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TEMPORAL AND SPATIAL RELAXATION OF ELECTRONS IN MAGNETIZED LOW-TEMPERATURE PLASMAS

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Non-equilibrium, low-temperature plasma discharges sustained and controlled by electric and magnetic fields are widely used in materials processing, gas lasers and other applications. Within these discharges the electric and magnetic fields can vary in space, time and orientation depending on the type of discharge. One particular example of most recent interest for the authors is the magnetron discharge. This type of discharge is predominantly used in the sputtering deposition of thin films [1] where magnetic field confines energetic electrons near the cathode. These confined electrons ionize neutral gas and form a high density plasma near the cathode surface while heavy ions and neutrals impinge on the solid surface ejecting material from that surface which is then deposited on the substrate. Within these discharges the angle between the electric and magnetic fields varies and thus for a detailed understanding and accurate modeling of this type of discharge, a knowledge of both electron and ion transport in gases under the influence of electric and magnetic fields at arbitrary angles is essential.

Transport coefficients for electrons under steady-state conditions in electric and magnetic fields crossed at arbitrary angle are well-documented for oxygen (O_2) [2] and carbon-tetrafluoride (CF_4) [3]. In this work, we focus entirely on the transient behavior of electrons in model and real gases under conditions critical for the applications. Two different situations are considered: (i) temporal relaxation of the spatially inhomogeneous electron swarms in an infinite gas; and (ii) spatial relaxation of electrons under steady-state Townsend (SST) conditions. Similar transient studies under hydrodynamic conditions have previously been performed in pure dc electric fields (see for example [4]) and in dc electric and magnetic fields [5,6]. This study represents an extension of these previous works by considering temporal relaxation of spatially inhomogeneous electron swarms in electric and magnetic fields crossed at arbitrary angle when non-conservative collisions (ionization/attachment) are operative. We employ a recently developed time-dependent multi-term theory for solving the Boltzmann equation [7] and both the implicit and explicit effects of non-conservative collisions on the temporal relaxation profiles are considered using physical arguments. As an illustrative example, in Fig.1 we display the temporal relaxation profiles of the bulk and flux longitudinal diffusion coefficients for a range of applied reduced magnetic fields in a crossed field configurations for electrons in O_2.

In addition to the temporal relaxation of electrons under hydrodynamic conditions, in this work we study the spatial relaxation of electrons in an idealized SST experiment including a superimposed magnetic field at arbitrary angle with respect to the electric field. We demonstrate the ability of a magnetic field to control the spatial relaxation characteristics of electrons in the presence of non-conservative collisions. The influence of a magnetic field on the spatial relaxation characteristics is examined for certain model gases by numerical solutions of the Boltzmann equation and Monte Carlo simulation. It was shown that magnetic field strength and/or angle between the electric and magnetic fields has an ability to suppress or enhance the oscillatory feature in the spatial relaxation profiles as well as to modify the spatial relaxation distance. Of particular note for this work is the *two-term* Boltzmann equation study of Winkler *et al.* [8], who considered the explicit effect of a magnetic field on the relaxation of the electrons in neon in the absence of ionization. This study represents an extension of this work by (i) considering the explicit effects of non-conservative collisions when electric and magnetic fields are crossed at arbitrary angle; and (ii) using a multi-term solution of Boltzmann's equation capable of handling velocity distributions with strong anisotropy.

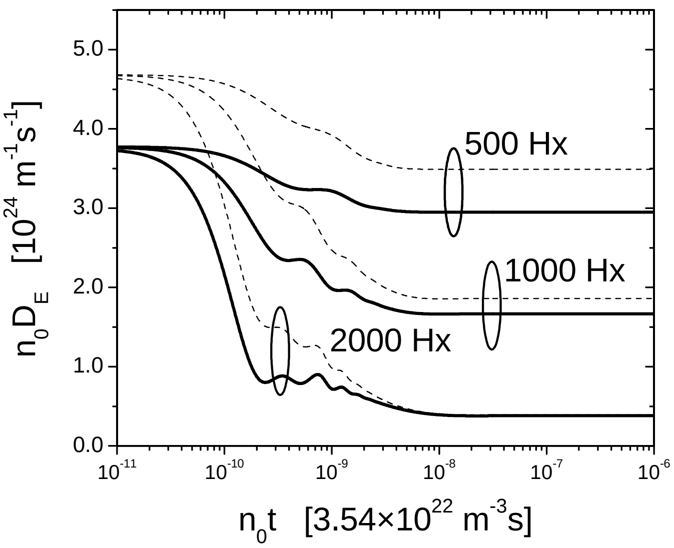

Fig. 1: Temporal relaxation of the longitudinal diffusion coefficient for various applied magnetic field strengths for electrons in molecular oxygen (E/n_0=270 Td). The dashed lines represent the bulk while the full lines represent the flux components.

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