T-4
Atomic & Optical Theory

Plasma Formation in the UCLA Large Plasma Device

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The LArge Plasma Device (LAPD) at UCLA is a linear plasma research facility primarily designed to study space plasma processes. A 2.95-k A-discharge current with a voltage near 50 V is used to create a 10-m-long plasma column with a diameter of 40 cm. A magnetic field of 1200 G is applied to confine the plasma. The plasma, which is formed from the interaction of the electrical discharge with the chamber gas, usually helium or argon, has densities in the 10^{12}- to 10^{13}-cm^{-3}-range and electron temperatures in the 5- to10-eV range. The geometry is well suited for making localized measurements of the plasma conditions. At early times in the discharge, the electron density builds up quickly due to the interaction of energetic primary discharge electrons with the target gas producing secondary electrons from electron impact ionization. In this phase, the electron energy distribution is highly non-Maxwellian, and the ionization rate of the plasma is unusually rapid. The bulk of the density is quickly formed by secondary electrons, which are Maxwellian in nature. The subsequent ionization is then determined by the action of these thermal electrons. Ionization in the plasma continues until the discharge current is switched off. The kinetics of plasma formation in the LAPD has been studied using the Los Alamos suite of atomic physics and kinetics codes. The codes are used to simulate a local volume element of the forming plasma. The results of the calculations provide a confirmation of the plasma conditions–an understanding of the important mechanisms involved in LAPD plasma formation–and a validation of the atomic physics models used in the codes.

Measurements of the emitted radiation can be compared to calculations to provide plasma diagnostics and additional confidence in the computational models.

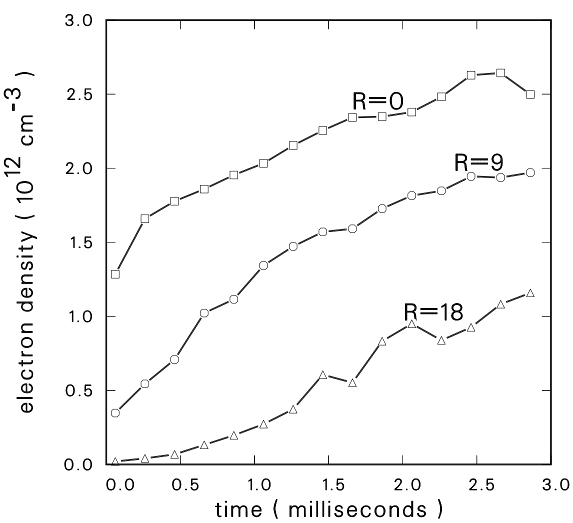

Figure 1a.

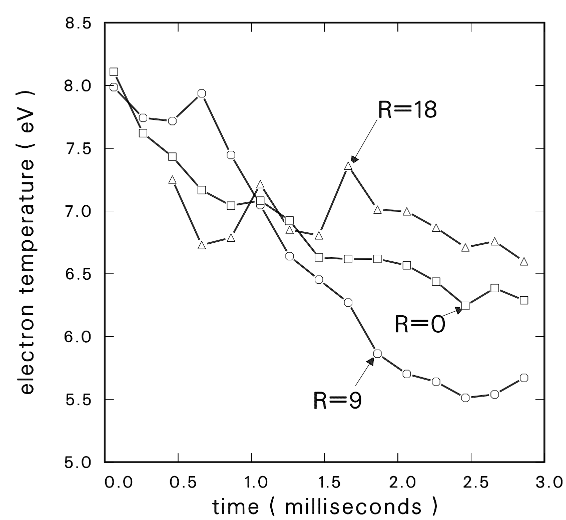

Figure 1b.

The electron density and electron temperature have been measured in a LAPD helium plasma at various times and locations during the discharge. These results are shown in Figures 1a and 1b. These measurements have been compared to the results of detailed time dependent atomic kinetics calculations using the Los Alamos codes. The kinetics calculations must include all the important atomic processes that can alter the populations of atomic levels existing in the plasma. Previous calculations for helium have considered only the steady state time-invariant case. Here, 300 coupled-rate equations are solved simultaneously as a function of time to predict level populations, and the free electron density using the measured temperature profile as input. The initial conditions for the integration were determined from the measured gas density of 2.6 ¥10^{12} cm^{-3}, the electron density at the earliest time point. Thus, the calculation involved no adjustable parameters. The calculated electron densities are compared to the measured values for radial positions of 0, 9, and 18 cm from the center of the plasma column in Figure 2. The results are in excellent agreement with experiment.

The rapid heating of electrons in the LAPD leaves the atoms in an under-ionized state relative to steady-state for the typical electron temperatures that are observed. Thus, the plasma populations are transient and require a time-dependent treatment. The good agreement between calculated and measured density provides an understanding of the experimental measurements, and confidence in the computational model. The plasma is observed to be nearly fully ionized to He^+ in the center of the column while it reaches only about 45% ionization at the edge. The model calculations are consistent with the measurements at three different radial positions using different initial conditions for the solution of the differential equations. The results show that bulk thermal secondary electrons control the plasma formation near the center of the column about 0.8 milliseconds earlier than at larger radial distances near the edge.

Additional calculations, not shown here, illustrate the importance of metastable excited atomic states in a transient plasma by comparing different atomic physics models with experiment. The results show a significant enhancement in ionization due to stepwise excitation-ionization of the metastable levels in neutral helium. Electron impact excitation builds up population in the long-lived metastable levels, which are then ionized directly by additional electron collisions. Inclusion of these levels proved to be essential to accurately predict the formation of the transient plasma encountered in the LAPD. The model was also tested for sensitivity to the various atomic processes included. The results suggest that collisional excitation, radiative decay, and collisional ionization are predominant in the formation of the LAPD helium discharge plasma, with collisional deexcitation making a small contribution. The influence of other processes such as three body recombination, radiative recombination, autoionization, and dielectronic capture appears to be negligible.

Possibilities for future collaborations include a study of early time behavior in the discharge where the primary current electrons are important. In addition, power balance calculations could be performed to predict local plasma conditions. The codes can also be used to study the cooling plasma after the discharge current has been switched off. Measurements of the emitted radiation can be compared to calculations to provide plasma diagnostics and additional confidence in the computational models. The models also can be extended to provide support for ongoing experiments in laser-induced fluorescence and for calculations involving other discharge gases.

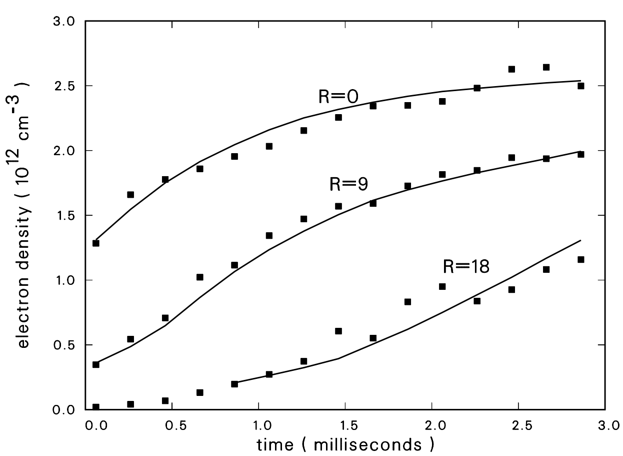

Figure 2.

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