A&A 425, 361–365 (2004)
DOI: 10.1051/0004-6361:20041197

Astronomy & Astrophysics

Stark broadening and transition probability ratios in the Mg I spectrum

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Received 30 April 2004 / Accepted 17 June 2004

Abstract. Stark widths (*W*) and shifts (*d*) of the six astrophysically important 285.212, 383.230, 383.829, 516.732, 517.268, and 518.360 nm neutral magnesium (Mg I) spectral lines in the $3s^2\,{}^1S{-}3p^1P^0$, $3p^3P^0{-}3d^3D$ and $3p^3P^0{-}4s^3S$ transitions have been measured in laboratory helium plasma at about 50 000 K electron temperature and 1×10^{23} m^{-3} electron density. They represent the first measured values and, also, the first experimental *W* and *d* data in the mentioned transitions. Using the relative line intensity ratios of the lines in the mentioned transitions we have obtained the ratios of corresponding transition probability values (Einstein's *A* values). They represent the first experimental data based on the analysis of the Mg I emission spectral lines. We have found agreement with theoretical transition probability ratios tabulated by NIST.

Key words. atomic data – line: profiles

1. Introduction

The 285.212, 383.230, 383.829, 516.732, 517.268, and 518.360 nm spectral lines of neutral magnesium (Mg I) in the $3s^2\,{}^1S{-}3p^1P^0$, $3p^3P^0{-}3d^3D$ and $3p^3P^0{-}4s^3S$ transitions are useful for investigations of various cosmic light sources (Gosai & Choudhary 2003; Hall et al. 2003; Peimbert 2003; Greenhill et al. 2002; Bower et al. 2001; Schinnerer et al. 2001, and in many other studies). At electron densities (*N*) higher than 10^{21} m^{-3} the Stark width (*W*) and the shift (*d*) begin to play an important role in the line shape and in the line center position formation (Griem 1974). These parameters are of interest in the modeling and diagnostics of various cosmic plasmas (Lesage 1995; Zeippen 1995). However, no experimental *W* and *d* values of the mentioned Mg I lines (Konjević et al. 2002, and references therein) exist. Only three studies, based on the semiclassical approach (Griem 1974; Dimitrijević & Sahal-Bréchot 1994, 1996) are dedicated to the calculations of these parameters. The aim of this work is to present the first measured Stark width (W_m) and shift (d_m) values of the mentioned Mg I spectral lines at about 50 000 K electron temperature and 1×10^{23} m^{-3} electron density in the helium plasma. Our W_m and d_m values are compared to the recent calculated values.

The transition probability (Einstein's *A*) values of these lines are, also, of an importance in radiation processes used in plasma modeling and diagnostics. In this work we present the transition probability ratios of the mentioned Mg I transitions using the relative line intensity ratio (RLIR) method (Griem 1964; Djeniže & Bukvić 2001; Djeniže et al. 2002a,b,c, 2003a,b, 2004a; Srećković et al. 2001, 2002) not applied up to now in the Mg I emission spectra. Our experimental transition probability ratios are compared to the tabulated (NIST 2004) ones. We have found agreement with values presented by NIST (2004) which were calculated 37 years before by Weiss (1967) and were primarily recommended in Wiese et al. (1969).

2. The experiment

A linear, low-pressure, arc was 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, 1992). The tube has end-on quartz windows. The magnesium atoms were introduced through erosion of the magnesium metal bands fixed on the discharge electrodes providing conditions free of the self-absorption (Djeniže et al. 2004b, and references therein; Bukvić et al. 2004). The working gas was helium in flowing regime at a 532 Pa pressure. A capacitor of 14 μF was charged up to 55 J bank energy. Chosen conditions provide sufficient evaporation of magnesium atoms. 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. 2002a, 2003). The averaged photomultiplier signal (seven shots at the same wavelength) was digitized using an oscilloscope interfaced to a computer.

