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Mg II spectral line broadening in helium, oxygen and argon-helium plasmas

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Abstract. Stark widths (W) and shifts (d) of the astrophysically very important six (279.0777, 279.5528, 279.7998, 280.2705, 292.8633 and 293.6510 nm) singly ionized magnesium (Mg II) spectral lines in helium, oxygen and argon-helium plasmas have been measured at electron temperatures between 30 000 and 52 300 K and electron densities between 1.2×10^{23} and 1.65×10^{23} m^{-3}. They are the first experimental results obtained at electron temperatures higher than 20 000 K. A linear, low-pressure, pulsed arc has been used as an optically thin plasma source. The magnesium atoms, as impurities in the driving gases, have been introduced by erosion from the pure magnesium bands fixed on the discharge electrodes. Our measured Stark width and shift values have been compared to the existing experimental and theoretical data. We have found a good agreement with W and d values calculated by the semiclassical perturbation formalism (SCPF).

Key words. plasmas – line: profiles – atomic data

1. Introduction

The singly ionized magnesium (Mg II) spectral lines (279.0777, 279.5528, 279.7998, 280.2705, 292.8633 and 293.6510 nm) in the 1 UV, 2 UV and 3 UV multiplets are very useful for investigations of various cosmic light sources, especially the resonance Mg II *h&k* lines (279.5528 nm and 280.2705 nm). They are used in astrophysical plasma diagnostics and modeling (Danezis et al. 2003; Eracleous & Halpern 2003; Bohm-Vitense et al. 2001; Arav et al. 2001; Lobel & Dupree 2000; Charlton et al. 2000; Wood & Karovska 2000; Luttermoser 2000; Popović et al. 2001; Uitenbroek & Briand 1995, and in many other studies). Therefore, knowledge of the Mg II spectral line characteristics (the widths and the shifts) are of interest. In the case when the Stark broadening is the principal pressure-broadening mechanism in plasmas (Griem 1974) various plasma compositions and kinetic processes (Lesage 1995; Zeippen 1995) can be modelled relying on the Stark width and shift values. The mentioned Mg II line profile characteristics have been investigated in a few experiments (Chapelle & Sahal-Bréchot 1970; Roberts & Barnard 1972; Purić & Konjević 1972; Helbig & Kusch 1972; Hadžiomerspahić et al. 1973; Kusch & Schweicker 1976; Fleurier et al. 1977). In all of the mentioned experiments magnesium atoms are introduced through magnesium salts deposited on the discharge electrodes or by working gases which contain magnesium in complex molecular structures.

The aim of our paper is contribution to the knowledge of the Stark FWHM (full-width at a half intensity maximum, W) and Stark shift (d) of the prominent Mg II lines in different plasma compositions at electron temperatures higher than 20 000 K (Konjević et al. 2002, and references therein). Our plasmas contain magnesium atoms as impurities in the driving gases, which provides conditions free of self-absorption in the Mg II 2 UV and 3 UV multiplets in our plasma compositions. Our measured W and d values are compared to the existing measured and calculated (Griem 1974; Chapelle & Sahal-Bréchot 1970; Dimitrijević & Sahal-Bréchot 1995) data.

