Stark broadening and shift of selected neutral neon lines

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(Received 20 November 1995)

Width and shift of five prominent neutral neon spectral lines have been measured using a wall-stabilized arc. Under the prevailing plasma conditions the broadening by neutral disturbers has to be taken into account besides the Stark effect. This is achieved by application of a least-squares fitting routine, which allows the separation of the two broadening effects. The data are compared to theoretical predictions and other measurements.

PACS number(s): 52.70.Kz, 32.70.Jz, 32.30.Jc

I. INTRODUCTION

Neon plays an important role in technical plasmas and is of interest in gas discharge research. Nevertheless the number of available experimental data for the Stark-effect broadening is quite limited. Moreover, recent measurements [1] in the temperature region around 10^4 K showed inconsistencies with theoretical widths obtained by Griem [2] and with earlier experiments [3]. For this reason the Stark effect of some prominent neon lines was measured in the present experiment. A special emphasis has been laid on the shift of the lines. In spite of the smallness of the shift of the neon lines under investigation, plasma diagnostic utilizing shift data has the advantage of being independent of the saturation effects.

II. EXPERIMENTAL SETUP

The spectra were obtained from the plasma of a wall-stabilized arc running in neon. The arc had a diameter of 4 mm and was operated at currents between 25 and 80 A and at atmospheric pressure. A 2 m Czerny-Turner monochromator equipped with a 2400 lines/mm plane grating blazed at 5000 Å was used for the recording of the profiles. The shape of the apparatus profile could be very well approximated by a Gaussian profile. The widths of the monochromator slits allowed an apparatus width of approximately 40 mÅ. A Hamamatsu R 928 photomultiplier served as an optical detector.

The detector was mounted right behind the exit slit of the monochromator. Slit and detector could be moved as a unit in the focal plane of the monochromator by a computer controlled stepping motor, each step corresponding to 1.2 mÅ. Therefore the grating did not have to be turned for the recording of a spectrum.

Though being isolated by foam plastics, the monochromator exhibits a temperature depending drift which slightly changes the position of a spectral line in the focal plane of the monochromator. As the expected shift of the examined neon lines was of the same order as the drift of the monochromator, an unshifted wavelength mark was necessary. This was achieved by simultaneous recordings of the neon spectral line emitted from a low pressure gas discharge, which was superimposed on the plasma emission by a beam splitter. In addition to the stepping motor that moved the slit and the detector the computer controlled two choppers. These choppers were situated between the beam splitter at the one hand and the arc and the gas discharge at the other. The choppers alternately opened and closed the optical way from the two light sources to the entrance slit of the monochromator. Thus it was possible to record the two spectral lines of different origin in two separated channels: one for the plasma line which was to be investigated and one for the unshifted reference line (see Fig. 1).

III. PLASMA DIAGNOSTICS AND DATA REDUCTION

The electron density was determined independently by a two wavelength ($\lambda_1 = 0.63$ μm, $\lambda_2 = 1.15$ μm) Michelson interferometer as described elsewhere [4]. The estimated error varied from 9% for the lowest electron density $N_e = 4.2\times10^{15}$ cm^{-3} to 4% for the highest $N_e = 22.9\times10^{15}$ cm^{-3}.

Using a least-squares fitting routine [5] the position and width of the spectral lines were determined. As shown in Fig. 1, the Stark-effect broadened neon profiles are approximated very well by the Voigt profiles. The optical depth was

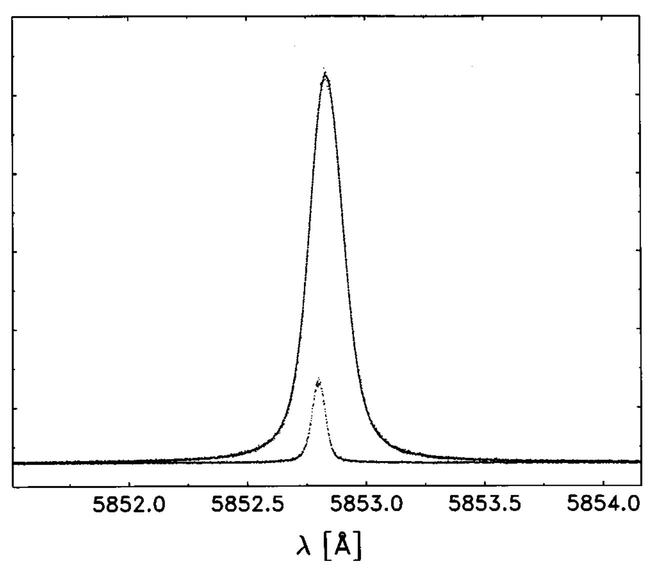

FIG. 1. Spectrum of the neutral neon spectral line at 5852 Å at an electron density of 1.36×10^{16} cm^{-3}. Top: the line emitted from the plasma arc (with fitted Voigt profile). Bottom: the line emitted from the low pressure gas discharge.