The Mg I lines are well isolated, with continuum close to the zero, which enables high accuracy of the measured line intensities (*I*) (within ±5%). The absence of the self-absorption, in the case of the investigated Mg I lines in the 3p–3d and 3p–4s transitions, was proved using the method described by

Table 1. Characteristics of the investigated Mg I transitions. The quantities J_f and J_i are the inner quantum numbers of the final (f) and initial (i) state of the transition. Atomic data such as the energy of the initial levels (E_i), the wavelengths (λ) and the transition probability values (A in 10^8 s^{-1}) are taken from NIST (2004). Measured Stark *FWHM* (W_m in pm) and shift (d_m in pm) are given at various electron temperatures (T in 10^3 K) and 1×10^{23} m^{-3} electron density with their estimated accuracies. Positive shift is toward the red.

Transition	λ (nm)	E_i (eV)	A	T	W_m	d_m
$3p^3P^0$–$4s^3S$						
J_f–J_i						
2–1	518.36043	5.108	0.575	49.5	35.0 ± 5.2	7.4 ± 0.8
1–1	517.26844	5.108	0.346	49.5	35.3 ± 5.3	8.4 ± 0.8
0–1	516.73213	5.108	0.116	49.5	33.0 ± 5.6	9.0 ± 0.8
$3p^3P^0$–$3d^3D$						
J_f–J_i						
2–3	383.82919	5.946	1.68	52.0	110 ± 16	−2.0 ± 0.8
1–2	383.23039	5.946	1.27	52.0	92 ± 14	−3.5 ± 0.8
$3s^2$ ^1S–$3p^1P^0$						
J_f–J_i						
0–1	285.21261	4.346	4.95	52.0	– – – –	1.8 ± 0.8

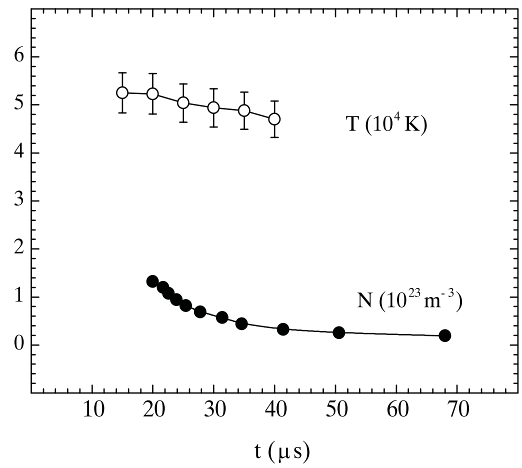

Fig. 1. Temporal evolution of the electron temperature (T) and electron density (N) during the plasma decay. Error bars represent experimental accuracies.

Djeniže & Bukvić (2001). The plasma parameters were determined using standard diagnostics methods. 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 within ±8% accuracy (Griem 1964). The electron density (N) decay was measured using 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%. Temporal evolution of the N and T values are presented in Fig. 1. The recorded Mg I spectral line profiles are shown in Figs. 2a and 3a.

3. Line width and shift measurements

The Mg I line profiles represent the convolutions of the Lorentzian Stark (electron + ion) and Gaussian profiles caused by Doppler and instrumental broadening. For the electron density, electron temperature and density of the emitters in our experiment the van der Waals (Griem 1974) and resonance (Griem 1974) broadenings were estimated to be smaller by more than one order of magnitude in comparison to the Stark, Doppler and instrumental broadening. We expect that the ion contribution to the total Stark width is small (within 5%, see the ion broadening parameters for the Mg I lines in the Griem 1974) and can be neglected giving symmetrical Mg I line profiles. This approximation results in slightly lower accuracies of the measured (W_m) values (up to ±17%). For symmetrical (Voigt) line profiles the standard deconvolution procedure (Davies & Vaughan 1963) was applied using the least squares algorithm. Accurate estimation of the spectrum base line is based on the procedure reported in Spasojević et al. (1996). The Stark widths were measured with up to ±17% error at a given N and T. Our measured Stark *FWHM* (full-width at a half intensity maximum, W_m) are presented in Table 1. The Stark shifts (d) were measured relative to the unshifted spectral lines emitted by the same plasma (Djeniže et al. 2002a, and references therein). Our measured Stark shifts (d_m) are presented in Table 1.

