# Stark broadening observations for a cool, dense plasma

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(Received 5 November 1996)

The impact-broadened linewidth of the Al II 467-nm line is compared with theory for ions embedded in plasma dense enough that the impact approximation becomes questionable, and where electron-electron correlations may be non-negligible. No significant difference in linewidth is found for plasmas in which the plasma parameter $g$ is as large as 0.8. [S1063-651X(97)03004-3]

PACS number(s): 52.70.Kz, 52.25.Rv, 52.80.Yr

Standard line-broadening theory [1] is explicitly valid for only a limited range of plasma electron density $n_e$ and temperature $T$. A principal result of this theory is that electron-radiator collisions induce Lorentzian spectral profiles with linewidths and shifts proportional to $n_e/T^{1/2}$. In the derivation of this relation, it has been assumed that there is no statistical correlation in the spatial positions of the free, perturbing electrons. Furthermore, computational simplifications implicit in the impact approximation require that an electron spend only a short time interacting with a radiator.

As the electron density increases and temperature decreases, electron-electron correlations are enhanced, since the pair correlation function is proportional to $g/8\pi$, where $g$ is the plasma parameter $g \equiv 1/N_D = 3/4\pi n_e \lambda_D^3$ with $N_D$ the number of particles in the Debye sphere and $\lambda_D$ the Debye length [2]. Furthermore, in cool, dense plasmas, the frequency width of the radiated spectral line (which is proportional to $n_e$) approaches the inverse of the electron-radiator interaction time (which is proportional to $n_e^{1/3}$), rendering the impact approximation questionable. The ratio of the frequency linewidth $\Delta f$ to the inverse interaction time is defined in this note by the parameter $\chi$. Noting that the frequency linewidth is proportional to $n_e/T^{1/2}$, we define a width parameter $a_\omega$ by $\Delta f = a_\omega n_e/T^{1/2}$. Previous comparison of measurements with theory have justified the small-$g$ and small-$\chi$ assumptions for $n_e = 10^{17}\text{cm}^{-3}$ and $T = 1.5$ eV, where $g = 0.10$ and $\chi = 0.006$ [3]. This note describes the results of experimental observations of the profile of the Al II 467-nm line in a high-density, low-temperature plasma in regimes where the Stark broadening theory assumptions are no longer obviously applicable.

A capillary discharge in which the plasma comprised wall-ablated material was used to generate an $n_e \sim 10^{18}\text{cm}^{-3}$, $T \sim 1$ eV plasma jet ($g = 0.82$ and $\chi = 0.07$) [4]. The jet, consisting of aluminum and oxygen, was exhausted from a 3-mm-diameter alumina discharge tube through a 3-mm-diameter hole in one of the Cu-W electrodes (Fig. 1). The discharge was driven by an overdamped $RLC$ circuit producing a current pulse having peak amplitude of 10 kA, and a duration of about 12 $\mu$sec. Plasma density was measured space and time resolved by observing the plasma

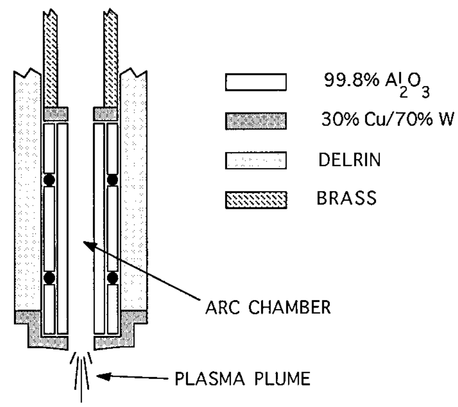


FIG. 1. The capillary discharge chamber.

