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**TECHNICAL REPORT**

**AOSR GRANT 92-J-0115**

**BASIC STUDIES IN PLASMA PHYSICS**

**February 1, 1992 — January 31, 1995**

by

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## Introduction

During the grant period we have carried out work on various aspects of plasma physics. These include theoretical studies of equilibrium and non-equilibrium properties of strongly coupled particle systems, and of the phenomena which take place when neutral or partially ionized atoms interact strongly with external fields and with each other in a plasma. The main tools of our study are statistical mechanics and kinetic theory, including the transition from a microscopic to a hydrodynamic description. Quantum mechanics plays a central role in many of these problems, and is an important ingredient in our work.

### 1. ELECTRON VELOCITY DISTRIBUTION IN A WEAKLY IONIZED PLASMA WITH AN EXTERNAL ELECTRIC FIELD

The velocity distribution  $f(v)$  of the electron component of a weakly ionized plasma is investigated in a spatially homogeneous external electric field  $E$ . Both static and time-dependent  $E$  are considered. The time evolution of  $f$  is described by a Boltzmann equation in which the ions and neutral particles are assumed to have a Maxwellian distribution with *a priori* specified temperatures while the electron-electron interactions are given by a Landau-type collision integral. The (approximate) solution scheme used to solve this equation for a stationary  $f$  (in a constant field) is found to have nonunique solutions for certain ranges of  $E$ , in agreement with that found in earlier investigations using a different method of solution. These results are interpreted to correspond to hysteresis effects when the field is changing very slowly: with the true stable solution undergoing a very sharp changeover, possibly a discontinuous transition, at a certain critical  $E$ . This can be understood intuitively as a transition in the stationary state of the electrons from a low-energy regime dominated by strong coupling to the ions to a high-energy regime dominated by electron-electron and electron-neutral collisions.

## 2. NONLINEAR RESPONSE OF A DISSIPATIVE BLOCH PARTICLE IN AN OSCILLATING FIELD

We study the Caldeira-Leggett model of a particle coupled to a heat bath moving in a periodic cosine potential. In the limit of small viscosity we obtain an integral equation for the nonlinear response of the system to a constant or a slowly oscillating field. The equation is derived by a resummation of the infinite series expansion in the strength of the cosine potential. When solved via a self-consistent approximation it gives an *analytic* expression for the response function. Applications to Josephson junctions driven by a low-frequency source are discussed.

## 3. ATOMIC VERSUS IONIZED STATES IN MANY-PARTICLE SYSTEMS AND THE SPECTRA OF REDUCED DENSITY MATRICES: A MODEL STUDY

We study the spectrum of appropriate reduced density matrices for a model consisting of one quantum particle ("electron") in a classical fluid (of "protons") at thermal equilibrium. The quantum and classical particles interact by a short-range, attractive potential such that the quantum particle can form "atomic" bound states with a single classical particle. We consider two models for the classical component: an ideal gas and the "cell model of a fluid". We find that when the system is at low density the spectrum of the "electron proton" pair density matrix has, in addition to a continuous part, a discrete part that is associated with "atomic" bound states. In the high-density limit the discrete eigenvalues disappear in the case of the cell model, indicating the existence of pressure ionization or a Mott effect according to a general criterion for characterizing bound and ionized electron proton pairs in a plasma proposed recently by M. Girardeau. For the ideal gas model, on the other hand, eigenvalues remain even at high density.

**LIST OF PUBLICATIONS**  
**SUPPORTED BY AFOSR GRANT**

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- [4] Generalized Gaussian Dynamics, Phase-Space Reduction, and Irreversibility: A Comment, (with G.L. Eyink), in Microscopic Simulations of Complex Hydrodynamics Phenomena, Proceedings of the NATO Advanced Study Institute, Alghero, 1991, Plenum, 1992
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- [6] Quantum Particle in a Washboard Potential - Part I: Linear Mobility and the Einstein Relation, (with Y.C. Chen), Phys. Rev. B, 46, 10743-10750, 1992
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- [15] Multidimensional Pattern Formation Has an Infinite Number of Constants of Motion, M.B. Mineev-Weinstein, submitted to *Physical Review A*, Rapid Communications.
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- [22] Stationary Shear Flow in Boundary Driven Hamiltonian Systems, (with N. Chernov), submitted to *Physical Review Letters*, 1994
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- [31] Kinetic Phase Transitions in the Electron Velocity Distribution in Homogeneous Plasmas, (with E. Carlen, R. Esposito, R. Marra and A.V. Rokhlenko), *Phys. Rev. E*, to appear
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