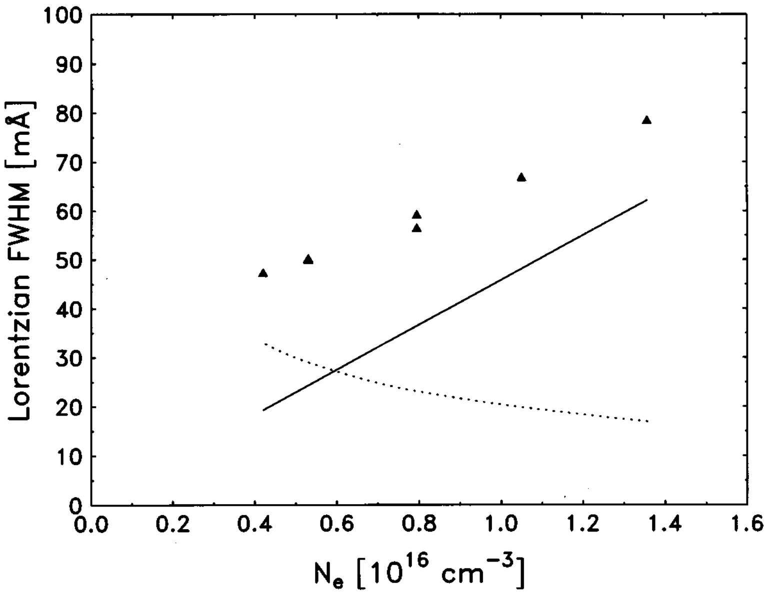

FIG. 2. Full Lorentzian width at half maximum of the neon spectral line at 6678 Å versus electron density. The dashed line indicates the Lorentzian width due to neutral broadening, while the influence of Stark broadening is given by the solid line.

found to be negligible. After subtraction of the apparatus width the Gaussian part of the half width was used to calculate the temperature of heavy particles, which lies between 4000 and 10 400 K. Even at the highest electron densities obtained at our experimental conditions no LTE is established [6]. Therefore the heavy particle temperature differs from the temperature of the electrons. The latter one was obtained from the plasma calculations [7].

The Lorentzian part of the width is due to pressure broadening. At higher electron densities the interaction of the radiating atom with the charged particles is the dominating effect. But using Dalton's law and the temperatures obtained as described above, one can show that the number of neutral particles per volume surpasses the electron density by more than two orders of magnitude, if the electron density falls below 1×10^{16} cm^{-3}. This leads to a perceptible influence of the neutral particles: if one assumes a linear dependence of the Lorentzian half width on the electron density corresponding to the quadratic Stark effect, the obtained Lorentzian half width at vanishing electron density is not equal to zero (see Fig. 2). Therefore the self-broadening of the neon spectral lines has to be taken into account. Both, Stark effect and self-broadening depend linearly on the number densities of the disturbing electrons and atoms, respectively. As the number of neutral neon atoms decreases with increasing electron density, both effects can be separated in the following way. Neglecting the natural linewidth and the temperature dependence of the two effects, one gets the total Lorentzian width w_L at an arc current I

$$w_L(I)=m_S N_e(I)+m_E N_0(I), \tag{1}$$

with m_S and m_E being the constants of Stark effect and self-broadening, which are to be determined. N_e is the electron density, N_0 the number density of neutral disturbers. In order to determine the constants m_S and m_E, one has to minimize the square sum of the difference between measured total Lorentzian width L and predicted width w_L

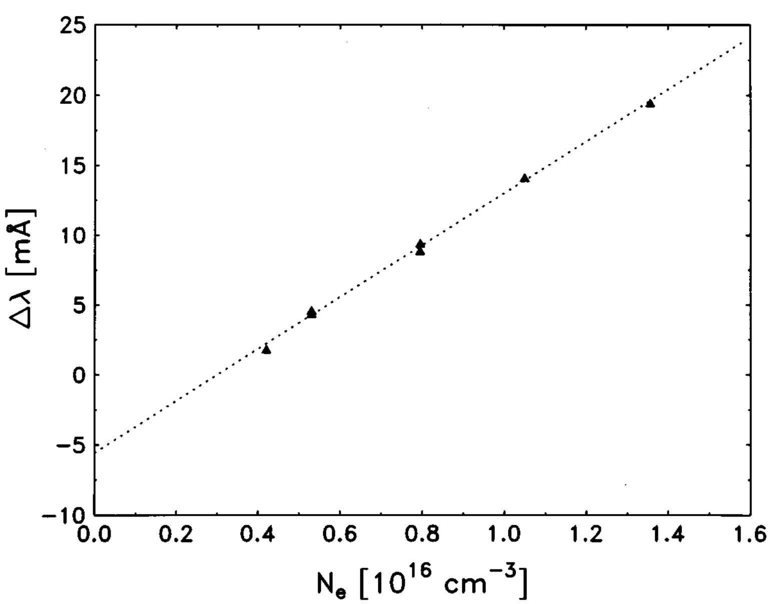

FIG. 3. Shift of the neon spectral line at 6678 Å versus electron density. The dashed line indicates a linear fit.