2. Experiment

A linear low pressure arc has been used as a plasma source. A pulsed discharge was driven in a pyrex discharge tube of 5 mm inner diameter and plasma length of 14 cm (Fig. 1 in Djeniže et al. 1991). The tube has end-on quartz windows. The magnesium atoms were introduced through erosion of the magnesium metal bands fixed on the discharge electrodes following the idea described in Djeniže et al. (1990a,b, 1991, 1992). The working gases were helium, oxygen and argon-helium (72% Ar + 28% He) mixture in flowing regime at a 133 Pa pressure in the oxygen and argon-helium plasmas and at a 532 Pa pressure in the helium plasma. Even if the density of magnesium atoms was low, a discharge length of 14 cm was sufficient to provide a measurable intensity of Mg II lines. A capacitor of 14 μF was charged up to 55 *J* bank energy.
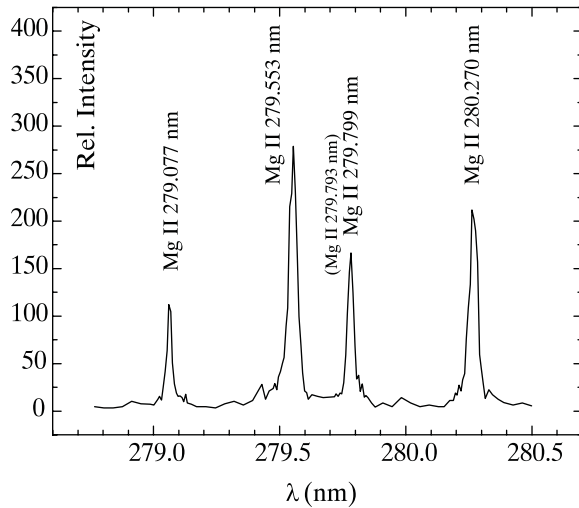
Fig. 1. Recorded Mg II spectral lines in the 1 UV (279.553 nm and 280.270 nm) and 3 UV (279.077 nm and 279.799 nm) multiplets in the helium plasma.

Fig. 2. Electron temperature (T) and electron density (N) decays in helium ($\otimes$), oxygen ($\oplus$) and argon-helium ($\bullet$) plasmas.

Spectroscopic observation of isolated spectral lines was made end – on along the axis of the discharge tube. The line profiles were recorded using a step-by-step technique described in our previous publications (Djeniže et al. 2002, 2003). The averaged photomultiplier signal (seven shots at the same spectral range) was digitized using an oscilloscope interfaced to a computer. The recorded Mg II spectral line profiles are shown in Figs. 1 and in 3a.

The absence of the self-absorption, in the case of the 2 UV and 3 UV multiplets, was proved using the method described by Djeniže & Bukvić (2001). However, in the case of the resonance Mg II *h&k* lines (in the multiplet 1 UV) presence of the self-absorption was found. Consequently, the Stark widths of the 279.553 nm and 280.270 nm lines are not presented in this work. The plasma parameters were determined using standard diagnostic methods (Griem 1964). The electron temperature (T) was obtained using the relative line intensity ratio method between the He II P_α 468.6 nm and the He I 587.6 nm lines in the case of the helium plasma within ±8% accuracy. In the cases of the oxygen and argon-helium plasmas the Saha equation was applied using O III (326.08 nm, 372.09 nm and 375.99 nm), O II (327.05 nm, 372.73 nm and 374.95 nm), Ar III (330.19 nm, 331.12 nm, 334.48 nm, 335.85 nm, 336.59 nm, 302.39 nm and 302.71 nm) and Ar II (329.36 nm, 330.72 nm, 335.09 nm, 302.89 nm and 347.67 nm) lines. These T values are obtained within 6% uncertainties. The electron density (N) decays were measured using a well-known single wavelength He–Ne laser interferometer technique (Ashby et al. 1965) for the 632.8 nm transition with an estimated error of ±7%. Necessary atomic date were taken from NIST (2004). Temporal evolution of the N and T values are presented in Fig. 2.

