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On the Stark broadening of CuI spectral lines

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Abstract. Using the semiclassical perturbation theory of Sahal-Bréchot Stark widths and shifts for CuI 324.75, 327.39, 510.55, 570.02 and 578.21 nm spectral lines have been calculated. Obtained results are compared with different available data. Also, they are used to study the dependence of Stark broadening parameters with temperature.

Key words. line: profiles – atomic data

1. Introduction

We investigate here the Stark broadening parameters of neutral cooper spectral lines. This metal is often used in electrical industry as electrode materials, so that the data on its spectral lines are important not only for plasma research but also for diagnostic techniques in industrial laboratories.

Recently, the temperature dependence of Stark widths for neutral atom spectral lines is investigated (Zmerli et al., 2008), in order to find a method for scaling of Stark broadening parameters with temperature, better than the dependence $T^{-1/2}$, used often in astrophysics. In Zmerli et al., (2008), Stark width dependence on T is analyzed using the lines of neutral helium, and it was found that for considered lines Stark width increases with T, contrary to the $T^{-1/2}$ dependence. It was found also that after a critical temperature, Stark width starts to decrease, and a simple method for interpolation with temperature is proposed.

In the present work, we calculate the Stark width and shift of CuI spectral lines due to collisions with electrons using the semiclassical perturbation formalism Sahal-Bréchot, (1969a,b). The obtained results are used here to confirm the conclusions of Zmerli et al., (2008) on the Stark width behaviour with temperature, using the more sophisticated theory and the spectrum of another neutral emitter.

2. Theory

For the transition between the levels i and f, the total width at half intensity FWHM ($W = 2w$) and the shift d can be put under the form (Sahal-Bréchot, 1969a,b, 1974):

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$$W = 2w = N \int_0^\infty v f(v)\, dv \times$$
$$\left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right), \quad (1)$$

$$d = \int_0^\infty v f(v)\, dv \int_{R_3}^{R_D} 2\pi\rho d\rho \sin 2\phi_p. \quad (2)$$

Here, i' and f' are the perturbing levels, N is the density of perturbers, v is the relative velocity and $f(v)$ is the Maxwellian distribution of velocities.

The inelastic cross section $\sigma_{ii'}(v)$ (resp. $\sigma_{ff'}(v)$) are given by an integration over the impact parameter ρ of the transition probability $P_{ii'}(v,\rho)$ (resp. $P_{ff'}(v,\rho)$) as:

$$\sum_{i' \neq i} \sigma_{ii'}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_D} 2\pi\rho d\rho \sum_{i' \neq i} P_{ii'}(\rho, v). \quad (3)$$

The elastic contribution to the width or elastic cross section is given by

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_D} 8\pi\rho d\rho \sin^2 \delta, \quad (4)$$

with

$$\delta = (\phi_p^2 + \phi_q^2)^{1/2}. \quad (5)$$

The phase shifts ϕ_p and ϕ_q are respectively due to the quadratic and quadrupolar interactions, described in Sahal-Bréchot, (1969a); Sahal-Bréchot and Van Regemorter, (1964) for one-electron atoms, and in Sahal-Bréchot, (1974) for complex atoms.

All the cutoffs (R_1, R_2, R_3), as well as the symmetrization procedures in the inelastic cross sections, are described in Sahal-Bréchot, (1969b). R_D is the upper cutoff allowing for Debye shielding. A description of the semiclassical perturbation formalism used here is given in Sahal-Bréchot, (1969a,b); Dimitrijević and Sahal-Bréchot, (1985).

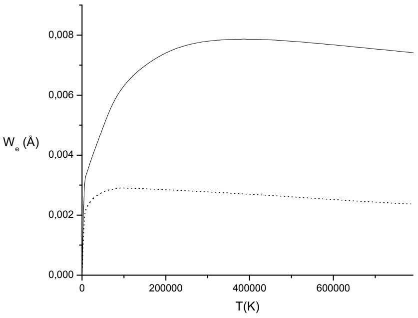

Fig. 1. Electron Stark width for the $4s\ ^2S_{1/2} - 4p\ ^2P^o_{3/2}$ transition of copper resonance spectral line (3247.54 Å) as a function of temperature T. (dot line)- electron width for the 3-level model and (solid line)- electron width for the multi-level model.

Table 1. Critical temperature T_c for CuI spectral lines.

λ (Å)	Transition	T_c (kK)
5105.54	$4s^2\ ^2D_{5/2} - 4p\ ^2P^o_{3/2}$	292
5700.24	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{3/2}$	370
5782.13	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{1/2}$	301
3273.96	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{1/2}$	398
3247.54	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{3/2}$	361

3. Results and discussion

In our calculations, energy levels and oscillator strengths have been taken from Fu et al., (1995), a compilation of CuI data including transition probabilities, oscillator strengths and lifetimes. The best values from this compilation are included in Corliss, (1970).

The widths W_{line} in Table 2 and the shifts d_{line} in Table 3 for a particular line within a multiplet are obtained by scaling the multiplet values W and d respectively using (Popović et al., 2001; Griem, 1964):

$$W_{line} = \left(\frac{\lambda}{\langle\lambda\rangle} \right)^2 W, \; d_{line} = \left(\frac{\lambda}{\langle\lambda\rangle} \right)^2 d, \quad (6)$$