4. Transition probability ratio

When two spectral lines (index 1 and 2) arise from mutually very close upper energy levels their relative line intensity ratio is given as (Griem 1964):

$$(I_1/I_2)_m = A_1 g_1 \lambda_2 / A_2 g_2 \lambda_1 \qquad (1)$$

where A, g and λ denote transition probability, statistical weight of the parent energy level and the wavelength of the transitions. I_m denotes measured relative line intensity. The Eq. (1) enables determination of the transition probability ratio on the basis of the measured relative line intensities. The characteristics of the investigated Mg I transitions are given in Table 1.

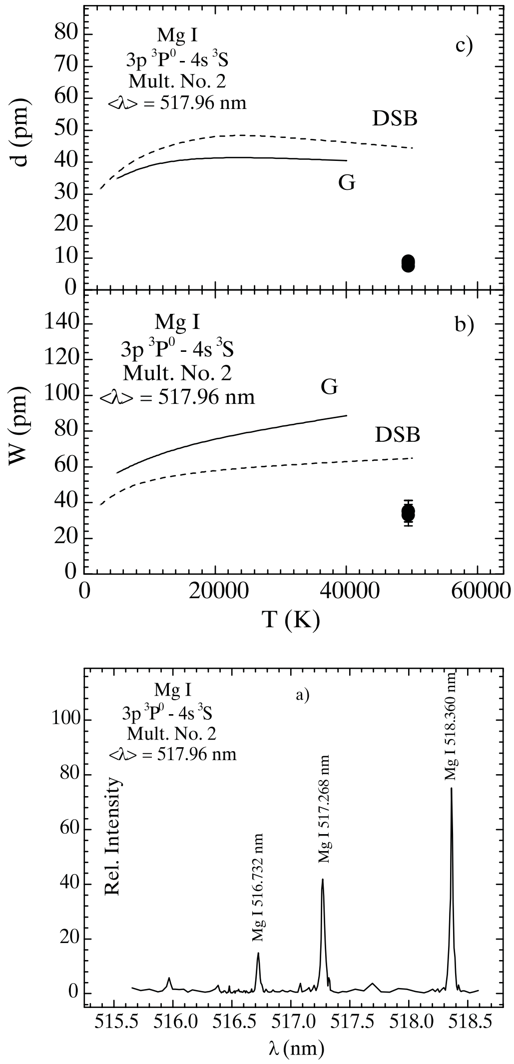

Fig. 2. The recorded 516.732, 517.268 and 518.360 nm Mg I line profiles at the 40 μs after the beginning of the discharge (**a**). The Stark *FWHM* (**b**) and shifts d (**c**) are also given at 1×10^{23} m^{-3} electron density. The filled circles represent our experimental data. The symbols G and DSB denote calculated values (electron component only) using the semiclassical approximations by Griem (1974) and Dimitrijević & Sahal-Bréchot (1994, 1996), respectively. Error bars represent estimated uncertainties. $\langle\lambda\rangle$ is the mean wavelength in the multiplet.

5. Results and discussion

Our W_m and d_m values are presented in Table 1. To compare measured and calculated Stark *FWHM* and shift values, the theoretical Stark *FWHM* and shift dependences on the electron temperature together with our experimental results at an electron density of 1×10^{23} m^{-3} are graphically presented in Figs. 2–4. Theoretical calculations are based on the semiclassical theory (G) (Griem 1974) and semiclassical perturbation formalism (DSB) (Sahal-Bréchot 1969a,b; Dimitrijević & Sahal-Bréchot 1994, 1996).