3. Line width and shift measurements

The measured profiles were of the Voigt type due to the convolutions of the Lorentzian Stark and Gaussian profiles caused by
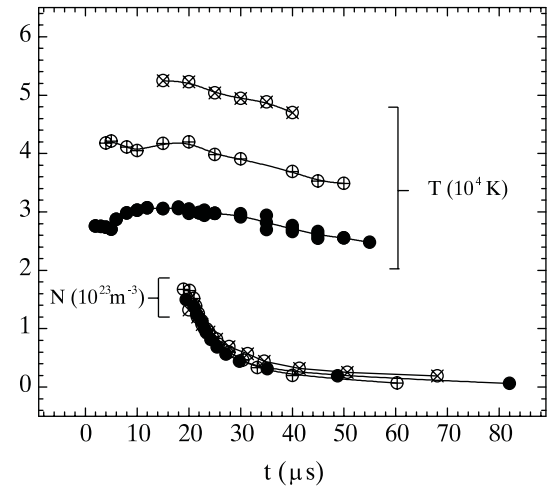
Doppler and instrumental broadening. For the electron density and temperature in our experiment the Lorentzian fraction was dominant. Van der Waals (Griem 1974) and resonance (Griem 1974) broadening were estimated to be smaller by more than one order of magnitude in comparison to Stark, Doppler and instrumental broadening. The standard deconvolution procedure (Davies & Vaughan 1963) was applied using the least squares algorithm. The Stark widths were measured within ±12% error at a given N and T. Our measured Stark FWHM (W_m) are presented in Table 1. The Stark shifts (d) were measured relative to the unshifted spectral lines emitted by the same plasma (Purić & Konjević 1972). Stark shift data are corrected for the electron temperature decay.

4. Results and discussion

Our measured W_m and d_m values are presented in Table 1.

In order to compare measured and calculated Stark FWHM and shift values, the theoretical Stark FWHM and shift dependences on the electron temperature together with the values of other authors and our experimental results, at an electron density of 1×10^{23} m^{-3} are graphically presented in Figs. 3–4.

Our Stark FWHM are in agreement with theoretical values calculated by Dimitrijević & Sahal-Bréchot (1995) based on the semiclassical perturbation formalism (Sahal-Bréchot 1969a,b) (see Figs. 3b and 4a). One can see that previously published (Griem 1974) Mg II W values are, also, in tolerable agreement with our results within the experimental accuracy of ±12% and within the uncertainties (±30%) of the calculations.

In the case of the Stark shifts the situation is different. Namely, the recently calculated DSB values (Dimitrijević & Sahal-Bréchot 1995) lie below the previous theoretical G (Griem 1974) data. Our d_m values agree very well with the DSB theoretical predictions, especially in the case of helium and oxygen plasmas. It turns out that inclusion of the helium ion contribution in the total (electron + ion) Stark FWHM and shift give DSB values with excellent agreement with our measured W_m and d_m (see value with asterix in Table 1 and the
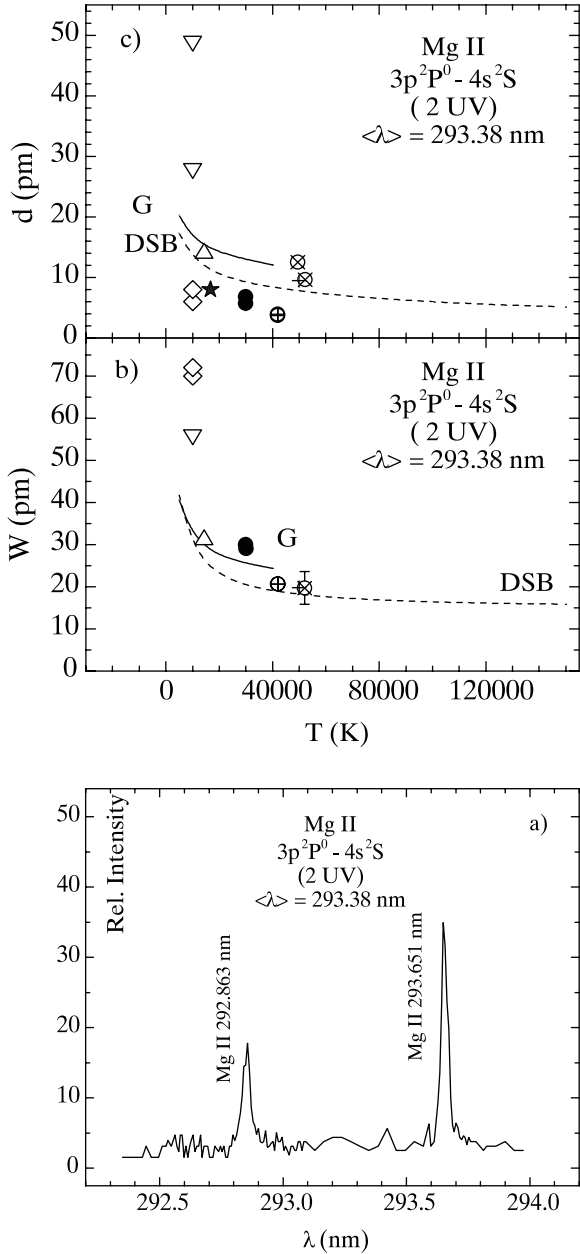
Fig. 4. Stark FWHM (W in pm) **a)** and shift (d in pm) **b)** values at 10^{23} m^{-3} electron density for Mg II lines in the 3 UV multiplet. The symbols are the same as in Fig. 3.

