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ON THE STARK BROADENING OF NEUTRAL GERMANIUM SPECTRAL LINES

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Abstract. Stark broadening of the eleven transitions of neutral germanium within the $4p^2$ - 4p5s transition array has been analyzed within the frame of the semiclassical perturbation method. Obtained results have been compared with available experimental and theoretical data. The importance of the electron-impact broadening in the case of the 4226.562 Å line for A star atmospheres has been tested

1. INTRODUCTION

Stark broadening of germanium lines, has been discussed firstly in Minnhagen (1964), who considered correlation between observed wavelength shifts produced in electrodeless discharge tube and predicted Stark shifts in the spectrum of neutral germanium. Shifts in the wavelength of spectral lines in spark discharges have been investigated as well in the first experimental work on Ge I Stark broadening (Kondrat'eva, 1970). After these pioneer works, reliable data on Ge I spectral lines Stark broadening parameters have been obtained experimentally by Jones and Miller (1974) and Musiol et al. (1988). For Ge I $4p^2\ {}^1S{-}5s^1S^o$ multiplet, Dimitrijević and Konjević (1983) performed semiclassical calculation within the frame of the theory developed by Griem et al. (1962) (see also Griem, 1974). Moreove, Lakićević (1983) estimated on the basis of regularities and systematic trends Stark broadening parameters for Ge I $4p^2\ {}^3P{-}5s^3P^o$ multiplet. The estimates based on regularities and systematic trends, performed also Sarandaev et al. (2000) for Ge I $4p^2\ {}^1S - 5s^1P^o$ and $4p^2\ {}^1S - 5s^3P^o$ multiplets. Here, we will calculate within the semiclassical perturbation approach, Stark broadening parameters of 11 Ge I transitions within the $4s^24p^2$ - $4s^24p5s$ transition array, for conditions typical for astrophysical and laboratory plasmas. The obtained results will be compared with available experimental and theoretical values. Also, the importance of the electron-impact broadening for A type star atmospheres will be tested.

2. RESULTS AND DISCUSSION

Stark broadening parameters (the full line width at half maximum - W and the line shift -d) of neutral germanium, have been determined by using the semiclassical perturbation formalism (Sahal−Bréchot, 1969ab). The discussion of updatings and validity criteria, has been briefly reviewed e.g. in Dimitrijević (1996). All details of the determination of Stark broadening parameters will be published elsewhere (Dimitrijević et al. 2003) so that we note here only that the atomic energy levels needed for calculations have been taken from Sugar and Musgrove (1993).

Results for electron-, proton-, and Ar II-impact broadening parameters for 11 Ge I transitions for perturber density of 10^{16}cm^{-3} and temperatures from 2,500 K up to 50,000 K will be published in Dimitrijević et al. (2003), together with the complete comparison of available experimental and theoretical data and discussion.

In Table 1, our results are compared with experimental results of Jones and Miller (1974) and Musiol et al. (1988). With W_m, are denoted experimental full widths at half maximum in [Å], and with W_e and W_{GeII} our theoretical values for Stark widths due to electron- and Ge II-impacts, respectively. Namely, since ionization potentials of H, Ar and Ge are 13.595 eV, 15.755 eV and 7.88 eV respectively, the most appropriate way to estimate the influence of ion-impact broadening for considered experiments

Table 1: Comparison of our theoretical results for Stark broadening of Ge I lines with experimental results. With W_m, are denoted experimental full widths at half maximum in [Å], and with W_e and W_{GeII} our theoretical values for Stark widths due to electron- and Ge II-impacts, respectively. Accuracy is denoted as in Konjević et al. (1984) and Konjević and Wiese (1990), C means that error bars are within ±50% and D^+ that they are larger than ±50%. Under Ref., 1 is for Musiol et al. (1988) and 2. for Jones & Miller (1974).

