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Session Name: All

SEAM: 7 (1966)

SEAM EDX URL: https://edx.netl.doe.gov/dataset/seam-7

EDX Paper ID: 196

ELECTRON DISTRIBUTION FUNCTION AND NUMBER DENSITY IN A NONEQUILIBRIUM SEEDED GAS

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Abstract

In recent years there have been several theoretical and experimental investigations[1-8] of the electrical conductivity of noble gases seeded with cesium or potassium. The theoretical calculations have been based on two assumptions: a) that volume ionization and recombination are in Saha equilibrium at the electron temperature, and b) that the electron distribution function is nearly maxwellian. Assuming two- and three-level model cesium atoms and solving the rate equations for the bound electrons, BenDaniel and Tamor[9] indicated that, at least for their model atoms and assumed cross sections, assumption (a) is valid for esium number densities greater than)^{14} cm^{-3} and electron temperatures above .3 ev. Assumption (b) has not been ioroughly investigated, however. In fact, ie reason advanced for the lack of good reement between theory and experiment at w current densities is that the electron stribution function is not maxwellian, ing to the relatively low electron-ectron collision frequency.[3]

In general, it is incorrect to deal with these two assumptions separately, because they are coupled. The rates of excitation and ionization by electron impact, as well as the inverse processes of three-body de-excitation and capture, depend strongly on the distribution function of the free electrons. If this distribution is far from maxwellian, the free electron number density may depart widely from the Saha value.[10] Conversely, if the populations of the various atomic states depart from equilibrium, e.g., by radiative transitions, then the depletion of the tail of the free electron distribution by inelastic collisions will not be balanced by superelastic collisions.

A complete analysis of a gas discharge in which both free and bound electrons are out of equilibrium requires solution of (1) the Boltzmann equation for the free electrons, (2) the rate equations for the bound states, and (3) the equation of radiative transfer. Usually only one aspect of the problem is considered. This paper reports research in progress on parts (1) and (2).

As the first step, the isotropic part of the electron distribution function was calculated from a Boltzmann equation which included the acceleration of the electric field and elastic electron-electron, electron-atom, and electron-ion collisions. These calculations show that for discharges in atmospheric pressure argon seeded with potassium, the electron distribution function is maxwellian over the entire range of experimental current densities.[3-5] This conclusion holds even for $N_e = 3 \times 10^{12}$ cm^{-3}, whereas Kerrebrock[3] estimated that the distribution function is nonmaxwellian below $N_e = 10^{13}$ cm^{-3}.

As the second step, the departure of the bound and free electron populations from Saha equilibrium was investigated for a maxwellian free electron distribution, in order to assess the magnitude of the inelastic collision terms in the Boltzmann equation. Because these terms include superelastic processes, they vanish for complete bound-free equilibrium. A five-level model cesium atom was chosen, consisting of the 6s; 6p,p'; 5d,d'; 7s states, and a lumped state with a binding energy of 0.6 ev and a degeneracy of 50. Both the classical Bohr-Thomson and Gryzinski[11] cross sections were used to calculate the rate coefficients and collision terms for excitation, de-excitation, ionization and three-body capture. Some calculations were also performed using an experimental cross section[12] for the 6s$\rightarrow$6p,p' excitation. Spontaneous radiative transition probabilities for cesium were taken from Ref. 13. If the gas is assumed optically thick to all radiation, the ionization rate from the lumped state is by far the largest. In the opposite limiting case of a gas optically thin to all radiation, the depletion of the population of this state by downward radiative transitions is responsible for a large reduction in the free electron density, especially at low electron temperatures. Various intermediate cases are presented where the gas is optically thin to only certain lines. The inelastic collision terms are compared with the elastic terms in all these cases. In the optically thin cases, the former become comparable with the electron-electron collision term, hence it is expected that the electron distribution function will depart from maxwellian in these cases.

Work on the third phase of the problem, the simultaneous solution of the Boltzmann equation and the rate equations, is in progress, and the method of solution and preliminary results are presented.

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