Table 1. Measured Mg II Stark FWHM (W_m) and shift (d_m) values at various electron temperatures (T) and 1.0×10^{23} m^{-3} electron density in various plasmas with corresponding accuracies. The letters a, b and c denote helium, oxygen and argon-helium plasmas, respectively. Asterix denotes W_m and d_m values in the helium plasma which agree very good with calculated ones using the SCPF approximation (Dimitrijević & Sahal-Bréchot 1995) that include the electron and helium ion contribution in the Mg II line broadening and shift. Atomic data are taken from NIST (2004). Negative shift is toward the blue.

Fig. 3. Mg II line profiles in oxygen plasma **a)**, Stark FWHM (W in pm) **b)** and shift (d in pm) **c)** values at 10^{23} m^{-3} electron density. Symbols (⊗), (⊕) and (•) denote our results in helium, oxygen and argon-helium plasmas, respectively. Other experimental values are: △, Fleurier et al. (1977); ▽, Kusch & Schweicker (1976); ★ Purić & Konjević (1972); ◊, Helbig & Kusch (1972). G and DSB denote theoretical electron widths and shifts calculated by Griem (1974) and Dimitrijević & Sahal-Bréchot (1995), respectively. The symbol + denotes sum of the electron and helium ion contributions to the total Stark width and shift taken from Dimitrijević & Sahal-Bréchot (1995). $\langle\lambda\rangle$ is the mean wavelength in the multiplet. Error bar represents estimated uncertainties.

Transition	λ (nm)	Exp.	T (10^3 K)	d_m (pm)	W_m (pm)
$3s\,^2S - 3p\,^2P^0$	279.5528	a	52.3	-1.5 ± 0.8	
1 UV		b	42.0	-0.5 ± 0.8	
		c	30.0	-1.0 ± 0.8	
	280.2705	a	52.3	$-0.5^* \pm 0.8$	
		b	42.0	0.4 ± 0.8	
		c	30.0	-0.2 ± 0.8	
$3p\,^2P^0 - 4s\,^2S$	292.8633	a	52.3	$9.6^* \pm 0.8$	$19.7^* \pm 12\%$
2 UV		b	42.0	3.9 ± 0.8	$20.6 \pm 12\%$
		c	30.0	5.7 ± 0.8	$29.0 \pm 12\%$
	293.6510	a	49.4	12.5 ± 0.8	$19.7^* \pm 12\%$
		b	42.0	3.7 ± 0.8	$20.6 \pm 12\%$
		c	30.0	6.8 ± 0.8	$30.0 \pm 12\%$
$3p\,^2P^0 - 3d\,^2D$	279.0777	a	52.3	$2.6^* \pm 0.8$	$15.3^* \pm 12\%$
3 UV		b	42.0	3.0 ± 0.8	$13.7 \pm 12\%$
		c	30.0	2.0 ± 0.8	$16.6 \pm 12\%$
	279.7998	a	52.3	1.9 ± 0.8	$15.3^* \pm 12\%$
		b	42.0	1.7 ± 0.8	$13.7 \pm 12\%$
		c	30.0	1.3 ± 0.8	$16.6 \pm 12\%$