Transition λ(Å)	T(K)	Ne 10^{17}cm^{-3}	W_m (Å)	W_e (Å)	W_{GeII} (Å)	Acc.	Ref.
$4p^2\ ^3P$ - $5s^3P^0$							
2754.59	12450	0.57	0.0509	0.0502	0.00644	C	1
2709.62	12450	0.57	0.0434	0.0490	0.00628	C	1
2651.57	12450	0.57	0.0358	0.0466	0.00596	C	1
2651.17	12450	0.57	0.0427	0.0517	0.00662	C	1
2592.53	12450	0.57	0.0452	0.0494	0.00633	C	1
$4p^2\ ^1S$ - $5s^3P^0$							
4685.83	11000	1	0.35	0.248	0.0339	C	2
$4p^2\ ^1D$ - $5s^3P^0$							
3124.82	12450	0.57	0.0628	0.0715	0.00928	C	1
$4p^2\ ^1D$ - $5s^1P^0$							
3039.07	12450	0.57	0.0622	0.0721	0.00924	C	1
$4p^2\ ^1S$ - $5s^1P^0$							
4226.56	11000	1	3.18	0.239	0.0318	C	2
	12450	0.57	0.0815	0.139	0.0185	D^+	1

is to compare electron-impact widths with widths due to impacts with ions of heavy electron donors like germanium. One can see that the ion contribution is around 13-14 per cent which is well within the estimated error bars of the semiclassical perturbation approach of ± 30 per cent (Griem, 1974).

Jones and Miller (1974) determined experimentally Stark widths of Ge I 4p^2 $^1S - 5s^1P^o$ 4685.83 Å and 4p^2 $^1S - 5s^3P^o$ 4226.56 Å spectral lines by using gas-driven spectroscopic shock tube with hydrogen as a driver gas, and runs were with various filling pressure and different compositions of GeH_4, Ar and Ne. They used photographic technique and Konjević and Wiese (1990) in his critical analysis of experimental Stark broadening data stated that "self-absorption may have been an important factor for the 4226.56 Å line" in his experiment. In Konjević et al. (1984), the error bars of their results are critically estimated to be within $\pm$ 50% (accuracy denoted as C in their notation).

Musiol et al. (1988) determined experimentally Stark widths of 9 lines from Ge I 4p^2-4p5s and 4p^2-4p4d transition arrays by using wall-stabilized arc operated at atmospheric pressure with various mixtures of GeH_4 and Ar. In Konjević and Wiese (1990), the error bars of their results are critically estimated to be within $\pm$ 50% (accuracy denoted as C in their notation), except for 4226.56 Å line where accuracy is denoted as D^+ (error bars larger than $\pm 50\%$).

Our results are in disagreement with experimental results of Jones and Miller (1974) for 4226.56 Å line. This result is in disagreement with other theoretical (Dimitrijević and Konjević, 1983; Sarandaev et al., 2000) and experimental (Musiol et al., 1988) results, and selfabsorption is indicated as a possible reason in Konjević and Wiese (1990). Ratio of experimental Stark width of Jones and Miller (1974) for 4685.83 Åline and our result is $W_m/W_e = 1.41$, what is within the estimated (Konjević et al., 1984) error bars of the experiment. Agreement of our values with experimental results of Musiol et al. (1988) is reasonable. The largest disagreement is for 4226.56 Å line, where $W_m/W_e = 0.59$, what is however within the estimated (Konjević et al., 1984) error bars of ± 50 per cent. The agreement for other lines is considerably better. However, if we analyse experimental and theoretical widths within 4p^2 ^{3}P - 5s^{3}P^o multiplet, one can notice that the largest difference of experimental values is for 2754.59 Å 4p^2 $^3P_2$ - 5s$^3P_1^o$ (W_m = 0.0509 Å) and 2651.57 Å 4p^2 $^3P_0$ - 5s$^3P_1^o$ (W_m = 0.0358 Å) line. The corresponding theoretical values are W_e = 0.0502 Å and 0.0466 Å respectively. Since both lines have the same upper energy level and the lower level contribution is small, this is in contradiction with findings that if the perturbing energy level positions are regular, line widths within a multiplet should be approximately the same (Wiese and Konjević, 1982). If we eliminate the influence of the wavelength differences multiplying values for 2651.57 Å line with $(2754.59/2651.57)^2$, we will obtain for theoretical width the value of 0.0503 Å which is practically equal to the calculated value for 2754.59 Å line (0.0502 Å). Contrary, for experimental width the scaled value is 0.0386 Å what is different from the experimental value of 0.0509 Å for 2754.59 Å line. It is interesting to obtain new experimental results for these lines in order to see if the reason is maybee the configuration mixing.