Using the measured relative line intensities (I_m) we have obtained, on the basis of Eq. (1), the transition probability ratio of the Mg I transitions during the whole plasma decay. Our experimentally obtained transition probability ratios are given

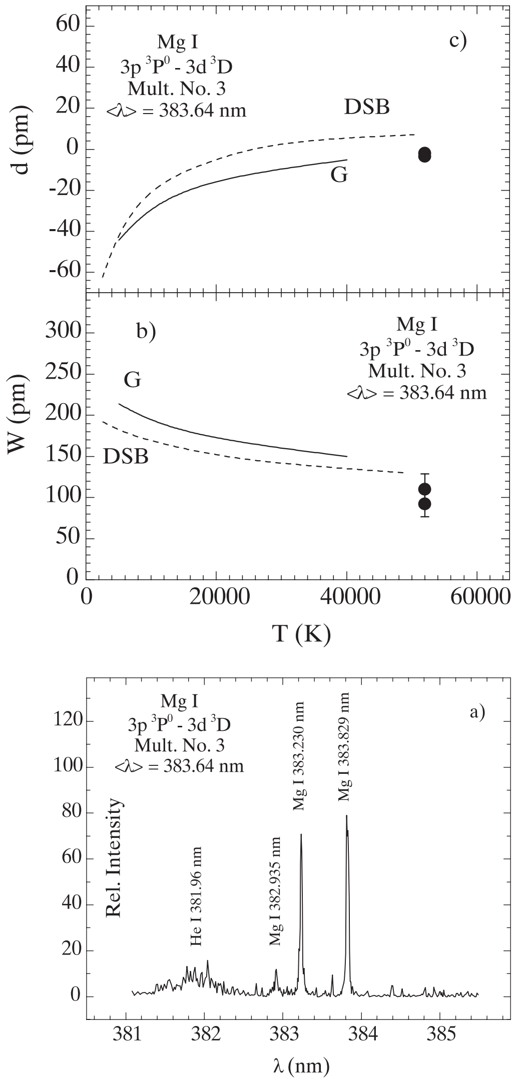

Fig. 3. The recorded 383.230 and 383.829 nm Mg I line profiles at the 70 μs after the beginning of the discharge **a**). The other symbols are the same as in Fig. 2. The 381.96 nm He I line (Srećković et al. 2004) not perturb the Mg I line intensities.

in Table 2 and in Fig. 5. One can notice that our experimental transition probability values are in very good agreement (within ±4%) with the values provided by NIST (2004) in the case of the 3p–4s transitions. In the case of the 3p–3d transition the agreement is within ±16% that can be also considered as acceptable. We note that the I (383.829 nm)/I (383.230 nm) line intensity ratio was monitored between the 90 and 160 μs after the beginning of the discharge.

In the case of the 3p–3d transition our W_m and d_m values agree well with the existing theoretical predictions G (Griem 1974) and DSB (Dimitrijević & Sahal-Bréchot 1994, 1996) within the accuracy of the measurements and estimated uncertainties of the calculations (see Figs. 3b and 3c). In the case of the $3s^2$–3p and 3p–4s transitions our measured (W_m and d_m) values lie far below the theoretical (G and DSB) predictions. We notice that the recently published DSB Stark *FWHM* values are about 50% lower than the G data. On the other hand, DSB Stark shifts are higher than Griem's d values.

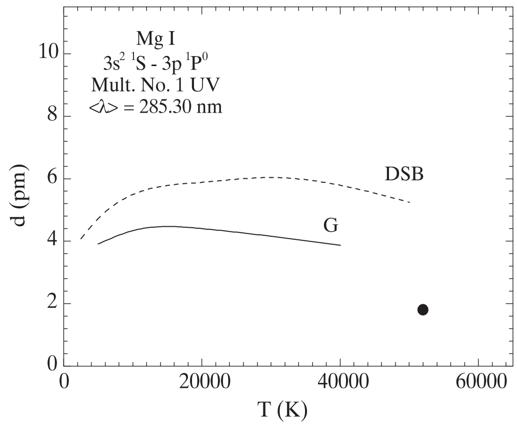

Fig. 4. Stark shift (d) dependence on the electron temperature (T) at 1×10^{23} m^{-3} electron density. The symbols are the same as in Fig. 2.