$$S=\sum_i \{L(I_i)-[m_S N_e(I_i)+m_E N_0(I_i)]\}^2. \tag{2}$$

The index i extends over the number of all experimental data. From

$$\frac{\partial S}{\partial m_S}=0, \quad \frac{\partial S}{\partial m_E}=0$$

follows

$$\sum_i N_e(I_i)L(I_i)=m_S\sum_i N_e^2(I_i)-m_E\sum_i N_0(I_i)N_e(I_i) \tag{3}$$

and

$$\sum_i N_0(I_i)L(I_i)=m_S\sum_i N_0(I_i)N_e(I_i)-m_E\sum_i N_0^2(I_i). \tag{4}$$

Using the abbreviation

$$a=\sum_i N_e(I_i)L(I_i), \quad b=\sum_i N_0(I_i)L(I_i)$$

$$c=\sum_i N_e^2(I_i), \quad d=\sum_i N_0^2(I_i), \quad e=\sum_i N_e(I_i)N_0(I_i),$$

one gets from Eqs. (3) and (4) the desired result

$$m_S=\frac{ad-be}{cd-e^2}, \tag{5}$$

$$m_E=\frac{ae-bc}{e^2-cd}. \tag{6}$$

In a similar way the shift due to the Stark effect and van der Waals effect can be calculated. In this case besides the two constants a further quantity has to be taken into account. The low pressure discharge is situated at another location than the arc. This leads to a slightly different entrance angle of the light emitted from the two sources entering the monochromator, producing a small offset of the spectra in the focal plane of the monochromator. This offset is of the order of 5 mÅ and is also observed, if two low pressure discharges are monitored. Therefore the offset cannot be contributed to the van der Waals effect. As the experimental setup is designed for the investigations of the broadening by charged particles, the results of self-broadening have to be seen as corrections to the Stark broadening and are therefore not listed as results in this work.

TABLE I. Stark width full width at half maximum (FWHM) and shift $\Delta\lambda$ of the investigated NeI lines at an electron density of 1×10^{16} cm^{-3} and an electron temperature of 10^4 K.

λ [Å]	FWHM [mÅ]	Δλ [mÅ]	author
6678	47	19	this work
	43	13.5	[2]
	52	25	[8]
6096	37	15	this work
	37.6	17.6	[2]
	38		[3]
	70	13	[1]
5945	34	16	this work
	36	17.8	[2]
	32		[3]
	52	17	[1]
5882	29	15	this work
	33		[2]
	80	15	[1]
5852	54	29	this work
	56		[3]
	94	23	[1]

IV. RESULTS AND DISCUSSION

Typical results of the full Lorentzian width at half maximum and shift as obtained by the least-squares fitting routine are shown in Figs. 2 and 3. One recognizes a very good reproducibility of the position and the width of the line. The shift is approximated very well by a linear fit, whereas the half width is influenced by the neutral particle effects in a much more obvious way. As described above, the Lorentzian width at the vanishing electron density exceeds the expected value of the natural linewidth as a result of self-broadening. Using Eqs. (5) and (6) for the width and a similar approach for the shift of the line, the Stark effect is separated from the neutral disturber effects. The results of these calculations are shown in Table I and compared with the data of other authors.

In general, the agreement of width and shift given in this work with the theoretical values of Griem [2] and with the experimental data of Miller, Roig, and Moo-Young [8] and Nubbemeyer, Stuck, and Wende [3] is very good. The widths given by Purić, Ćuk, and Rathore [1] for an electron temperature of $T_e=10^4$ K exceed the results of this and other works by a factor of 1.5 to 2.7. As stated in [1], self-absorption might be responsible for this problem. This thesis is supported by the remarkably good agreement of the measured shifts given by Purić, Ćuk, and Rathore and ours.

[1] J. Purić, M. Ćuk, and B. A. Rathore, Phys. Rev. A **35**, 1132 (1987).

[2] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).

[3] H. Nubbemeyer, D. Stuck, and B. Wende, Z. Phys. **234**, 29 (1970).

[4] V. Helbig and K.-P. Nick, J. Phys. B **14**, 3573 (1981).

[5] K. Jeβ, V. Helbig, F. Greiner, J. Kaspareit, V. Rohde, and T.

Weirauch, J. Quant. Spectrosc. Radiat. Transfer **41**, 69 (1989).
[6] J. Uhlenbusch, E. Fischer, and J. Hackmann, Z. Phys. **239**, 120 (1970).
[7] J. Irmer and M. Worm, *Die Zusammensetzung Thermischer Edelgasplasmen* (Akademie-Verlag, Berlin, 1974).
[8] M. H. Miller, R. A. Roig, and G. A. Moo-Young, Phys. Rev. A **4**, 971 (1971).