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LETTER TO THE EDITOR

Stark broadening of He II 4686 Å: a direct comparison of predictions from two theories with experiment

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Abstract. In an earlier measurement of the He II 4686 Å line (at electron densities of $(1-3) \times 10^{18} \text{ cm}^{-3}$ and electron temperatures of 9.4 to 19.9 eV) we compared the measured profile with the only available calculation. Good agreement was found between the electron densities predicted by the Stark-broadening theory and those measured in the experiment. In this letter we present the comparison of our experimental data with a Stark-broadening profile using the unified theory. Both the theories describe the experimentally obtained profile, but the densities obtained by fitting to the unified theory line profile is in strong disagreement with the experiment.

The Stark broadening of He II 4686 Å ($n = 4 \rightarrow n = 3$) has been the subject of several experimental studies (Jones *et al* 1977 and references therein). Since our work (Jones *et al* 1977), new experimental investigations have appeared (Bacon *et al* 1977, Pittman *et al* 1979) as well as a new calculation (Greene 1976 and private communication) which motivates this letter.

The He II 4686 Å line was measured using a single-coil theta pinch device producing plasma with electron densities of $(1-3) \times 10^{18} \text{ cm}^{-3}$ and electron temperatures of 9–20 eV. The details of the experiment are described in Jones *et al* (1977). The line profiles at these conditions were fitted to the Stark-broadening profiles as calculated by Kepple (1972) (see also Griem 1974). Good agreement was found between the electron density as predicted by Stark-broadening theory and the experimentally obtained density. We measured the electron density independently from He II 4686 Å line by two different techniques: from an absolute measurement of the total continuum and by taking shadowgrams to get the compression of the plasma and thereby the final density. Both these measurements agreed within the error limits ($\pm 20\%$) with the density obtained from the width of the He II 4686 Å line profile.

As there was only one theoretical profile available at that time, we thought it would be worthwhile to make a new comparison with the newly available profile calculated by the unified theory (Greene 1976 and private communication). The fitting was made in the same way as before with a four-parameter least-squares fit. The profiles have been fitted for different experimental conditions representing four different times in the discharge and they have been fitted to calculations made at an electron temperature of 4 eV since this was the only available profile from the unified theory. The Stark-broadened profile, as obtained from calculations based on the quasi-static approximation for ion perturbers, is largely insensitive to temperature except for dynamical

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corrections which might have to be included depending on the plasma conditions. This point is discussed later in this letter. The fits at the time of $0.8 \mu\text{s}$ in the discharge are shown in figure 1. It is clear that both theories fit equally well to the experimental profile. The densities from the two profile fits and as measured by the experiment are shown in table 1. The first case, at $0.6 \mu\text{s}$, is the least reliable fit as it shows large sensitivity to the input parameters. The remaining three cases converged quickly (after 4–5 iterations) even with different sets of input parameters. It is clear from the table that the predicted density is insensitive to the temperature since we get the same density for the profile fitted at 4 eV as for the one fitted with the actual measured temperature.

Figure 1. He II 4686 Å line profile. ●, experiment (Jones *et al* 1977); +, theory (Greene 1976); △, theory (Griem 1974, Kepple 1972).

Table 1. Electron densities for a 3 Torr He plasma at four different times in the discharge in units of 10^{18} cm^{-3} . The theoretical profiles refer to an electron temperature of 4 eV.

Time (μs)		0.6	0.8	1.0	1.2
Theory	Griem-Kepple	0.5 (0.87)†	1.5 (1.6)†	2.2 (2.3)†	1.2 (1.2)†
	Greene	1.35	6.4	8.0	5.6
Experiment	Absolute continuum	0.97	1.6	2.7	1.7
	Total compression	1.3	2.2	1.8	1.3
	Electron temperature (eV)	10.3	9.4	14.7	12.1

† These densities are obtained from profiles calculated near the experimentally determined electron temperatures given in the last row of the table.

Therefore, we can compare the predicted densities with the two independently measured ones. We see that the density obtained using the unified theory is too large to be within experimental errors. The ratio between the densities obtained from the best fit profiles by Greene (1976) and the one by Kepple (1972) is 4.1 ± 0.4 . In view of the good agreement with the densities using Griem-Kepple profiles and the experimentally determined one, we conclude that the unified theory does not describe the Stark broadening as measured by experiment.

It is interesting to note that recent experiments performed at lower densities (Bacon *et al* 1977, Pittman *et al* 1979) tend to agree with the unified theory. The discrepancy between the two theories at the higher density is even more surprising since one would expect the two theories to approach each other at higher densities. It must be emphasised, however, that the independent measurement of electron density by means other than line broadening is an absolute requirement in order to distinguish between the two theories.

We might speculate on the reason for the differences in the theories even if the purpose of this letter is to point out the disagreement in predicted densities. It is important to notice that the two calculated profiles fit equally well to the experimental one. The influence of ion dynamics has been discussed in general (Hey and Griem 1975, Stamm and Voslamber 1979) and for Lyman α lines of hydrogen in particular (Voslamber 1977, Seidel 1977, Lee 1978, Greene 1979). In a recent paper we have shown that the He II 4686 Å profile from a plasma containing a mixture of nitrogen and helium (49% He + 51% N₂) could be fitted with the Griem-Kepple theory to predict densities in agreement with the experiment (Källne *et al* 1979). In the nitrogen-mixed plasma the variation in reduced emitter ion mass ($\frac{3}{4}m_{\text{He}}$ compared to $\frac{1}{2}m_{\text{He}}$) is too small to expect a variation in the line profile due to the influence of ion dynamics. However, the fact that the profile predicted by the Griem-Kepple theory fits equally well to the two experimental profiles indicates that ion dynamics is of minor influence since this is not included in the theory. This is interesting because discussions of the influence of ion dynamics (Voslamber 1977, Seidel 1977, Lee 1978, Greene 1979) claim an increase of a factor of two in the width of the line profile. Thus a density predicted from a comparison of a calculated and an experimental line profile would be a factor of two lower when ion dynamics is included. This has also been found experimentally at lower electron densities (Grützmacher and Wende 1977). From our independent measurement of the densities in both the pure helium plasma and in the mixed nitrogen-helium plasma we can conclude that the density predicted by the Stark-broadening theory of Kepple (1972) is within 20% of the measured value. However, the discrepancy of a factor of four between the two theories still remains. It then seems reasonable to assume that the differences between the two theories emanate from the influence of the upper-lower state interference term on the electron impact broadening as discussed by Hey and Griem (1975), Voslamber (1976) and Griem and Hey (1976).

Thus this letter has shown experimental evidence for a large discrepancy in the two most recent theoretical calculations of the Stark-broadened He II 4686 Å line profile. A final solution to the reason for the discrepancy thus calls for a new calculation of the He II 4686 Å line considering the influence of the full upper-lower state interference term and of dynamic ions.

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