
Domain: Physics
Section: Elaboration of the doctoral thesis

Motivation

A quantum plasma is, by definition, a plasma with a dynamic dominated by quantum effects. In the recent decades, the subject has attracted considerable interest from the scientific community from both a theoretical and experimental perspective. This is due to the wide range of systems that can be associated with the concept of quantum plasmas and, especially, due to the impact which the understanding of such systems has on technological applications: future generations of nano-electronic devices, for example. The theoretical description and experimental handling of quantum plasmas remain "hot" topics with a number of open problems. In particular, transport phenomena characterize the dynamics, their understanding being of interest for any practical application.

Methodology of Research

The aim of this work is to bring new contributions to the theoretical description of transport phenomena characteristic to quantum plasmas. Several theoretical models which already exists in the scientific literature are extended in order to correct their various pathologies. The validity of the resulting models is extensively tested by comparing the resulting data against experimental results or results provided by more precise theories. Throughout this thesis, the transport models are classified in three main categories: microscopic, kinetic and macroscopic models.

Results and Comparison with State-of-the-art

From the category of microscopic models the RPA schematic model was extended to a model called NBSRPA by relaxing the condition of an unique coupling constant. Thus, it was obtained a method of describing normal modes in a finite quantum plasma (nano-plasma): faster than the standard RPA equations, with qualitatively correct results and with direct access to the physical interpretations of different resonances. The method is tested on sodium clusters and fullerene C60.

From the category of macroscopic models, the Schrodinger-Poisson system was extended to a model called Schrodinger-Poisson-Induction through the inclusion of a rotational (solenoidal) velocity _eld component. The time evolution of the latter is described by an induction equation. The resulting model is used to investigate the evolution of free turbulence in a two-dimensional quantum plasma. In particular, it was investigated the natural formation of direct-indirect cascades in the energy spectrum.

Chapter IV aims to solve one of the open problems of Density Functional Theory, namely, the structure of the density functional for the kinetic pressure tensor. The standard approximations used in literature (Thomas-Fermi-von-Weiszacker) are corrected through the addition of a novel, non-local, term such that the dispersion relation of plasma oscillation will be correctly reproduced within the Quantum Hydrodynamic Model. The quantitative improvements brought by the proposed functional are confirmed by extensive numerical tests on a series of model systems and the following atomic clusters: Na20, Na40 and C60.

Conclusions

In this work we have tackled three distinct transport models dedicated to quantum plasmas. These models suffer from various technical pathologies that we have managed to improve, at least in part. As a result, we end up with three new theoretical models. Their applicability is tested, yielding positive results, against more accurate theories or experimental data.

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