For Ge I 4p^2 $^1S - 5s^1P^o$ multiplet, Dimitrijević and Konjević (1983) performed semiclassical calculation within the frame of the theory developed by Griem et al. (1962) (see also Griem, 1974). It should be noted that atomic data needed for calculations have not been taken in Sugar and Musgrove (1993), not available at that time, but in Moore (1971) and, Kaufman and Edlén (1974). The comparison of semiclassical method of Griem et al. (1962) (see also Griem, 1974), used in Dimitrijević and Konjević (1983) and the semiclassical perturbation method (Sahal-Bréchot, 1969ab) used here, as well as explanation of differences, is given in Dimitrijević and Sahal-Bréchot (1996). The present results are considerably smaller. For example at $T = 10$ 000 K and $N_e = 10^{17}\mathrm{cm}^{-3}$, Dimitrijević and Konjević obtain a Stark width of 0.408Å and present results are 0.235Å.

Lakićević (1983) estimated on the basis of regularities and systematic trends Stark broadening parameters for Ge I 4p^2 $^3P - 5s^3P^o$ multiplet, and he obtained that W is 0.1 Å and the absolute value of the shift 0.055 Å for an electron density of $10^{17}\mathrm{cm}^{-3}$ and T = 20 000 K. The distance between energy levels within the 5s$^3P^o$ term is not negligible in comparison with the distance to the nearest perturbing levels. Consequently, the particular line widths within the corresponding multiplet differ. Our width values vary between 0.087 and 0.097 Å and shift values between 0.072 and 0.080Å. If one takes into account the simplicity of this method, the agreement is good.

On the basis of examination of systematic trends (Purić, 1996), dependencies enabling the estimation of the Stark widths of spectral lines for s-p and p-s transitions of neutral atoms have been found by Sarandaev et al. (2000). These simple relations, based on the known ionization potential of the lower/upper level of the corresponding transitions and on the regularities and systematic trends, have been used to determine Stark widths for Ge I 4p^2 ^{1}S - 5s^{1}P^o and 4p^2 ^{1}S - 5s^{3}P^o transitions. For example at $T = 20$ 000 K and $N_e = 10^{17}\mathrm{cm}^{-3}$ they obtain for Ge I 4p^2 ^{1}S - 5s^{1}P^o a Stark width of 0.33 Å while the present value is 0.261 Å.

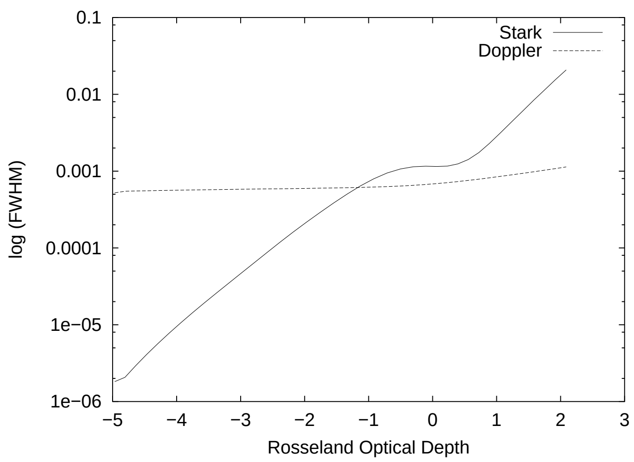

Fig. 1: Thermal Doppler (dotted line) and Stark widths (full line) for Ge I ($\lambda =$ 4226.562 Å) spectral line as functions of Rosseland optical depth.

In order to see the influence of Stark broadening mechanism for Ge I spectral lines in stellar plasma conditions, we have calculated the Stark widths for Ge I 4226.562 Å spectral line for a Kurucz's (1979) A type star atmosphere model with $T_{eff} = 10$ 000 K and log g =4. From Fig. 1 one can see the existence of atmospheric layers where Doppler and Stark widths are comparable and where Stark width is dominant, and that the Stark broadening effect should be taken into account in abundance determination, spectra synthesis and modeling of stellar plasmas.

New experimental determination of Stark broadening of neutral germanium spectral lines will be obviously useful for comparison with experimental and theoretical data as well as for astrophysical plasma investigation and modeling.

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