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Kinetic and fluid descriptions of charged particle swarms in gases and nonpolar fluids: Theory and applications

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In this work we review the progress achieved over the last few decades in the fundamental kinetic theory of charged particle swarms with the focus on numerical techniques for the solution of Boltzmann's equation for electrons, as well as on the development of fluid models. We present a time-dependent multi term solution of Boltzmann's equation valid for electrons and positrons in varying configurations of electric and magnetic fields. The capacity of a theory and associated computer code will be illustrated by considering the heating mechanisms for electrons in radio-frequency electric and magnetic fields in a collision-dominated regime under conditions when electron transport is greatly affected by non-conservative collisions. The kinetic theory for solving the Boltzmann equation will be followed by a fluid equation description of charged particle swarms in both the hydrodynamic and non-hydrodynamic regimes, highlighting (i) the utility of momentum transfer theory for evaluating collisional terms in the balance equations and (ii) closure assumptions and approximations. The applications of this theory are split into three sections. First, we will present our 1.5D model of Resistive Plate Chambers (RPCs) which are used for timing and triggering purposes in many high energy physics experiments. The model is employed to study the avalanche to streamer transition in RPCs under the influence of space charge effects and photoionization. Second, we will discuss our high-order fluid model for streamer discharges. Particular emphases will be placed on the correct implementation of transport data in streamer models as well as on the evaluation of the mean-energy-dependent collision rates for electrons required as an input in the high-order fluid model. In the last segment of this work, we will present our model to study the avalanche to streamer transition in non-polar fluids. Using a Monte Carlo simulation technique we have calculated transport coefficients for electrons in liquid argon and liquid xenon. We employ the two model processes in which only momentum and only energy are exchanged to account for structure dependent coherent elastic scattering at low energies. The specific treatment of inelastic collisions in our model will be also discussed using physical arguments.