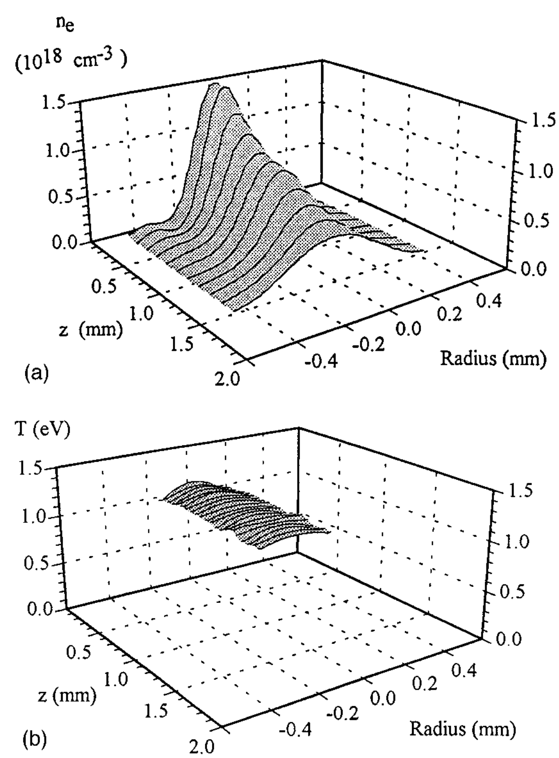


FIG. 2. (a) Electron-density spatial profile of capillary jet at time 12 $\mu$sec after the start of the current. (b) Temperature spatial profile of the capillary jet at time 12 $\mu$sec after the start of the current.

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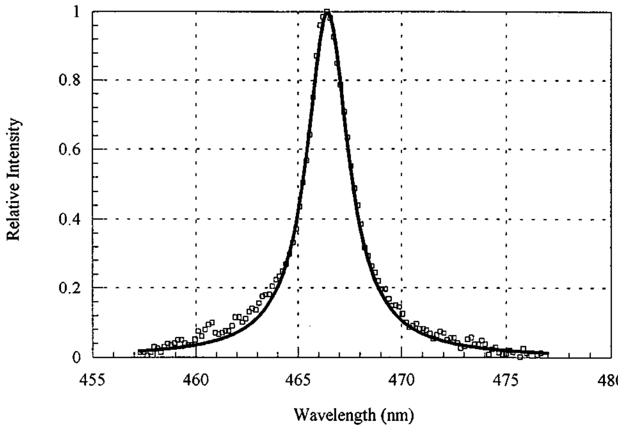


FIG. 3. Comparison of observed Al II 467-nm line shape (data points) with fitted line shape (solid line).

perpendicular to the axis of symmetry using a shearing plate imaging interferometer [5]. The chord-integrated phase-shift image obtained from the interferometer was Abel inverted to determine the radial and axial variation of $n_e$. The plasma temperature was also measured both time and space resolved. Separate images were made of the line and adjacent continuum emission in a direction perpendicular to the symmetry axis. These were Abel inverted to obtain the radial profiles of emission, and the ratio utilized to deduce the plasma temperature. Representative density and temperature spatial profiles are shown in Fig. 2.

The 467-nm Al II ion line emission was observed perpendicularly through the center of the jet at 0.2 mm from the discharge exhaust at the time of peak current, and a least-squares fit of the observed line shape to calculated chord-integrated line shape was performed (Fig. 3). The chord-integrated line shape was calculated assuming that the radiated emission at each position along the line of sight is Lorentzian with a Stark width and shift given by the observed local electron density and temperature; thus, the Stark parameter, $a_\omega$, is used as the fit parameter. The resulting best-fit Stark parameter is compared to the previous lower-density, higher-temperature measurement and calculation from the standard theory [3] in Table I.

TABLE I. Observed Stark width parameter $a_\omega$ in units of $cm^3\ eV^{1/2}$ rad/sec compared to previous observations and theory for more weakly coupled plasmas[3] ($10^{17} cm^{-3}$, 1.5 eV).

| Observed $a_\omega$ | $a_{\omega\ ALLEN}$ | $a_{\omega\ THEORY}$ |
|---|---|---|
| $9.71\times10^{-6}$ | $9.88\pm1.7\times10^{-6}$ | $9.02\times10^{-6}$ |

Quasistatic ion broadening is estimated to increase the observed linewidth by approximately 10% [1] and absorption at the line center is calculated to broaden the line by an additional 15%. After subtracting these effects, the observed $a_\omega$ is calculated to be $9.71\times10^{-6} cm^3 eV^{1/2}$ rad/sec, which is within 10% of the values observed and calculated by Allen *et al.* [3] This result demonstrates explicitly that the standard Stark broadening theory is insensitive to the small-$g$ and small-$\chi$ assumptions required in its derivation.

## ACKNOWLEDGMENTS

This work was supported by the National Science Foundation.


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