symbol plus in Figs. 3b,c and 4a,b). In the case of the multiplet 1 UV we have found very low negative Stark shift values. Within our experimental accuracy these are practically equal to zero in a wide range of the electron temperatures confirming
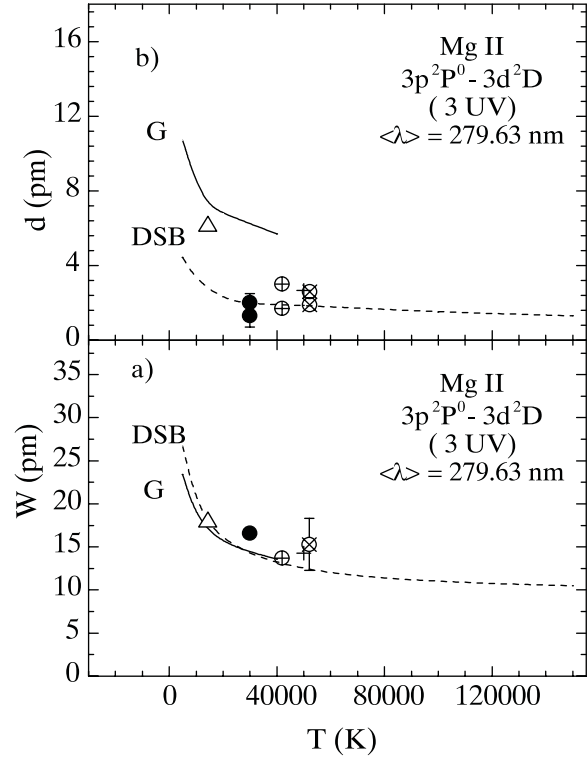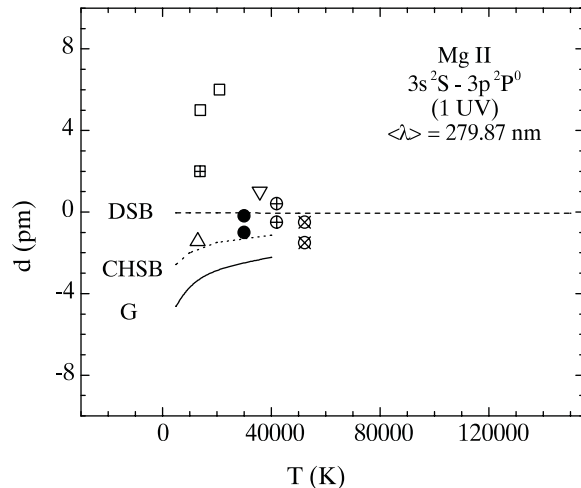
Fig. 5. Stark shift (*d* in pm) values at 10^{23} m^{-3} electron density for the resonance Mg II *h&k* lines. Symbols (⊗), (⊕) and (•) denote our results in helium, oxygen and argon-helium plasmas, respectively. Other experimental values are: ⊞ Chapelle & Sahal-Bréchot (1970); □, Roberts & Barnard (1972); ▽, Hadžiomerspahić et al. (1973); △, Fleurier et al. (1977). G, CHSB and DSB denote theoretical electron shift values taken from Griem (1974), Chapelle & Sahal-Bréchot (1970) and Dimitrijević & Sahal-Bréchot (1995), respectively. ⟨λ⟩ is the mean wavelength in the multiplet.

the DSB Stark shift values calculated by SCPF (Dimitrijević & Sahal-Bréchot 1995).

5. Conclusion

On the basis of the agreement between experimental and calculated *W* and *d* values we have found that the 279.0777 nm, 279.7998 nm, 292.8633 nm and 293.6510 nm Mg II lines have convenient Stark parameters useful for plasma modelling and diagnostic purposes.

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