Table 2. Transition probability ratios of the Mg I lines. The symbol Tw (this work) denotes our experimentally obtained results. Data from NIST (2004) represent tabulated theoretical values (see Table 1).

Mg I lines (nm)	Transition probability ratios	
	Tw	NIST
518.3/517.2	1.71 ± 0.13	1.66
518.3/516.7	5.16 ± 0.41	4.96
517.2/516.7	3.06 ± 0.24	2.98
383.8/383.2	1.14 ± 0.11	1.32

Our $d_{\rm m}$ values are up to four times lower than the theoretical (G and DSB) ones (see Figs. 2c and 4). Similar discrepancies were found in a number of previous experiments (Helbig & Kusch 1972; Kusch & Schweicker 1976; Goldbach et al. 1982) dedicated to the 552.841, 470.299, 291.545 and 285.213 nm Mg I line Stark widths and shifts. New theoretical calculations would be helpful of the Stark *FWHM* and shifts in the Mg I 3p−4s and $3s^2$−3p transitions.

6. Conclusions

On the basis of the accurately measured intensities of three Mg I spectral lines in the 3p−4s transition we have obtained probability ratios which are in a good agreement with values provided by NIST (2004). This implies that the transition probability values of the 518.360, 517.268 and 516.732 nm Mg I lines presented by NIST (2004) (see Table 1) represent convenient atomic data (within ±5% uncertainties). Also, we have found good agreement between our measured and calculated W and d values (Dimitrijević & Sahal-Bréchot 1994, 1996) in the case of the 383.829 and 383.230 nm Mg I lines in the 3p−3d transition. These lines can be considered as lines with convenient Stark broadening parameters important in astrophysical plasma diagnostics and modeling.

Acknowledgements. This work is a part of the project "Determination of the atomic parameters on the basis of the spectral line profiles" (OI 1228) supported by the Ministry of Science, Technologies and Development of the Republic of Serbia.

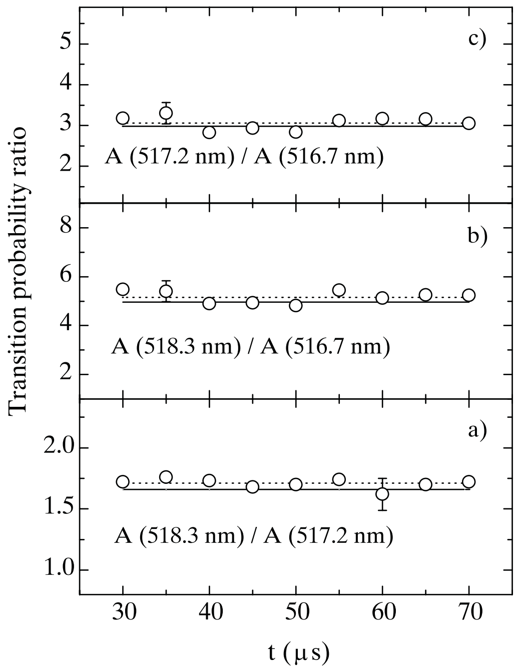

Fig. 5. Mg I transition probability ratios (**a**), **b**), **c**)) in the $3p^3P^0$−$4s^3S$ transition during the plasma decay. The solid line represents calculated ratios taking A values from NIST (2004). The open circles represent our experimental values obtained by Eq. (1) with estimated accuracy of ±8%. The dotted line denotes our averaged experimental values (see Table 2).

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