Table 2. Electron widths: W_{eK} - results of Konjević and Konjević, (1986) using the approximate method of Dimitrijević and Konjević, (1986), W_{eG} - results of Grishina et al., (1998a,b) (without the accounting for the "back reaction" and the $\bar{\lambda}$ cutoff), W_{eGb} - results of Grishina et al., (1999) (with the accounting for the "back reaction"), W_{eB} - results of Babina et al., (2003), W_e - our calculations according to the semiclassical formalism of Sahal-Bréchot, (1969a), for CuI lines as a function of temperature T, for electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	W_{eK} (Å)	W_{eG} (Å)	W_{eGb} (Å)	W_{eB} (Å)	W_e (Å)
5105.54	$4s^2\ ^2D_{5/2} - 4p\ ^2P^o_{3/2}$					
	5000	0.0149	0.0103	0.0117	0.0085	0.0093
	10000	0.0193	0.0126	0.0122	0.0099	0.0102
	20000	0.0238	0.0156	0.0139	0.0123	0.0105
	30000	0.0262	0.0177	0.0161	0.0142	0.0111
5700.24	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{3/2}$					
	5000	0.0186	0.0128	0.0146	0.0106	0.0114
	10000	0.0240	0.0157	0.0152	0.0123	0.0136
	20000	0.0297	0.0194	0.0173	0.0153	0.0127
	30000	0.0327	0.0221	0.0201	0.0177	0.0143
5782.13	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{1/2}$					
	5000	0.0191	0.0132	0.0150	0.0109	0.0117
	10000	0.0247	0.0162	0.0156	0.0127	0.0129
	20000	0.0306	0.0200	0.0178	0.0158	0.0134
	30000	0.0336	0.0227	0.0206	0.0182	0.0133
3273.96	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{1/2}$					
	5000	-	0.00332	0.00403	0.00267	0.00300
	10000	-	0.00433	0.00400	0.00304	0.00321
	20000	-	0.00581	0.00475	0.00408	0.00330
	30000	-	0.00687	0.00563	0.00508	0.00391
3247.54	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{3/2}$					
	5000	-	0.00327	0.00397	0.00263	0.00320
	10000	-	0.00426	0.00394	0.00299	0.00332
	17000	-	0.00567	0.00473	0.00401	0.00385
	20000	-	0.00572	0.00467	0.00401	0.00380
	30000	-	0.00676	0.00554	0.00500	0.00398

where, W, d and $\langle\lambda\rangle$ are values for the multiplet, and W_{line}, d_{line} and λ refer to the line within the multiplet.

We can see in Table 1 that Stark widths increase with temperature as the helium lines in Zmerli et al., (2008), contrary to the $T^{-1/2}$ dependence. However, if we calculate the temperature dependence far beyond the physical temperature range for neutral copper, we can see in Fig. 1, that after some critical temperature, Stark width values will start to decrease.

In Table 1 are given the critical temperature from which the width start to decrease for the different transitions of Cu I.

One can see that they are at very high temperatures where neutral copper lines do not exist, so that for the lower temperatures, of interest for Stark broadening of Cu I, Stark widths of considered lines always increase with temperature, and the using of $T^{-1/2}$ dependence for interpolation with temperature is incorrect.

4. Conclusion

We have calculated electron Stark widths and shifts for five lines of neutral copper, using the semiclassical perturbation formalism. These data can be used for laboratory and stellar plasmas diagnostics, investigation and modelling.

Table 3. Electron shifts: d_{eK} - results of Konjević and Konjević, (1986) using the approximate method of Dimitrijević and Konjević, (1986), d_{eG} - results of Grishina et al., (1998a,b) (without the accounting for the "back reaction" and the$\bar{\lambda}$ cutoff), d_{eGb} - results of Grishina et al., (1999) (with the accounting for the "back reaction"), d_{eB} - results of Babina et al., (2003), d_e - our calculations according to the semiclassical formalism Sahal-Bréchot, (1969a), for CuI lines as a function of temperature T, for electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	d_{eK} (Å)	d_{eG} (Å)	d_{eGb} (Å)	d_{eB} (Å)	d_e (Å)
5105.54	$4s^2\ ^2D_{5/2} - 4p\ ^2P^o_{3/2}$					
	5000	-0.00027	0.00799	0.00783	0.00783	0.00683
	10000	-0.00082	0.00883	0.00889	0.00886	0.00802
	20000	-0.00118	0.00929	0.00947	0.00947	0.00882
	30000	-0.00136	0.00925	0.00945	0.00944	0.00853
5700.24	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{3/2}$					
	5000	-0.00034	0.00996	0.00976	0.00976	0.00838
	10000	-0.00102	0.01101	0.01108	0.01104	0.01020
	20000	-0.00147	0.01158	0.01180	0.01180	0.01060
	30000	-0.00170	0.01153	0.01178	0.01177	0.01090
5782.13	$4s^2\ ^2D_{3/2} - 4p\ ^2P^o_{1/2}$					
	5000	-0.00035	0.01025	0.01004	0.01004	0.00816
	10000	-0.00105	0.01133	0.01140	0.01136	0.00977
	20000	-0.00152	0.01192	0.01215	0.01215	0.00995
	30000	-0.00175	0.01186	0.01212	0.01211	0.01000
3273.96	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{1/2}$					
	5000	-	0.00237	0.00230	0.00228	0.00210
	10000	-	0.00251	0.00254	0.00254	0.00210
	20000	-	0.00243	0.00250	0.00251	0.00184
	30000	-	0.00227	0.00234	0.00234	0.00144
3247.54	$4s\ ^2S_{1/2} - 4p\ ^2P^o_{3/2}$					
	5000	-	0.00231	0.00226	0.00224	0.00241
	10000	-	0.00247	0.00250	0.00250	0.00273
	20000	-	0.00239	0.00246	0.00247	0.00272
	30000	-	0.00223	0.00230	0.00230	0.00237

Our results demonstrate that the considered Stark widths increase with temperature for all T values of interest and that the critical temperature when they start to decrease is beyond the temperature range of interest. The temperature trend of Stark widths is not in accordance with $T^{-1/2}$ dependence.

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